

Multi – Depot Electric Vehicle Scheduling Problem in Public Transportation

Praveen Kumar M¹, Charles Raja S², Arun Mozhi S³ and Arul Jeyaraj K⁴

¹⁻³Thiagarajar College of Engineering, Madurai, India

Email: praveen1@student.tce.edu

⁴PSNA College of Engineering and Technology, Dindigul, India

Email: charlesrajas@gmail.com, arunmozhi49@gmail.com, kajeyaraj@gmail.com

Abstract— The sustainable practice of green transportation depends on the efficient scheduling of electric buses (EBs) for multiple vehicle types. The Electric Vehicle Scheduling Problem (EVSP) in public transportation is addressed in this work and a new methodology is proposed for scheduling the trips of electric buses that is based on the timetables framed with 768 trips - weekend and 640 trips - weekday. To compare annual total scheduling costs, which include the purchase cost of EBs and chargers as well as the operating costs of timetabled trips, etc., a nonlinear objective function is first created with explicit consideration of variations in the driving range, recharging duration, and energy consumption of EBs for Multiple Vehicle Types (MVT). The suggested methodology is then tested on a transit network that exists in the Madurai District, Tamil Nadu which considers three different routes with three depots. The outcome results in the comparison of Weekend and Weekday based annual total scheduling cost and operating cost of timetabled trips. Paramics is traffic micro simulation software used for analyzing and modeling transportation systems for three routes.

Keywords—Electric vehicles, Vehicle scheduling problem, Multiple vehicle types, Recharging trips, charging station.

I. INTRODUCTION

Due to the rapid urban growth in the past few years, several cities have suffered from a severe snarl of traffic. Promoting public transportation has been the consensus of the entire population as a solution to this issue. A significant environmental problem in many nations is global warming, which is partly brought on by the high use of gasoline in road transportation. To cut back on emissions in the transportation industry, we have to adopt suitable energy policies and electric vehicles (EVs) contribute significantly to the low-carbon transition. Pollution in the transportation sector is increasing day by day all over the world. In many countries, pollution occurs due to fuel vehicles, especially fuel buses. To reduce pollution, the introduction of electric buses in the public transportation sector is mandatory and thereby reducing operating cost and maintenance costs [1]. Vehicle scheduling problems (VSPs) can be classified into single-depot VSPs and multi-depot VSPs. In a single-depot, only less a variety of electric vehicles can be depoted and the plugs for charging each bus must be fewer so the multi-depot can be used instead of a single-depot. Because in multi-depot more vehicles can be depoted and the charging outlet for each bus can be increased [2][3].

Electric vehicles are being used in public transportation sectors, especially in buses, thereby scheduling the timetabled trips for bus routes by applying the column-generating method based on genetic algorithms. The branch-based column-generating strategy is contrasted with the genetic algorithm-based column-generation attitude in the context of a vehicle's route and is 40 times less expensive than the genetic functions-based baluster-generation strategy in the pricing algorithm and human scheduling system [4]. Using multiple-depot vehicle scheduling issues with time windows and a method that approaches a mixed integer non-linear model for these issues, electric buses can be recharged at depots. [5].

Compared to buses that use conventional fuel, electric buses provide advantages for the environment, the economy, and the energy sector [6]. Implementing an adaptive scheduling method based on convex optimization and model predictive control and comparing its performance to baseline algorithms by introducing three-phase infrastructure, non-ideal battery charging behavior and quantized control signals [7]. While scheduling vehicles, the limits must be taken into account for EBs. A sensitivity analysis was done to offer transportation authority's advice on how to create a quick charging infrastructure. In addition, a lot of bus routes are now working with various types of electric vehicles due to fleet renewal and the promotion of electric buses, which makes it more likely overpopulation inside the vehicle or capacity waste will occur than under an organization mode that only uses a single type of vehicle [8].

Implementing electric buses in public transport instead of fuel buses also explains the charging outputs for each bus in the depots, it also deals with the operating trips of buses and the charging duration and assigns a route for electric buses [9][10]. In order to reduce the price of EBs and chargers, and an installation price of chargers, an optimization technique is proposed and thereby minimize the annual total scheduling cost including the cost of operating timetabled trips, before that fix the shoving range of EBs and the recharging duration of chargers [11]. Additionally, comprehensive planning is vital for trade, transportation, and Vehicle scheduling is one of the most crucial stages in the planning process. Vehicle assignment for the trips in a specific timetable is a process called "vehicle scheduling," which is directly tied to scheduling costs for operators [12].

