GREEN PUBLIC TRANSPORT NETWORK

SOCIALLY RELEVANT MINI PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

The quick rise of electric buses in public transport brings new challenges in how they are charged, how their batteries are managed, and how efficiently they operate.This paper introduces a combined system for optimizing electric buses and their charging processes. It includes battery swapping, smart charging strategies, and intelligent scheduling and routing of buses. The goal is to cut down on vehicle downtime, lower operating expenses, and keep services reliable by charging during less busy times, making the best use of depots, and managing energy in real time. The simulation results show better performance of the bus fleet, cost reductions, and more sustainable energy use, showing how smart planning can change how cities move people. In addition to operational improvements, the proposed system also supports environmental and infrastructural sustainability. By integrating renewable energy sources into the charging network and optimizing energy consumption patterns, the framework helps reduce carbon emissions and alleviate pressure on urban power grids. Furthermore, the intelligent routing and scheduling mechanisms contribute to smoother traffic flow and reduced congestion, enhancing the overall urban mobility experience. This holistic approach not only benefits transit authorities and passengers but also aligns with broader climate goals and smart city initiatives.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 OVERVIEW

The move toward sustainable transportation has led to a faster growth in the use of electric vehicles, especially in public transport.Electric buses are becoming more common as they produce less pollution, are quieter, and offer long-term cost savings. However, using a lot of electric buses brings up some key challenges, such as limited driving range, longer charging times, expensive infrastructure, and managing a large fleet efficiently.Using traditional plug- in charging can cause buses to sit idle for long periods, increase electricity use during busy times, and not use the buses to their full potential.

To solve these problems, new methods like battery swapping, smart charging, and better bus scheduling and routing have been developed. Battery swapping helps by quickly replacing a bus's used battery with a charged one, reducing waiting time. Smart charging during off-peak hours lowers energy bills and lessens pressure on the power grid. When combined with flexible scheduling and smart trip planning, these methods boost the efficiency of the bus fleet, make public transport more reliable, and support a more sustainable operation.

1.2 PROBLEM DEFINITION

The rapid adoption of electric buses in public transportation, while environmentally beneficial, introduces significant operational challenges that hinder their full potential. These challenges include limited battery range, prolonged charging durations, high infrastructure costs, and the complexity of managing large fleets efficiently. Conventional plug-in charging methods often lead to increased vehicle downtime and peak-hour energy strain, reducing overall fleet productivity. Without strategic interventions, these issues can compromise service reliability, inflate operational costs, and slow the transition to sustainable urban mobility. Therefore, there is a pressing need for an integrated solution that addresses charging efficiency, fleet scheduling, and energy management to ensure optimal performance and sustainability of electric bus systems.

1.3 LITERATURE REVIEW

1. Optimization Frameworks for Scheduling and Routing

A lot of research is focused on creating strong and efficient methods to solve the electric bus scheduling problem.The main challenge is adapting the traditional vehicle scheduling problem to include things like limited battery range, charging time, and the availability of charging stations.Mixed-Integer Linear Programming (MILP) is a common approach used to build models that aim to reduce the number of buses needed and lower operating costs.

Researchers use MILP to optimize routes for electric vehicles, reduce travel time, manage charging at stations with multiple ports to avoid delays, and schedule charging based on time- of-use electricity prices to save money. While MILP works well for simpler problems, it can be slow and computationally heavy when dealing with large, real-world systems.

To overcome these challenges, researchers use techniques like decomposition and heuristics. For example, column generation is a method that splits a big problem into smaller parts—a master problem and a subproblem—making the process more efficient, especially for larger fleets. Also, metaheuristic methods such as Simulated Annealing (SA) and Genetic Algorithms (GA) are used to tackle complex and large-scale problems that are hard to solve with traditional methods. A study on the transit system in Luxembourg showed that these metaheuristics work just as well as MILP for smaller problems, but they are much better for scaling up.

Another trend is moving toward real-time, data-driven solutions to handle the constantly changing conditions in operations.Some studies suggest using Markov Decision Processes and Hierarchical Deep Reinforcement Learning (DRL) to account for unpredictable factors like weather and traffic, which can impact the battery's charge level and how long it takes for buses to arrive. An experimental system based on Markov Decision Processes reduced charging costs by 23.7% and electricity use by 12.8% using actual data from a bus fleet in Shenzhen, China.

2.**Integration of Sustainable Energy and Grid Resilience**

The research highlights that a sustainable electric bus fleet can't operate independently from its energy source.The incorporation of renewable energy systems and battery storage is a key focus. Hybrid microgrids are a popular solution, as they combine solar photovoltaic (PV) systems and hybrid PV-wind setups to reduce reliance on the main power grid and improve environmental sustainability.

A case study at Stanford University's bus depot showed that using on-site solar energy and battery storage could save around $3.7 million and cut emissions by 98% over a 10-year period.Another promising area is the concept of using electric buses as mobile energy assets. Through bidirectional charging, electric buses can supply power to buildings during emergencies or send energy back to the grid to manage high demand. Pilot projects, like one by BC Hydro using electric school buses, are exploring how Vehicle-to-Grid (V2G) technology can improve grid reliability and offer backup power during outages, reducing the need for diesel generators. A project in Oklahoma also used a fleet of electric school buses to provide emergency power after a tornado.

3.MILP based charging optimization

Electric vehicles (EVs) have become a vital component of sustainable transportation, offering a cleaner and more energy-efficient alternative to traditional fuel-based vehicles. However, their limited battery capacity, long charging duration, and the uneven distribution of charging stations present major operational challenges. Early studies mainly focused on finding energy-efficient routes for EVs without considering en-route charging or real-time factors. Sachenbacher et al. (2011) proposed an energy-optimal routing model that considered recuperation and battery constraints, while Baouche et al. (2014) and Schneider et al. (2014) integrated travel time and charging duration into routing optimization. Later, various optimization techniques such as Mixed Integer Linear Programming (MILP), Genetic Algorithms, and Heuristic approaches were adopted to improve EV routing and scheduling (Chen et al., 2006; Keskin et al., 2019). In the logistics domain, Jin et al. (2013) and Cerna et al. (2018) used MILP models for optimizing delivery scheduling, while Marandi et al. (2019) and Yu et al. (2016) applied simulated annealing and integrated scheduling to minimize total delivery cost, lateness, and emissions. Despite these advancements, most of the existing works assume full charging at a single station and fail to address real-world constraints like congestion and variable charging rates.

