OPEN ACCESS
Indo-JC Indonesia Journal of Computing
ISSN 2460-9056
journals.telkomuniversity.ac.id/indojc

Ind. Journal on Computing
Vol. 11, Issue. 2, August 2026. pp. 92-97
doi:10.21108/indojc.v11i2.11105

Route Optimization for Public Transportation Type Electric Vehicles Using a with Branch and Bound Solution

Fikri Haiqal Boang Manalu[1], Esther Sorta Mauli Nababan[2], Muhammad Romi Syahputra[3], Aghni Syahmarani[4]

Department of Mathematics, University of North Sumatra

[1] fikrihaiqalboangmanalu@gmail.com

Abstract

Electric public transportation has increasingly been adopted as an environmentally friendly mobility solution. However, its implementation still faces a major challenge due to the uneven distribution of supporting infrastructure, particularly the limited number and coverage of charging stations. This condition affects route planning, as vehicles must consider energy constraints in addition to passenger demand. This study aims to optimize electric vehicle routes by formulating the problem as an Electric Vehicle Routing Problem (EVRP) using a Mixed Integer Linear Programming (MILP) approach. The objective function is to minimize total travel cost based on distance, subject to constraints such as vehicle capacity, route flow balance, and battery energy consumption. The decision variables include binary variables X_{ijkr} to determine routing decisions and continuous variables representing the remaining battery energy. The model is solved using the Branch and Bound method implemented in LINGO 18.0 to obtain a global optimal solution. The results show that the proposed model is capable of generating optimal routes while satisfying all constraints. This approach is effective in handling the combinatorial complexity of the problem and can support the development of more efficient electric public transportation systems.

Keywords: Electric vehicles, EVRP, MILP, Branch and Bound, Route optimization

Abstrak

Angkutan umum berbasis kendaraan listrik semakin banyak digunakan sebagai solusi transportasi yang ramah lingkungan. Namun, implementasinya masih menghadapi kendala utama berupa belum meratanya infrastruktur pendukung, khususnya keterbatasan jumlah dan sebaran charging station. Hal ini mempengaruhi perencanaan rute karena kendaraan harus mempertimbangkan keterbatasan energi selain permintaan penumpang. Artikel ini bertujuan untuk mengoptimalkan rute kendaraan listrik dengan memodelkan permasalahan ke dalam Electric Vehicle Routing Problem (EVRP) menggunakan pendekatan Mixed Integer Linear Programming (MILP). Fungsi tujuan adalah meminimalkan total biaya perjalanan berdasarkan jarak tempuh, dengan kendala kapasitas kendaraan, aliran rute, dan konsumsi energi baterai. Variabel keputusan terdiri dari variabel biner X_{ijkr} untuk penentuan rute dan variabel kontinu untuk sisa daya baterai. Model kemudian diselesaikan menggunakan metode Branch and Bound melalui perangkat lunak LINGO 18.0 untuk memperoleh solusi optimal global. Hasil penelitian menunjukkan bahwa model mampu menghasilkan rute yang optimal dan memenuhi seluruh kendala. Pendekatan ini efektif dalam menangani kompleksitas permasalahan dan dapat mendukung pengembangan sistem transportasi listrik yang lebih efisien.

Kata Kunci: Kendaraan listrik, EVRP, MILP, Branch and Bound, Optimasi rute

Received on January, 2026. Accepted on June, 2026

I. INTRODUCTION

Mixed Integer Linear Programming (MILP) is an approach in mathematical optimization that combines integer and continuous decision variables with a linear objective function and linear constraints. Applications of MILP span supply chain optimization, process network design, production planning and scheduling, and many other combinatorial domains.

The Branch and Bound method is widely employed to solve integer programming problems because it systematically evaluates all feasible solutions and identifies the globally optimal one. In transportation, the algorithm has been used to reduce delivery distances by up to 15% in logistics [6] and to improve urban traffic efficiency by up to 20% in intelligent traffic-light management [3]. The exact branch and bound method is used to solve integer programming problems because there is usually more than one optimal solution; this method allows us to determine the best solution from among the solutions obtained, making it more accurate and superior to other methods [1].

The Vehicle Routing Problem (VRP), first introduced as the truck dispatching problem, seeks the most efficient set of routes for a fleet of vehicles to serve customers at minimum cost [2]. VRP is classified as NP-hard, meaning no polynomial- time exact algorithm is known for large instances [5]. Electric vehicles also have become an effective solution for reducing energy consumption and environmental pollution in manufacturing logistics systems [8].

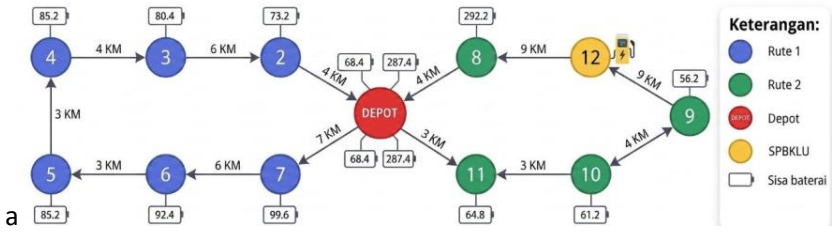
The Electric Vehicle Routing Problem (EVRP) extends the classical VRP by additionally accounting for battery capacity constraints, charging station locations, energy consumption rates, and battery-swapping decisions [4] [7]. The primary study object is the TransMedan electric bus fleet, specifically Corridor 4 (Medan Tuntungan – Lapangan Merdeka) and Corridor 5 (Medan Tembung – Lapangan Merdeka). The central challenge addressed in this paper is determining optimal routes for electric buses executing multiple trips per day while respecting battery capacity limits and leveraging a Battery Swapping Station. A comprehensive MILP mathematical model is developed to represent all operational constraints, and globally optimal solutions are obtained via the exact Branch and Bound method implemented in LINGO 18.0.