Bidding of charging stations for private and public sectors according to price demands and the process of scheduling the charging and recharging trips can be scheduled by the owner of the charging station and the infrastructure of charging stations can be installed as per the owner's opinion [13]. The framework for EB recharging scheduling optimization offers operational and planning choices to reduce annual overall expenditures. A sensitivity analysis was done to offer transportation authority's advice on how to create a quick charging infrastructure. The depot charging concept is implemented based on the concept of park charging concept while parking the vehicles in depots and the charging can be done while parking in the depots whether it is in housing at night [14]. According to a comprehensive literature review, it is important to keep the scheduled excursion operation price, EB buying price, and charger buying and installing price to a minimum.

II. METHODOLOGY

In this section, a cost-effective decision-making approach is developed that may assign each trip of a given timetable to an EB for a suitable type while taking into account the recharging demand and the replacement between vehicle types to use EBs for various vehicle types more efficiently.

A collection of timetabled trips for multiple vehicle types, a set of vehicle types, and a set of depots where EBs are charged or kept overnight are the inputs for the challenge of scheduling multiple vehicle types. The timetables trips scheduled for multiple vehicle types have a specific start time, end time, and recharging time. Finding the schedule of each EB is the objective to effectively complete all timetabled trips. Each trip can only be in one schedule of an EB for a suitable type, and the scheduling expenses must be as minimal as possible.

When compared to a typical fuel bus, the EB is required to make both scheduled trips and trips for recharging. When a scheduled trip is made, EBs can be recharged at the nearby depot or sent back to their base depot. By defining V as the vehicle type and each vehicle should have a reaching trip whether the available SOC is not enough to take the next trip. Based on State Of Charge (SOC), the recharging trip may vary according to the loads consumed by the EB's. Selection of EB is the main process to schedule the timetabled trips.

To simplify the problem, several major assumptions have to be made:

- To ensure that all trips can be carried out as planned, unanticipated circumstances like traffic accidents, severe weather, etc. are not taken into consideration.
- For a specific vehicle type operating under a specific load scenario, the energy usage rate i.e., the amount of energy spent per unit distance is fixed, however different EV types with varied passenger loads have different energy usage rates.
- After each recharging trip, all EB types are fully charged.

➤ Each charger has a single outlet and all of them are homogenous fast chargers.

The three depots are to be considered depot-1 is Thirumangalam, depot-2 is Mattuthavani, and depot-3 is Arapalayam.

III. MODEL FORMULATION

For modelling formulation, l and m can be defined as timetabled trips in the model. The V is the set of electric vehicles ($v \in V$). Let G be various timetabled trips for all types of vehicles. Let G_v be timetabled trips for type v ($l \in G_v$), therefore it can be explained in the equation as $G = \sum_{v \in V} G_v$. Let X is the various types of vehicle types of all EBs. Let X_v be the various type of EBs for type v ($x_v \in X_v$), therefore it can be explained in the equation as $X = \sum_{v \in V} X_v$. Let O be the various type of chargers ($o \in O$) and the Y be the various type of depots ($y \in Y$).

Other variables and parameters are listed below:

β Annualized factor;

W_v The price in rupees of buying an EB for a type of vehicle v ;

Z_{x_v} If EB x_v was utilized within one day, the variable will be 0 or 1;

A Number of working days in a year;

W_j The price in rupees of buying and installing a charger;

F_o If the charger o was utilized within one day, the variable will be 0 or 1;

W_l Rupees as the fixed amount of recharging the journey;

R_l^o If EB is recharged by charger o after completing the scheduled trip l , the variable will be 0 or 1;

W_v^2 Operational expenses per km (in INR) of an EB for the type of vehicle v for people transporting range;

E_l Driving range in kilometers of the scheduled excursion;