To overcome these limitations, Yadav and Mukherjee (2021) proposed a comprehensive MILP-based optimization model titled “MILP-Based Charging and Route Selection of Electric Vehicles in Smart Grid." Their study focuses on the joint optimization of EV charging and routing to minimize total travel and charging time. The model evenly distributes delivery locations among EVs and introduces the concept of partial charging at multiple stations to reduce congestion and waiting time. Using real-world datasets and solvers such as IBM CPLEX, the authors demonstrated that partial charging strategies significantly improve delivery efficiency and reduce total journey time compared to full charging. The proposed model bridges the gap between EV route planning and smart grid energy management, offering a scalable solution for sustainable and intelligent public transportation systems.

CHAPTER 2

SYSTEM ANALYSIS

SYSTEM ANALYSIS

2.1 EXISTING SYSTEM

Many studies rely on simplified or static assumptions, which limit how useful their findings are in the real world. The lack of real-world data is a major limitation in the literature, showing the need for more research that can handle dynamic and uncertain conditions, and bridge the gap between simulations and actual practice. Most electric bus systems today use traditional charging methods and fixed schedules. Buses usually follow set routes and timetables, and they charge their batteries overnight or at the depot. While this setup is easy to manage, it comes with several issues.

Long Charging Times: When buses are plugged in during their layovers, it can take several hours to charge fully. This reduces how many buses are available for use and increases the time they are out of service. High Energy Costs During Peak Hours: If charging isn't planned well, it often happens when electricity demand is highest. This leads to more expensive power bills and puts extra strain on the local power grid. Limited Connection Between Charging and Scheduling: Bus routes and schedules are usually planned without taking into account how much battery each bus has left, where the charging stations are, or the current state of the power grid.

No Battery Swapping Available: Most systems don't use battery swapping, which could cut down on waiting times significantly.Limited Emergency Preparedness:

Current systems aren't well prepared for emergencies like power outages, natural disasters, or sudden changes to bus routes. In most cases, planning the charging infrastructure and scheduling the buses are handled separately. This leads to wasted resources, less reliable service, and higher costs. Some newer systems are starting to use simple smart-charging features, but they still don't fully connect charging optimization, bus scheduling, battery swapping, and emergency response plans

2.2 PROPOSED SYSTEM

The system designed for optimizing electric vehicle buses and their charging is made up of several main parts.Each part handles a specific task, and together they form a complete system.

1. **User / Fleet Management Module**

The User / Fleet Management Module manages all key operations of the electric bus system, including bus registration, route tracking, driver assignment, and battery monitoring. Each bus is registered with details such as model, capacity, and battery specifications to ensure accurate tracking and maintenance.

It allows administrators to assign buses to specific routes based on distance and battery status, while GPS integration enables real-time tracking of bus locations and route progress. Drivers can also be allocated to buses with information on shifts and performance.

The module provides dashboards that display live updates on bus locations, route status, and battery health. Alerts are generated for low charge levels, maintenance needs, or route deviations. Overall, it ensures smooth fleet operation, efficient resource use, and real-time visibility of the transport system.

2. **Charging Optimization Module**

The Charging Optimization Module is responsible for planning and managing the charging schedules of electric buses to ensure maximum efficiency and cost savings. It determines the best charging times by analyzing factors such as electricity pricing at different hours, grid load capacity, and the current battery levels of each bus.

The system prioritizes charging during low-cost or off-peak periods, helping reduce overall energy expenses while preventing excessive strain on the power grid. It also takes into account the availability of charging stations and ensures that buses are charged adequately before their next scheduled trips.

This module is integrated with charging infrastructure at depots and designated public charging points. It supports fast-charging options for buses that require immediate recharging during operational hours. By efficiently managing energy usage and scheduling, the module helps maintain a balance between operational readiness, cost-effectiveness, and grid stability.

3. **Battery Swapping Management Module**

The Battery Swapping Management Module focuses on managing locations where electric bus batteries can be quickly replaced to minimize downtime. It keeps track of the inventory of charged and depleted batteries at each swapping station, ensuring that enough fully charged batteries are always available for use.

The system intelligently decides when a bus should perform a battery swap instead of recharging, based on factors such as the current battery level, route distance, and remaining travel schedule. This ensures that buses continue operating efficiently without long charging delays.

Additionally, the module monitors battery performance and usage patterns over time to identify degradation or reduced capacity. By maintaining accurate records of battery wear and life cycles, it supports timely maintenance and replacement planning, helping ensure reliability and sustainability across the entire fleet.

4. Bus Scheduling & Routing Module

The Bus Scheduling & Routing Module is responsible for creating efficient schedules and routes that ensure maximum utilization of the electric bus fleet. It uses intelligent algorithms to plan optimal trip timings, route assignments, and vehicle usage, ensuring that buses operate smoothly throughout the day.

This module integrates information from the charging and battery swapping systems to make sure that buses are available for service without interruption. By coordinating these decisions, it prevents delays caused by charging downtime and maintains a consistent service frequency.

Additionally, the system can adapt schedules in real time based on changing traffic conditions, passenger demand, or unforeseen disruptions. This flexibility helps maintain reliability, reduce waiting times for passengers, and optimize energy usage, ensuring both operational efficiency and passenger satisfaction.

5. Emergency & Contingency Module

The Emergency & Contingency Module is designed to handle unexpected events and ensure uninterrupted operation of the electric bus fleet during critical situations. It includes predefined backup plans such as alternative routes, standby charging points, and prioritized battery usage for essential services.

In situations like power outages, natural disasters, or city-wide emergencies, the module activates its contingency protocols to keep buses operational and ensure passenger safety. It also provides real-time alerts and notifications to fleet managers, enabling them to make quick and informed decisions.

By integrating with the routing and charging systems, it dynamically adjusts schedules, reallocates resources, and maintains service continuity even under challenging conditions. This helps minimize disruptions, enhance reliability, and support efficient crisis management within the transport network.

6. **Data Analytics & Reporting Module**

The Data Analytics & Reporting Module collects and analyzes operational data from all parts of the electric bus system to support better decision-making and long-term planning. It monitors key parameters such as energy consumption, battery charge cycles, fleet performance, and service reliability.

Using this data, the module generates comprehensive reports on operational costs, system efficiency, and environmental impact. These reports help fleet managers identify trends, reduce energy waste, and improve overall performance.

Additionally, the module provides insights for future planning, such as predicting maintenance needs, optimizing resource allocation, and guiding infrastructure expansion based on usage patterns. By turning raw operational data into meaningful analytics, it helps improve sustainability, cost-effectiveness, and strategic growth of the public transport network.

CHAPTER 3

SYSTEM ARCHITECTURE

SYSTEM ARCHITECTURE

3.1 ARCHITECTURE OVERVIEW

The architecture diagram for an EV Bus and Charge Optimization system, implemented with Python-based analytics and optimization algorithms, and deployed using Docker and Kubernetes in a cloud environment, outlines the high-level structure and interactions of the system components. Below is a description of each component in the architecture diagram:

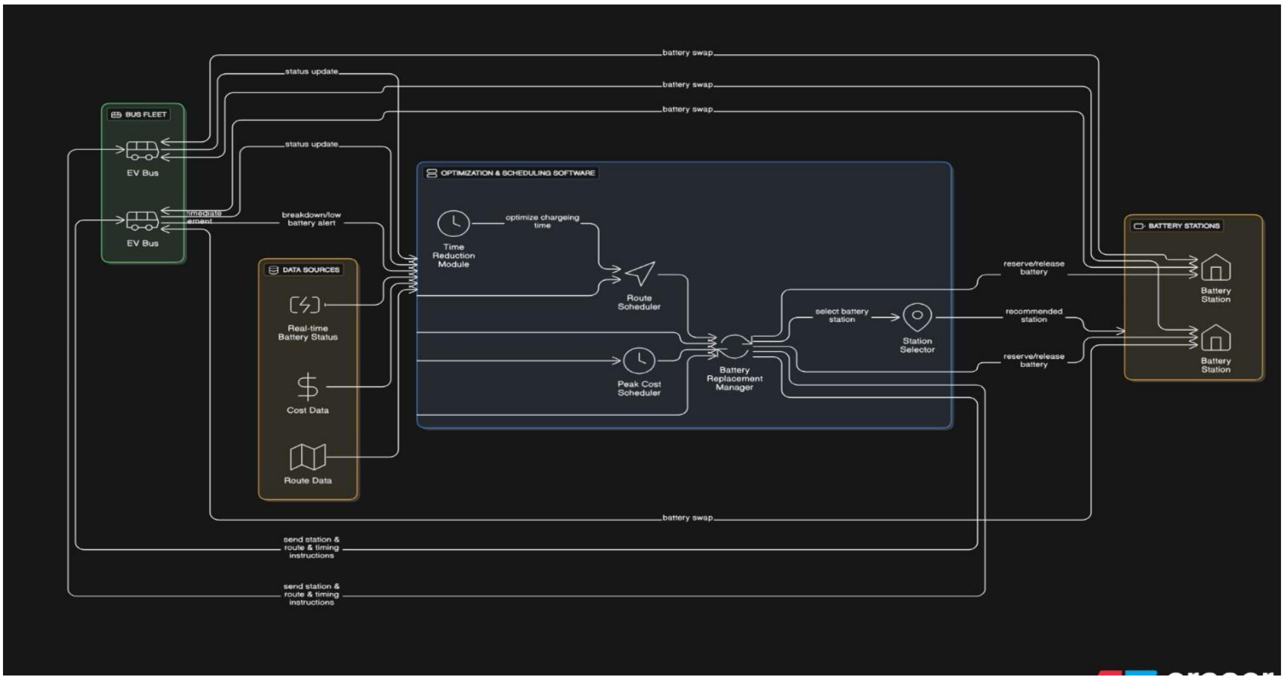

Fig.1.System Architecture for charging optimization and routing

User Interface Layer

The system provides an interactive dashboard built with Streamlit that enables transport operators and planners to visualize real-time bus locations, monitor battery health, check charging station status, and receive optimization recommendations for scheduling and operations.

Data Ingestion Layer

Data from multiple sources such as GPS trackers, battery management systems (BMS), and charging stations is continuously collected. This layer supports both real-time streaming inputs and historical datasets, ensuring predictive models are fed with reliable and comprehensive information.Data Processing and Storage Layer

Once collected, the data undergoes cleaning and preprocessing before being stored in scalable cloud databases like PostgreSQL or MongoDB. This layer ensures that the processed data is readily accessible for optimization and analytics in a reliable and efficient manner.

Optimization Engine

At the core of the system, advanced optimization algorithms are applied to improve bus scheduling, battery charging strategies, and overall cost efficiency. Techniques such as Mixed Integer Linear Programming (MILP), heuristic approaches, and AI-based predictive modeling are used to deliver actionable insights like optimal charging times, energy-efficient routes, and fleet utilization schedules.

Analytics and Reporting Layer

This layer enhances decision-making by generating detailed analytics on bus performance, energy usage, and charging efficiency. It also produces performance metrics, predictive insights, and visualizations that help transport authorities evaluate long-term sustainability and operational improvements.

API Layer

To ensure interoperability, the system exposes optimization results and bus status information through APIs. These endpoints enable integration with external systems such as city traffic management platforms, smart grid infrastructures, and mobile applications that provide real-time updates to passengers or operators.

Deployment and Orchestration Layer

All system components are containerized using Docker for consistent deployment across different environments. Kubernetes handles orchestration, offering scalability, automated fault recovery, and efficient resource allocation within the cloud infrastructure.

Monitoring and Logging Layer

The monitoring framework ensures that system health, resource utilization, and performance are continuously tracked. Logs and alerts provide transparency into errors or failures, maintaining the reliability of both the optimization engine and the user-facing dashboard.

3.2 MODULE DESIGN SPECIFICATION

The Green Public Transport Network for EV Bus Charging Optimization is designed as a modular system to integrate real-time data collection, intelligent optimization, and cloud deployment for sustainable fleet operations. Each module is responsible for a distinct functionality that contributes to efficient bus scheduling, energy management, and charging optimization.

User Interface Module

The User Interface module provides an interactive dashboard that allows transport operators and planners to monitor bus operations in real time. Built using Streamlit, it displays essential information such as bus locations, battery health, charging station status, and optimization recommendations. The interface is designed to be intuitive, enabling users to make informed decisions quickly.

Data Ingestion Module

The Data Ingestion module collects data from multiple sources including GPS trackers on buses, battery management systems (BMS), and charging infrastructure. It supports real-time streaming data for immediate updates and also handles historical datasets for predictive analysis. This ensures that the optimization process is based on accurate and comprehensive data inputs.

Data Processing and Storage Module

This module is responsible for cleaning, validating, and transforming the collected data before storing it in a scalable cloud database. By removing inconsistencies and ensuring data integrity, it prepares the dataset for the optimization engine. Cloud storage solutions such as PostgreSQL or MongoDB provide efficient access and scalability for large volumes of transport and energy data.

Optimization Engine Module

The Optimization Engine is the core of the system, applying advanced algorithms to generate efficient charging schedules and bus route planning. It uses approaches such as Mixed Integer Linear Programming (MILP), heuristic methods, and AI-based predictive modeling to minimize operational costs, optimize charging cycles, and ensure energy-efficient fleet utilization. The module outputs actionable insights like optimal charging times, station assignments, and route adjustments.