A mathematical model is proposed for the multi-vehicle type vehicle scheduling problem and that can be formulated as:

$$\min B = B_1 + B_2 + B_3 + B_4 \quad (1)$$

$$B_1 = \sum_{v \in V} \sum_{x_v \in X_v} \beta W_v Z_{x_v} \quad (2)$$

$$B_2 = \sum_{o \in O} \beta W_j F_o \quad (3)$$

$$B_3 = \sum_{o \in O} \sum_{v \in V} \sum_{l \in G_v} A W_l R_l^o \quad (4)$$

$$B_4 = \sum_{v \in V} \sum_{l \in G_v} A W_v^2 E_l \quad (5)$$

Objective (i) is to compare the weekend and weekday scheduling cost B_1 , B_2 , B_3 , and B_4 (i.e., B) overall annually. B_1 indicates the purchase cost of EBs for all vehicle types, which are considered by the number of EBs, required covering all timetabled trips. Based on the number of chargers required to meet all recharging trips, B_2 indicates the costs associated with the purchase and installation of chargers. B_3 indicates the fixed recharging cost based on the number of recharging trips. B_4 is the operating cost for scheduled trips based on the number of passengers carried.

A. Specification of Electric Bus

The Fig.1 has the electric powertrain features of AC induction motor paired with a Lithium-ion (Li-ion) battery, typically ranging from 160 kWh to 200 kWh in capacity, and supports both AC and DC fast charging for flexibility across different infrastructures. It delivers around 245 horsepower (180 kW) and 700 Nm of torque, with a top speed electronically limited to 70 km/h, depending on the configuration and regulations. The vehicle offers a range of 150 to 200 kilometers per charge, depending on battery capacity and driving conditions. Seating configurations of Fig.2 accommodate 25 to 35 passengers, with additional standing capacity, allowing customization for various transit needs. Battery Electric Vehicles (BEVs), also known as All-Electric Vehicles (AEVs), rely solely on electric drive trains powered by large battery packs charged from the power grid. The charged battery powers one or more electric motors to drive the vehicle. BEVs are more efficient compared to hybrid and plug-in hybrid vehicles. Depot chargers, installed at bus depots or terminals, quickly charge buses overnight or during breaks using high-power AC or DC chargers. AC chargers convert AC power from the grid into DC power, charging buses with onboard AC chargers at power levels ranging from a few kilowatts to several hundred kilowatts. DC chargers directly provide DC power to the bus's battery, enabling rapid charging at power levels from tens to hundreds of kilowatts. The benefits of electric buses include energy efficiency, environmental sustainability, cost savings, noise reduction, flexibility, integration with

renewable energy, improved passenger experience, and long-term planning. Electric bus scheduling further enhances these advantages by optimizing deployment and operations, contributing to more sustainable public transportation systems.

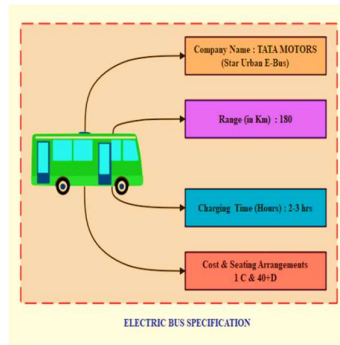


Figure 1. Electric Bus Specification



Figure 2. TATA Star bus

IV. FINDING OF ROUTE MAP FOR EBS

Electric buses are selected as Electric Vehicles and why electric buses are chosen because electric vehicles like two-wheelers and four-wheelers are mostly used in transportation. But in public transportation, they are using still fuel vehicles instead of electric vehicles and thereby introducing electric buses in public transportation. The transportation network consists of three depots considering Thirumangalam bus stand (depot 1), Mattuthavani bus stand (depot 2), and Arapalayam bus stand (depot 3) as well as three bus routes namely Thirumangalam to Mattuthavani (T-M) (Fig.3), Mattuthavani to Arapalayam (M-A) (Fig.4), and Arapalayam to Thirumangalam (A-T) (Fig.5) and the routes maps are taken with the help of Google maps and thereby adding the stops, we can easily calculate the distance for each stop and the entire distance of the routes and the route distance were varied for each route. Table I shows the scheduling timings between the routes.

TABLE I. SCHEDULED TIMINGS BETWEEN THE ROUTES

DEPOTS	
T-M	6:00 AM - 11:10 PM
M-A	6:00 AM - 10:25 PM
A-T	6:00 AM - 10:50 PM

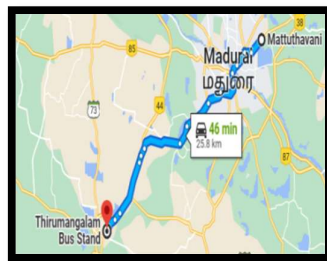


Figure 3. T-M route map

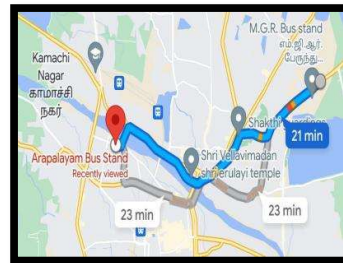


Figure 4. M-A route map



Figure 5. A-T route map

A. Scheduling of Bus Routes

The simplified diagram of bus routes is shown in Fig. 6 and the depots are mentioned in the diagram. The routes for the up and down trip for each route are mentioned in the bidirectional arrows. Each route has a different distance and different travelling time as per the scheduling.