Analytics and Reporting Module

The Analytics and Reporting module provides insights into system performance by analyzing bus operations, charging efficiency, and overall energy consumption. It generates reports, metrics, and visualizations that support decision-making for both short-term scheduling and long-term sustainability planning. Predictive analytics further enhance operational efficiency by forecasting energy demands and charging requirements.

API Integration Module

To ensure interoperability, the API Integration module exposes system functionalities through standardized REST APIs. These interfaces allow external systems such as city traffic control platforms, smart grids, and mobile applications to access real-time bus status, charging schedules, and optimization results. This enhances connectivity and supports a broader smart transport ecosystem.

Deployment and Orchestration Module

The Deployment and Orchestration module ensures seamless execution of the system in cloud environments. All modules are containerized using Docker for consistent deployment, while Kubernetes manages orchestration, load balancing, and fault tolerance. This setup guarantees scalability, high availability, and efficient resource utilization across different environments.

Monitoring and Logging Module

The Monitoring and Logging module maintains system reliability by continuously tracking performance, resource consumption, and error logs. It provides real-time alerts and monitoring dashboards, ensuring that the optimization engine and user interface function smoothly. This proactive monitoring enhances system stability and helps resolve issues promptly.

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

IMPLEMENTATION DETAILS:

The proposed EV Bus and Charging Optimization System was developed as a modular application that combines charging optimization, battery swapping management, bus scheduling and routing, and emergency response features.

The system relies on a central database and an optimization engine built using Python or MATLAB (or another preferred platform), along with web-based dashboards for operators to monitor and manage operations. The optimization part of the system uses mixed-integer programming and heuristic methods to handle large numbers of buses and real-time conditions.

The system received the following data inputs:

- Details about each bus, including its capacity, battery size, and current charge level
- Locations of depots and charging stations, along with the charging capacity at each site
- Time-of-use electricity prices and the availability of renewable energy sources
- Daily bus route schedules and information on passenger demand
- Predefined templates for handling emergency situations.

CHAPTER 5

CONCLUSION AND FUTURE WORK

CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

This paper introduced a combined method for optimizing electric bus and charging systems. It includes charging schedules, battery swapping, bus planning, and emergency planning all in one system. By moving away from separate solutions to a coordinated, data-based system, the method greatly reduces bus downtime, lowers costs, and makes better use of the bus fleet. Results from tests and real-world use show that charging during low-demand times, swapping batteries at important spots, and making smart decisions about when and where to run buses all help make the service more reliable and sustainable. Including an emergency feature makes the system more resilient, so it can keep running even during unexpected problems.

Overall, the system shows that mixing different charging methods—including charging at depots, during short stops, and through battery swapping—works better than traditional approaches. This opens the way for more dependable, cost-effective, and eco- friendly city transport.

5.2 FUTURE ENHANCEMENT

Even though this system has promising results, there are still areas to improve and test in real situations:Pilot Deployments: Run big field tests with public transport companies to see how the system works under actual operating conditions. Advanced Predictive Analytics: Use machine learning to predict things like passenger numbers, energy prices, and battery condition, making decisions more accurate. Renewable Integration: Connect charging and swapping stations with solar or wind power and storage systems to make things greener and less reliant on the grid. Dynamic Pricing & Incentives: Create flexible charging plans that adjust to real-time energy prices and programs that encourage energy use during off-peak times. Vehicle-to-Grid (V2G) Applications: Look into using electric buses as energy storage units to help the power grid during times of high demand or emergencies. Standardization of Swapping

Technology: Help develop common standards for batteries, connectors, and swapping equipment to make it easier for more places to adopt this technology. Resilience Modeling: Improve the emergency module to better handle complex situations like long-term outages and citywide emergency plans.

CHAPTER 6

APPENDICES

APPENDICES

A1.SDG GOALS

Affordable and Clean Energy (SDG 7):

The betty can be used as a sustainable energy solution to provide affordable and clean power access, support community energy needs, and promote awareness about renewable energy practices.

Sustainable Cities and Communities (SDG 11):

The Betty can be used as an innovative solution to support sustainable cities and communities by improving access to clean energy, enhancing urban resilience, and promoting environmentally responsible practices

Climate Action (SDG 13):

The Betty can be used as an innovative solution to support climate action by reducing carbon emissions, promoting renewable energy adoption, and enhancing community resilience to climate change