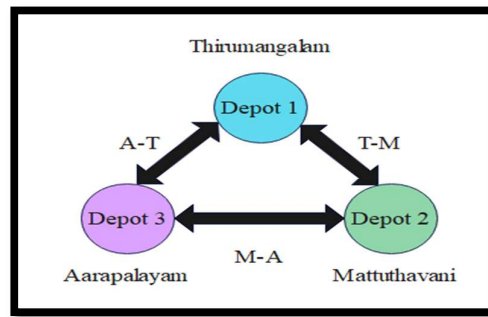


Figure 6. Simplified diagram of bus route

T-M Route

The bus routes are scheduled for Thirumangalam to Mattuthavani and there are 7 stops between Thirumangalam and Mattuthavani, it takes 2 hours to complete the trip with a distance of 30.1 km and here we are scheduled as per peak and non-peak hours, so far we scheduled the timings between 6:00 am -11:10 pm as per the calculated timings and the bus route timings are differ for T-M and M-T, it's like routes up and routes down. The bus route begins from Thirumangalam Bus Stand and travels to Thiru Nagar Bus Stop, covering a distance of 10.6 km in 27 minutes. From Thiru Nagar Bus Stop, the next destination is Thirupurakundram Kovil Stop, which is 2.2 km away and takes 10 minutes. The route then continues from Thirupurakundram Kovil Stop to Palankanatham Bus Stop, covering 3.7 km in 15 minutes. From Palankanatham Bus Stop, the bus travels to Periyar Bus Stand, a distance of 3.2 km that takes 16 minutes. Next, the bus moves from Periyar Bus Stand to Koripalayam Bus Stop, covering 3.6 km in 20 minutes. From Koripalayam Bus Stop, it travels to Apollo Signal Stop, which is 3.6 km away and takes 19 minutes. The final leg of the route is from Apollo Signal Stop to Mattuthavani, covering 3.2 km in 13 minutes. Overall, the total distance covered is 30.1 km, with a total duration of 2 hours.

M-A Route

The bus routes are scheduled for Mattuthavani to Arapalayam and there are 5 stops between Mattuthavani and Arapalayam, it takes 45 minutes to complete the trip with a distance of 10.5 km and here we are scheduled as per peak and non-peak hours, so far we scheduled the timings between 6:00 am -10:25 pm as per the calculated timings and the bus route timings are differ for M-A and A-M, it's like route up and route down. The bus route starts from Mattuthavani Bus Stand and travels to KK Nagar Bus Stop, covering a distance of 1.9 km in approximately 9 minutes. From KK Nagar Bus Stop, the bus continues to Madurai Medical College Stop, with a distance of 3.2 km and a travel time of 12 minutes. The next leg of the journey takes the bus from Madurai Medical College Stop to Thiruvapudaiyar Bus Stop, which is 2.5 km away, and takes around 10 minutes. Afterward, the bus travels 1.4 km to reach Mela Kailasapuram Bus Stop, which takes about 7 minutes. The final part of the route covers the 1.5 km from Mela Kailasapuram Bus Stop to Arapalayam, taking another 7 minutes. In total, the bus route covers 10.5 km with an overall duration of 45 minutes.

A-T Route

The bus routes are scheduled for Arapalayam to Thirumangalam and there are 6 stops between Arapalayam and Thirumangalam, it takes 1 hour and 15 minutes to complete the trip with a distance of 22.8 km. Here we are scheduled as per peak and non-peak hours, so far we scheduled the timings between 6:00 am and 10:50 pm as per the calculated timings and the bus route timings differ for A-T and T-A, it's like routes up and routes down. The bus route starts from Arapalayam and travels to Guru Theatre, covering a distance of 1.3 km in approximately 7 minutes. The next segment is from Guru Theatre to Kalavasal Bus Stop, which is 0.5 km away, and it takes around 6 minutes. From Kalavasal Bus Stop, the bus proceeds to Palankanatham Bus Stop, covering 4.5 km in 16 minutes. Afterward, the bus heads to Thirupurakundram Kovil Stop from Palankanatham, covering 3.7 km in about 13 minutes. The route continues from Thirupurakundram Kovil Stop to Thiru Nagar Bus Stop, a 2.2 km journey that takes 9 minutes. Finally, the bus travels from Thiru Nagar Bus Stop to Thirumangalam Bus Stop, a longer stretch of 10.6 km that takes 24 minutes. In total, the bus covers a distance of 22.8 km with a total travel time of 1 hour and 15 minutes.