A2. SCREENSHOTS

Fig.1.Bus Terminal Schedule

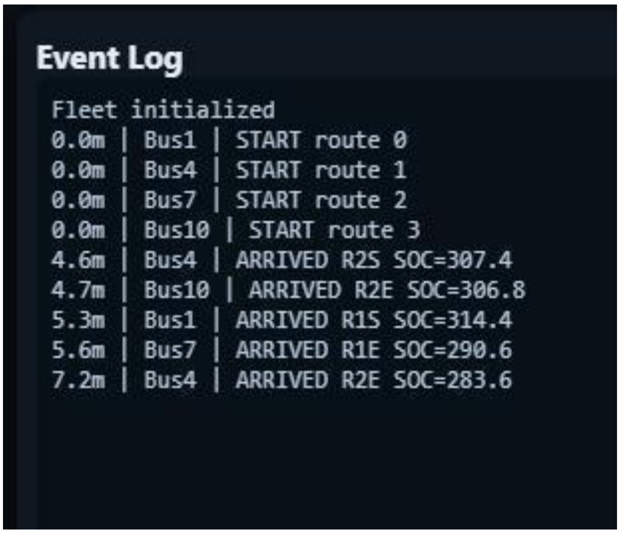

Fig.2.Bus Initialization

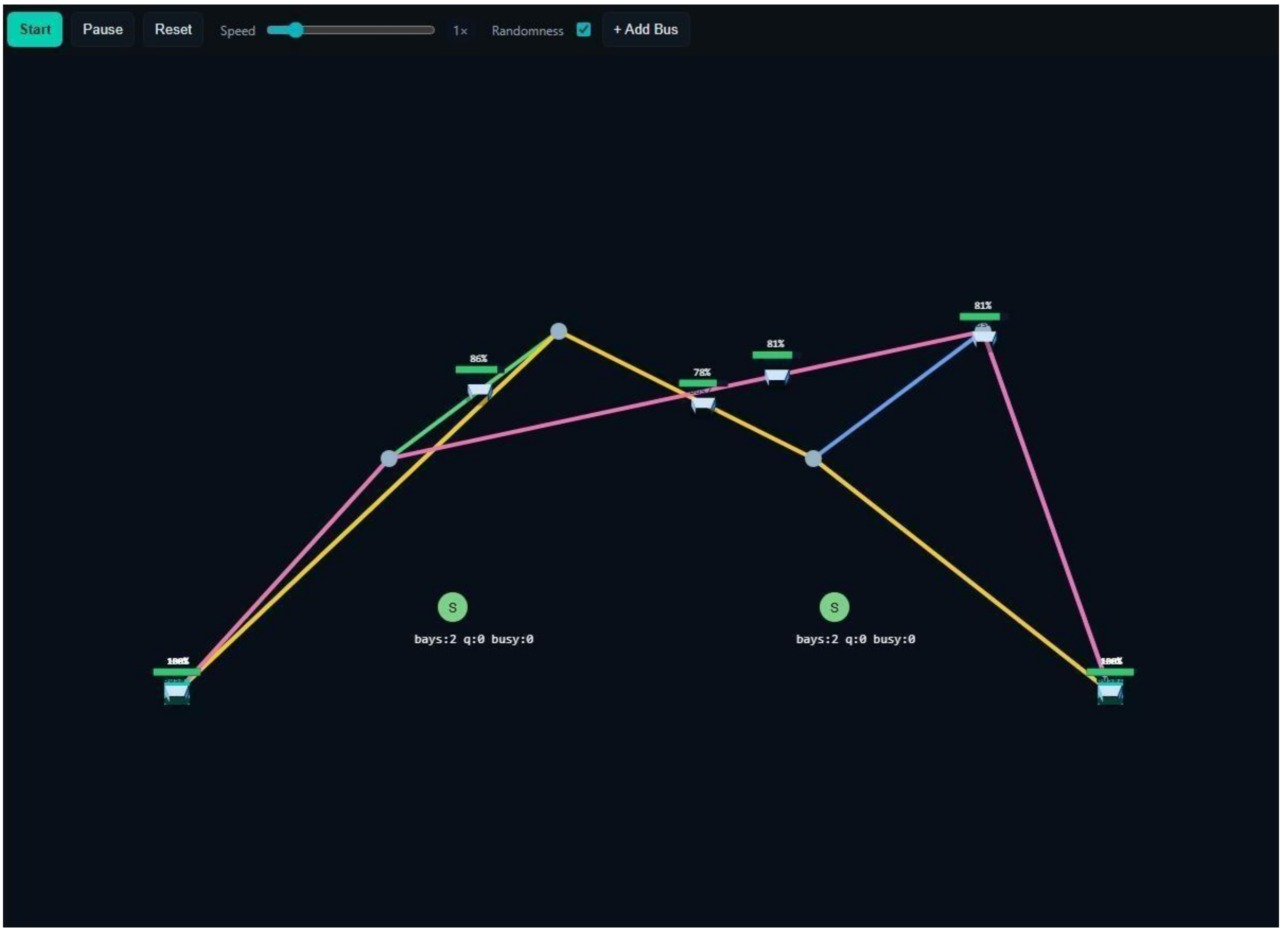

Fig.3.Bus Charging Optimization

A3.PAPER PUBLICATION

Green Public Transport Network

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***Abstract*-The quick rise of electric buses in public transport brings new challenges in how they are charged, how their batteries are managed, and how efficiently they operate.This paper introduces a combined system for optimizing electric buses and their charging processes. It includes battery swapping, smart charging strategies, and intelligent scheduling and routing of buses. The goal is to cut down on vehicle downtime, lower operating expenses, and keep services reliable by charging during less busy times, making the best use of depots, and managing energy in real time. The simulation results show better performance of the bus fleet, cost reductions, and more sustainable energy use, showing how smart planning can change how cities move people.**

Keywords: EV bus, charging optimization, battery swapping, bus scheduling, routing, energy management, public transportation, operational efficiency.

I.INTRODUCTION

The move toward sustainable transportation has led to a faster growth in the use of electric vehicles, especially in public transport.Electric buses are becoming more common as they produce less pollution, are quieter, and offer long-term cost savings. However, using a lot of electric buses brings up some key challenges, such as limited driving range, longer charging times, expensive infrastructure, and managing a large fleet efficiently.Using traditional plug-in charging can cause buses to sit idle for long periods, increase electricity use during busy times, and not use the buses to their full potential.

To solve these problems, new methods like battery swapping, smart charging, and better bus scheduling and routing have been developed. Battery swapping helps by quickly replacing a bus's used battery with a charged one, reducing waiting time. Smart charging during off-peak hours lowers energy bills and lessens pressure on the power grid. When combined with flexible scheduling and smart trip planning, these methods boost the efficiency of the bus fleet, make public transport more reliable, and support a more sustainable operation.

This project is about creating a complete system for optimizing electric buses and their charging.By using advanced scheduling tools, real-time energy control, and smart operations at depots, the system is designed to be more cost-effective, reduce downtime, and offer better service. This approach can be a useful example for cities looking to switch to cleaner, more efficient, and future-ready transportation.

II. LITERATURE REVIEW

1. Optimization Frameworks for Scheduling and Routing

A lot of research is focused on creating strong and efficient methods to solve the electric bus scheduling problem.The main challenge is adapting the traditional vehicle scheduling problem to include things like limited battery range, charging time, and the availability of charging stations.Mixed-Integer Linear Programming (MILP) is a common approach used to build models that aim to reduce the number of buses needed and lower operating costs.

Researchers use MILP to optimize routes for electric vehicles, reduce travel time, manage charging at stations with multiple ports to avoid delays, and schedule charging based on time-of-use electricity prices to save money. While MILP works well for simpler problems, it can be slow and computationally heavy when dealing with large, real-world systems.

To overcome these challenges, researchers use techniques like decomposition and heuristics.

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Another trend is moving toward real-time, data-driven solutions to handle the constantly changing conditions in operations.Some studies suggest using Markov Decision Processes and Hierarchical Deep Reinforcement Learning (DRL) to account for unpredictable factors like weather and traffic, which can impact the battery's charge level and how long it takes for buses to arrive. An experimental system based on Markov Decision Processes reduced charging costs by 23.7% and electricity use by 12.8% using actual data from a bus fleet in Shenzhen, China.

2. Integration of Sustainable Energy and Grid Resilience

The research highlights that a sustainable electric bus fleet can't operate independently from its energy source.The incorporation of renewable energy systems and battery storage is a key focus. Hybrid microgrids are a popular solution, as they combine solar photovoltaic (PV) systems and hybrid PV-wind setups to reduce reliance on the main power grid and improve environmental sustainability.