V. DATA PREPARATION

Totally 96 EBs are required to cover all the timetabled trips scheduled and it is optimized by excel sheet calculations. The price of EB (35 seaters) is 6500000 rupees. The price of purchase and installation cost per charger is 2000000 rupees. The chargers available in depot 1 are 4, depot 2 is 5, and depot 3 is 4. The capacity of depot 1 is 26 and then the capacity of depot 2 is 40, while the capacity of depot 3 is 30. The fixed capital expenses are annualized assuming an 8-year useful life and a 10% interest rate because EBs has an average lifespan of 7.8 years. So, using the economic engineering formula $(A/P, 10\%, 8) = 0.1874$, the annualized factor is determined. The number of operating days in a year is 360, hence $A = 360$. The fixed cost of a recharging trip is rupees.

VI. SOC CALCULATION

SOC represents the energy stored in a battery as a percentage of its total capacity, crucial for estimating the driving range of electric vehicles. Monitoring SOC is vital for efficient battery management, optimal performance, and planning trips. It prevents overcharging and deep discharging, which can harm battery life. SOC is displayed as a percentage on the vehicle's dashboard or battery management system, increasing with charging and decreasing with discharging. EV software often provides estimated charging times and SOC predictions to help manage charging needs. Battery management systems continuously monitor SOC to ensure proper functioning and protect against battery degradation or safety hazards. SOC estimation algorithms use factors like battery capacity, voltage, current, temperature, and historical data for accuracy. Understanding and monitoring SOC helps optimize charging patterns, plan routes, and ensure battery longevity and efficiency. SOC is typically recharged at 10%, with remaining SOC (R) shown graphically in Fig.7.

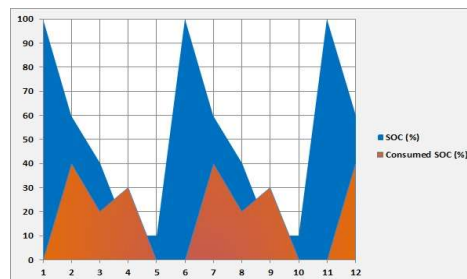


Figure 7. Visualization of SOC

VII. RESULT AND DISCUSSION

A. Routing Analysis

Paramics is traffic micro simulation software used to analyze and model transportation systems, aiding planners, engineers, and researchers in optimizing road networks and traffic scenarios. It is widely used in transportation planning, traffic engineering, and research to improve traffic flow, enhance safety, and support decision-making.

In this context, Paramics simulates public transportation between specified routes (T-M, M-A, A-T). First, routes are drawn, demand across each zone is fixed, and speed limits for buses are set, as shown in figures 8, 9, and 10. Public Transport (PT) Services are used to schedule buses according to the set timings. The software visualizes bus scheduling, showing buses waiting at stops with adjustable wait times, either manually or automatically. Stops and wait times can be fixed along routes, and the software prototype visualizes the scheduling process.

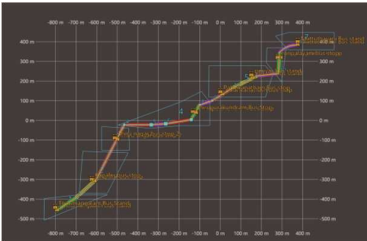


Figure 8. Paramics work flow diagram for T-M route (Route 1)

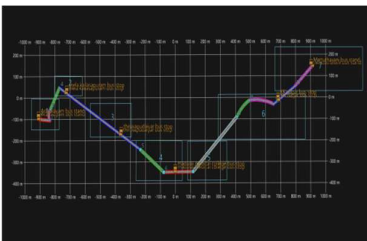


Figure 9. Paramics work flow diagram for M-A route (Route 2)

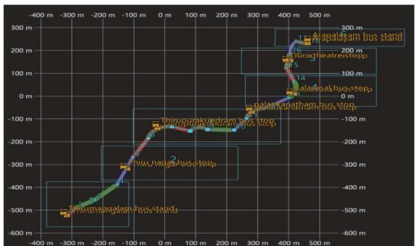


Figure 10. Paramics work flow diagram for T route (Route 3)

A common method is used to schedule the remaining routes, specifically the 2nd and 3rd routes. This method is based on Fig.11, Fig.12, and Fig.13, which provide details on demand allocation for specific zones, route and stop selection settings, and the scheduling of timings.