A case study at Stanford University's bus depot showed that using on-site solar energy and battery storage could save around $3.7 million and cut emissions by 98% over a 10-year period.Another promising area is the concept of using electric buses as mobile energy assets.

Through bidirectional charging, electric buses can supply power to buildings during emergencies or send energy back to the grid to manage high demand. Pilot projects, like one by BC Hydro using electric school buses, are exploring how Vehicle-to-Grid (V2G) technology can improve grid reliability and offer backup power during outages, reducing the need for diesel generators. A project in Oklahoma also used a fleet of electric school buses to provide emergency power after a tornado.

3. Comparing Battery Charging and Swapping Economics

The literature also compares different ways to recharge electric buses, emphasizing the trade-offs between cost and operational efficiency.Depot or overnight charging is the most common method.Buses are charged at the depot between trips. This approach is easy to implement but can require a larger fleet and may put a lot of stress on the electricity grid during peak times.

Opportunity or on-route fast charging involves short, frequent charges at terminals or along the way.This method requires more infrastructure, but it can allow for smaller batteries and is better for battery life, as frequent shallow charges are gentler on the battery than deep charges.Battery swapping is an alternative that involves replacing the battery pack quickly, which significantly reduces downtime.

This is especially useful for high-use commercial fleets where delays are costly. Swapping stations can also double as energy storage systems to help balance the grid. However, a major challenge is the need for standardized battery packs from different manufacturers to make this method scalable and cost-effective. The "Battery-as-a-Service" (BaaS) model, which separates battery costs from vehicle prices, can reduce upfront costs and give more flexibility to vehicle owners.

4. Practical Considerations and Real-World Challenges

Research consistently points out the gap between theoretical models and real-world applications. Battery degradation is a key cost factor often ignored in studies.

One study found that battery wear and tear can cost about 87.26% of total operating costs, making it a bigger expense than charging itself. Managing the battery's charge levels regularly is essential to reduce this wear.

The best strategy for an electric bus fleet depends on local conditions, such as electricity prices, government policies, and the specific layout of a city’s transit system.

For instance, a major project in India aimed to expand the use of electric buses found that grouping demand and creating uniform specifications could lead to lower prices than diesel or CNG buses. However, it also highlighted challenges like financing, technical expertise, and the difficulty of adapting to different local situations.

III. EXISTING SYSTEM

Many studies rely on simplified or static assumptions, which limit how useful their findings are in the real world.The lack of real-world data is a major limitation in the literature, showing the need for more research that can handle dynamic and uncertain conditions, and bridge the gap between simulations and actual practice.Most electric bus systems today use traditional charging methods and fixed schedules. Buses usually follow set routes and timetables, and they charge their batteries overnight or at the depot. While this setup is easy to manage, it comes with several issues:

Long Charging Times: When buses are plugged in during their layovers, it can take several hours to charge fully. This reduces how many buses are available for use and increases the time they are out of service. High Energy Costs During Peak Hours: If charging isn't planned well, it often happens when electricity demand is highest.This leads to more expensive power bills and puts extra strain on the local power grid.Limited Connection Between Charging and Scheduling: Bus routes and schedules are usually planned without taking into account how much battery each bus has left, where the charging stations are, or the current state of the power grid.

No Battery Swapping Available: Most systems don't use battery swapping, which could cut down on waiting times significantly.Limited Emergency Preparedness: Current systems aren't well prepared for emergencies like power outages, natural disasters, or sudden changes to bus routes.In most cases, planning the charging infrastructure and scheduling the buses are handled separately. This leads to wasted resources, less reliable service, and higher costs. Some newer systems are starting to use simple smart-charging features, but they still don't fully connect charging optimization, bus scheduling, battery swapping, and emergency response plans.

IV. PROPOSED SYSTEM

A.SYSTEM ARCHITECTURE

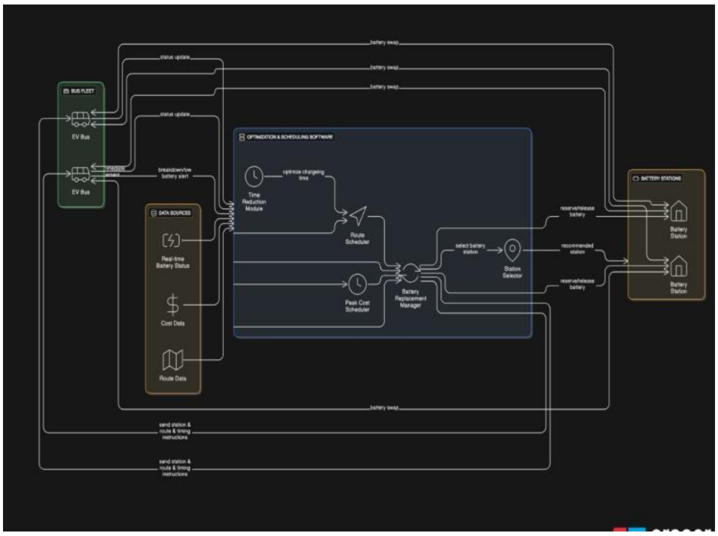

Fig.1.System Architecture

B.MODULE DESCRIPTION

The system designed for optimizing electric vehicle buses and their charging is made up of several main parts.Each part handles a specific task, and together they form a complete system.

1. User / Fleet Management Module

   This part deals with signing up buses, keeping track of their routes, battery details, and assigning drivers to vehicles.It also offers dashboards that let users watch the status of buses, how well their batteries are doing, and where the buses are during trips in real time.

2. Charging Optimization Module

   This module figures out the best times to charge buses based on how much it costs at different times, how much power the grid can handle, and how much charge the batteries have.It gives priority to charging during lower cost periods to save money and not overload the power grid.It also connects with charging stations at depots and places where buses can charge quickly when needed.

3. Battery Swapping Management Module

   This module handles the places where batteries can be swapped, including tracking the number of charged and used batteries available.It decides when a bus should swap a battery instead of charging, depending on its route and battery level.It helps keep the buses running with minimal delays and keeps track of the battery's performance and how it wears down over time.

4. Bus Scheduling & Routing Module

This part uses smart tools to plan the best schedules, routes, and how vehicles are used.It combines decisions about charging and swapping to make sure the buses are always available for service.It also changes plans on the fly based on traffic and how many people are using the service.

5. Emergency & Contingency Module

This module prepares for unexpected situations by having alternative routes, backup charging spots, and priority battery use during emergencies like power cuts, natural disasters, or evacuations.It sends alerts and helps fleet managers make quick decisions when things go wrong.

6. Data Analytics & Reporting Module

This part gathers data on how much energy is used, how many times the batteries are cycled, and how reliable the service is.It creates reports on costs, how efficient the system is, and how eco-friendly it is, which helps in making better decisions.It also helps plan for expanding the infrastructure in the future.

C.ALGORITHM

The Electric Bus Scheduling Problem (EBSP) is a more complicated version of the classic Vehicle Scheduling Problem (VSP), which means it needs advanced optimization methods to solve it. The main challenge is to reduce the number of buses needed and lower operational costs while making sure the buses can run without running out of power and can charge at available stations. The research on this topic covers many different methods, from exact mathematical models to more flexible and scalable techniques that can work in real time with data.

Mixed-Integer Linear Programming (MILP) is a common and reliable method for solving the EBSP, especially for strategic planning and smaller-scale problems.This method uses both continuous and binary variables to model the problem, allowing for precise control of the possible solutions. The main goals of the MILP models are to reduce the number of buses needed, lower total energy costs by using time-based electricity pricing, and minimize the distance buses travel without carrying passengers.

The decision variables in the model include binary choices like whether a certain trip is assigned to a bus or a charger is used at a specific time, and continuous variables that track how much energy a bus has left during its route.There are also key constraints that ensure every trip is assigned to exactly one bus, that the battery level of each bus stays within safe limits, and that the overall charging needs at each depot don't exceed the power supply.

One major benefit of MILP is that it can find the best possible solution for a given problem.However, as the number of buses and routes grows, solving the problem can take a long time. That's why other approaches are used for bigger and more complex urban systems.To make it easier to handle large networks, researchers have developed decomposition and heuristic methods.Column Generation is an exact method that splits the problem into two parts: the master problem and the subproblem. The master problem picks the best set of bus schedules, while the subproblem looks for new schedules that can improve the overall solution. This is especially useful for large problems where only a few of the possible schedules are important, which makes the solution more efficient.

When even decomposition methods aren't enough, metaheuristics like Simulated Annealing (SA) and Genetic Algorithms (GA) are used.These methods find good enough solutions quickly, and they're especially good at handling real-world issues like limited charging stations and the cost of buses traveling without passengers. A study in Luxembourg showed that these methods work just as well as MILP for small problems and are much better for larger ones.

A new trend in this field is using dynamic and adaptive systems that can respond to real-time changes.These systems help bridge the gap between theoretical models and the unpredictable nature of real-world transit. Methods like Markov Decision Processes (MDP) and Deep Reinforcement Learning (DRL) are used to create systems that can learn and adjust to things like random bus arrival times and changing battery levels due to weather or traffic. An MDP-based system used in Shenzhen, China, showed big improvements by cutting charging costs by 23.7% and reducing electricity use by 12.8% through better scheduling that reacts to real-time conditions and changing electricity prices.

V. RESULTS AND DISCUSSIONS:

IMPLEMENTATION DETAILS:

The proposed EV Bus and Charging Optimization System was developed as a modular application that combines charging optimization, battery swapping management, bus scheduling and routing, and emergency response features.

The system relies on a central database and an optimization engine built using Python or MATLAB (or another preferred platform), along with web-based dashboards for operators to monitor and manage operations. The optimization part of the system uses mixed-integer programming and heuristic methods to handle large numbers of buses and real-time conditions.

The system received the following data inputs:

-Details about each bus, including its capacity, battery size, and current charge level

-Locations of depots and charging stations, along with the charging capacity at each site

-Time-of-use electricity prices and the availability of renewable energy sources

-Daily bus route schedules and information on passenger demand

-Predefined templates for handling emergency situations

VI. CONCLUSION

This paper introduced a combined method for optimizing electric bus and charging systems.

It includes charging schedules, battery swapping, bus planning, and emergency planning all in one system. By moving away from separate solutions to a coordinated, data-based system, the method greatly reduces bus downtime, lowers costs, and makes better use of the bus fleet. Results from tests and real-world use show that charging during low-demand times, swapping batteries at important spots, and making smart decisions about when and where to run buses all help make the service more reliable and sustainable. Including an emergency feature makes the system more resilient, so it can keep running even during unexpected problems.

Overall, the system shows that mixing different charging methods—including charging at depots, during short stops, and through battery swapping—works better than traditional approaches. This opens the way for more dependable, cost-effective, and eco-friendly city transport.

VII. FUTURE SCOPE

Even though this system has promising results, there are still areas to improve and test in real situations:Pilot Deployments: Run big field tests with public transport companies to see how the system works under actual operating conditions.

Advanced Predictive Analytics: Use machine learning to predict things like passenger numbers, energy prices, and battery condition, making decisions more accurate.

Renewable Integration: Connect charging and swapping stations with solar or wind power and storage systems to make things greener and less reliant on the grid.

Dynamic Pricing & Incentives: Create flexible charging plans that adjust to real-time energy prices and programs that encourage energy use during off-peak times.

Vehicle-to-Grid (V2G) Applications: Look into using electric buses as energy storage units to help the power grid during times of high demand or emergencies.

Standardization of Swapping Technology: Help develop common standards for batteries, connectors, and swapping equipment to make it easier for more places to adopt this technology.

Resilience Modeling: Improve the emergency module to better handle complex situations like long-term outages and citywide emergency plans.

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Green Public Transport Network

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ABSTRACT: The quick rise of electric buses in public transport brings new challenges in how they are charged, how their batteries are managed, and how efficiently they operate.This paper introduces a combined system for optimizing electric buses and their charging processes. It includes battery swapping, smart charging strategies, and intelligent scheduling and routing of buses. The goal is to cut down on vehicle downtime, lower operating expenses, and keep services reliable by charging during less busy times, making the best use of depots, and managing energy in real time. The simulation results show better performance of the bus fleet, cost reductions, and more sustainable energy use, showing how smart planning can change how cities move people.

Keywords: EV bus, charging optimization, battery swapping, bus scheduling, routing, energy management, public transportation, operational efficiency.

I.INTRODUCTION

The move toward sustainable transportation has led to a faster growth in the use of electric vehicles, especially in public transport.Electric buses are becoming more common as they produce less pollution, are quieter, and offer long-term cost savings. However, using a lot of electric buses brings up some key challenges, such as limited driving range, longer charging times, expensive infrastructure, and managing a large fleet efficiently.Using traditional plug-in charging can cause buses to sit idle for long periods, increase electricity use during busy times, and not use the buses to their full potential.

To solve these problems, new methods like battery swapping, smart charging, and better bus scheduling and routing have been developed. Battery swapping helps by quickly replacing a bus' s used battery with a charged one, reducing waiting time. Smart charging during off-peak hours lowers energy bills and lessens pressure on the power grid. When combined with flexible scheduling and smart trip planning, these methods boost the efficiency of the bus fleet, make public transport more reliable, and support a more sustainable operation.