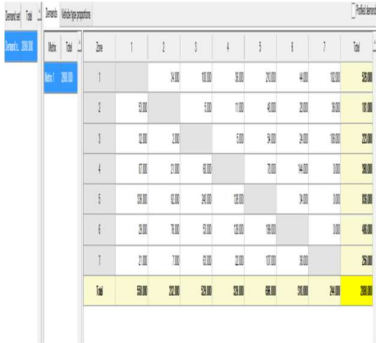


Figure 11. Demands needed in zones for T-M route (Route 1)

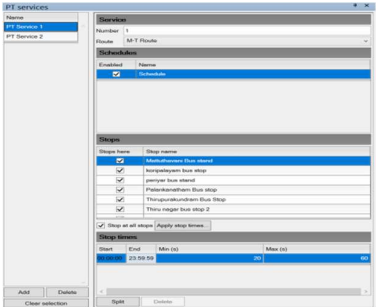


Figure 12. PT services (Route 1)

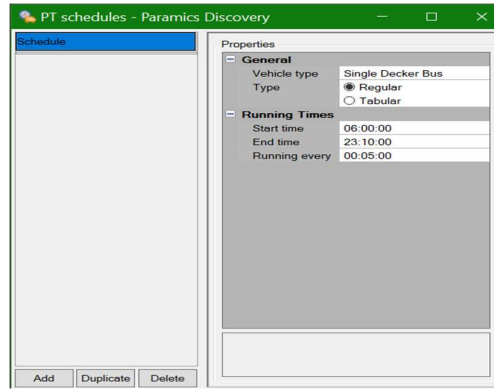


Figure 13. PT schedules (Route 1)

B. Cost of Scheduling

The results were manually calculated using data scheduled in the Excel sheet. The cost parameters B1 and B2 represent capitalized costs, while the parameters B1, B2, and B4 vary between the weekend and weekday schedules. The weekend schedule involves 96 buses, whereas the weekday schedule uses 80 buses. This variation is due to the differences in timetabled trips, with peak hours included in the weekday schedule. The weekday schedule runs buses every 5 minutes during peak hours and every 15 minutes during non-peak hours. In contrast, the weekend schedule operates buses every 5 minutes consistently, as public demand is generally higher on weekends compared to weekdays. The results are compared and presented in table II.

TABLE II. COMPARISON OF COST PARAMETERS BETWEEN WEEKDAY AND WEEKEND SCHEDULES

Cost Parameter	Weekday Schedule (In Crores)	Weekend Schedule (In Crores)
B1	10.4	11.7
B2	0.5	0.5
B3	0.22	0.24
B4	1.46	1.75
B	12.58	14.19

VIII. CONCLUSION

A comprehensive literature review was conducted, and the abstract was formulated. The MVT-E-VSP model considers EB for various vehicle types and includes the following cost factors: B1 represents the cost of EBs for different vehicle types, based on the number of EBs required to complete all scheduled trips. B2 estimates the cost of purchasing and installing chargers, depending on the number needed to support recharging operations. B3 reflects the recurring cost of recharging based on the frequency of recharging trips, while B4 accounts for the operational expenses of scheduled trips, based on the number of passengers carried. This model is applied to analyze a real-world transit system in the Madurai District of Tamil Nadu. The results provide the required number of EBs and chargers for both types of vehicles and their respective schedules.

FUTURE WORK

The manually calculated comparison between weekend and weekday scheduling will be implemented in MATLAB software and optimized using various techniques to reduce the number of buses required. A software prototype will be developed, integrating a real-time map of the Madurai district to visualize public transportation scheduling. This will be implemented using the full version of the software, accessible only to Paramics authorities. The electric bus scheduling has been manually calculated in Excel sheets, which serve as the source file for future use in MATLAB for comparison and result verification.

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