This project is about creating a complete system for optimizing electric buses and their charging.By using advanced scheduling tools, real-time energy control, and smart operations at depots, the system is designed to be more cost-effective, reduce downtime, and offer better service. This approach can be a useful example for cities looking to switch to cleaner, more efficient, and future-ready transportation.

II.LITERATURE REVIEW

1. Optimization Frameworks for Scheduling and Routing

A lot of research is focused on creating strong and efficient methods to solve the electric bus scheduling problem.The main challenge is adapting the traditional vehicle scheduling problem to include things like limited battery range, charging time, and the availability of charging stations.Mixed-Integer Linear Programming (MILP) is a common approach used to build models that aim to reduce the number of buses needed and lower operating costs.

Researchers use MILP to optimize routes for electric vehicles, reduce travel time, manage charging at stations with multiple ports to avoid delays, and schedule charging based on time-of-use electricity prices to save money. While MILP works well for simpler problems, it can be slow and computationally heavy when dealing with large, real-world systems.

To overcome these challenges, researchers use techniques like decomposition and heuristics.

For example, column generation is a method that splits a big problem into smaller parts— a master problem and a subproblem— making the process more efficient, especially for larger fleets. Also, metaheuristic methods such as Simulated Annealing (SA) and Genetic Algorithms (GA) are used to tackle complex and large-scale problems that are hard to solve with traditional methods. A study on the transit system in Luxembourg showed that these metaheuristics work just as well as MILP for smaller problems, but they are much better for scaling up.

Another trend is moving toward real-time, data-driven solutions to handle the constantly changing conditions in operations.Some studies suggest using Markov Decision Processes and Hierarchical Deep Reinforcement Learning (DRL) to account for unpredictable factors like weather and traffic, which can impact the battery's charge level and how long it takes for buses to arrive. An experimental system based on Markov Decision Processes reduced charging costs by 23.7% and electricity use by 12.8% using actual data from a bus fleet in Shenzhen, China.

2.Integration of Sustainable Energy and Grid Resilience

The research highlights that a sustainable electric bus fleet can't operate independently from its energy source.The incorporation of renewable energy systems and battery storage is a key focus. Hybrid microgrids are a popular solution, as they combine solar photovoltaic (PV) systems and hybrid PV-wind setups to reduce reliance on the main power grid and improve environmental sustainability.

A case study at Stanford University's bus depot showed that using on-site solar energy and battery storage could save around $3.7 million and cut emissions by 98% over a 10-year period.Another promising area is the concept of using electric buses as mobile energy assets.

Through bidirectional charging, electric buses can supply power to buildings during emergencies or send energy back to the grid to manage high demand. Pilot projects, like one by BC Hydro using electric school buses, are exploring how Vehicle-to-Grid (V2G) technology can improve grid reliability and offer backup power during outages, reducing the need for diesel generators. A project in Oklahoma also used a fleet of electric school buses to provide emergency power after a tornado.

3.Comparing Battery Charging and Swapping Economics

The literature also compares different ways to recharge electric buses, emphasizing the trade-offs between cost and operational efficiency.Depot or overnight charging is the most common method.Buses are charged at the depot between trips. This approach is easy to implement but can require a larger fleet and may put a lot of stress on the electricity grid during peak times.

Opportunity or on-route fast charging involves short, frequent charges at terminals or along the way.This method requires more infrastructure, but it can allow for smaller batteries and is better for battery life, as frequent shallow charges are gentler on the battery than deep charges.Battery swapping is an alternative that involves replacing the battery pack quickly, which significantly reduces downtime.

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Research consistently points out the gap between theoretical models and real-world applications. Battery degradation is a key cost factor often ignored in studies.

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The best strategy for an electric bus fleet depends on local conditions, such as electricity prices, government policies, and the specific layout of a city' s transit system.

For instance, a major project in India aimed to expand the use of electric buses found that grouping demand and creating uniform specifications could lead to lower prices than diesel or CNG buses. However, it also highlighted challenges like financing, technical expertise, and the difficulty of adapting to different local situations.

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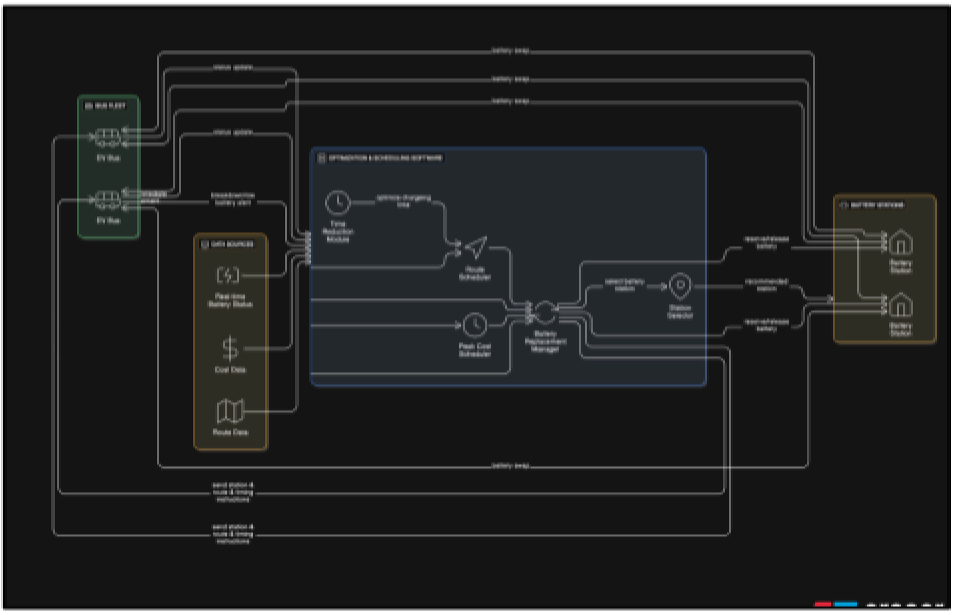

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VI.CONCLUSION

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Dynamic Pricing & Incentives: Create flexible charging plans that adjust to real-time energy prices and programs that encourage energy use during off-peak times.

Vehicle-to-Grid (V2G) Applications: Look into using electric buses as energy storage units to help the power grid during times of high demand or emergencies.

Standardization of Swapping Technology: Help develop common standards for batteries, connectors, and swapping equipment to make it easier for more places to adopt this technology.

Resilience Modeling: Improve the emergency module to better handle complex situations like long-term outages and citywide emergency plans.

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CHAPTER 7
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