II. RESEARCH METHOD

This study is a quantitative study that employs an optimization approach using a mathematical model to solve the routing problem for electric public transportation vehicles. The problem is modeled as an EVRP, taking into account the specific characteristics of electric vehicles, such as battery capacity, energy consumption, and the availability of battery swap stations.

A. Development of a Mathematical Model

In this study, a mathematical EVRP model with multi-trip characteristics was developed. In the model, each vehicle departs from the depot, drops off several passengers at each stop, and then returns to the depot, traveling along different routes and returning to the depot again within a single round trip. Each vehicle can visit a specific stop only once more per round trip. The developed model aims to minimize total transportation costs, which can also be interpreted as the total distance traveled by the vehicles. Figure 1 illustrates the system to be modeled.



a

Figure.1 Illustration of a multi-trip system

The model is based on the following assumptions:

1. The service office has only one depot and a number of electric vehicles.
2. The route is a loop, meaning that for each trip, the electric vehicle starts and ends the route at the depot.
3. The power consumption of an electric vehicle is determined solely by the distance traveled and is not affected by the vehicle's speed or weight. The rate of power consumption per unit of distance is constant.
4. Fully charged batteries of various capacities are available only at the depot. Every vehicle leaves the EV charging station with a fully charged battery.
5. Passenger demand at bus stops is not constant.

B. Model Formulation

Sets and Indices

$\boldsymbol{R}$ = {1,2,3,4,5}: set of trips (ritasi)

$\boldsymbol{K}$ = {1,...,7}: set of vehicles

$\boldsymbol{N}$ = {1,...,11}: set of bus-stop nodes

$\boldsymbol{B}$ = {1}: set of charging station nodes (node 12)

$\boldsymbol{A_1}$ = {1,...,12}: nodes including initial depot; $\boldsymbol{A_{N+1}}$ = {2,...,13}: nodes including terminal depot

Decision Variables

$\boldsymbol{X_{ijkr} \in \{0,1\}}$: equals 1 if vehicle *k* travels from node *i* to node *j* on trip *r*, and 0 otherwise.

TABLE I. Parameters

$\boldsymbol{d_{ij}}$	Distance from node i to node j (km)
$\boldsymbol{\delta_i}$	Passenger demand at node i (persons)
$\boldsymbol{Q_k}$	Vehicle capacity (28 persons)
$\boldsymbol{B_k}$	Battery capacity (303 kWh)
$\boldsymbol{C_k}$	Travel cost per km (IDR 2,290)
$\boldsymbol{h}$	Battery consumption rate (1.2 kWh/km)

Objective Function

The objective is to minimize total operational costs, comprising travel costs:

$$\boldsymbol{min\ Z = \sum_i \sum_j \sum_k \sum_r C_k \cdot d_{ij} \cdot X_{ijkr}} \quad (1)$$

Constraints

Constraint 1: Each bus stop is visited exactly once per trip.

$$\boldsymbol{\sum_{j \in A} \sum_{k \in K} X_{ijkr} = 1, \quad \forall i \in N} \quad (2)$$

Constraint 2: Each vehicle visits each charging station node at most once per trip (entry and exit).

$$\boldsymbol{\sum_{j \in AN+1} X_{ijkr} \leq 1, \quad \forall i \in B, \ \forall r \in R, \ \forall k \in K} \quad (3)$$

$$\boldsymbol{\sum_{i \in A1} X_{ijkr} \leq 1, \quad \forall j \in B, \ \forall r \in R, \ \forall k \in K} \quad (4)$$

Constraint 3: Each vehicle must depart from the initial depot and return to the terminal depot.

$$\sum_j X_{0jkr} \geq 0, \quad \forall k \in K, \ \forall r \in R \tag{5}$$

$$\sum_i X_{i,N+1,k,r} \geq 0, \quad \forall k \in K, \ \forall r \in R \tag{6}$$

Constraint 4: No vehicle may travel from a node to itself (no self-loops).

$$X_{iikr} = 0, \quad \forall i \in A_{1,N+1}, \ \forall k \in K, \ \forall r \in R \tag{7}$$

Constraint 5: Total passengers served by vehicle k on trip r must not exceed vehicle capacity Qk.

$$\sum_i \sum_{j,\, i \neq j} \delta_i \cdot X_{ijkr} \leq Q_k, \quad \forall k \in K, \ \forall r \in R \tag{8}$$

Constraint 6: Subtour elimination using Miller-Tucker-Zemlin (MTZ) formulation. Auxiliary variable Uikr imposes an ordering on nodes to prevent illegal sub-tours.

$$U_{ikr} - U_{jkr} + n \cdot X_{ijkr} \leq n - 1, \tag{9}$$

$$\forall i \in A_{N+1}, \ \forall j \in A_{1,N+1}, \ i \neq j, \ \forall r \in R, \ k \in K$$

Constraint 7: Binary and non-negativity constraints.

$$X_{ijkr} \in \{0, 1\}, \quad \forall i, j \in A_{1,N+1}, \ \forall r \in R, \ \forall k \in K \tag{10}$$

$$U_{ikr} \geq 0, \quad \forall i \in A_{1,N+1}, \ \forall k \in K, \ \forall r \in R \tag{11}$$

C. Software Implementation

The MILP model is implemented in LINGO 18.0, which internally applies the Branch and Bound algorithm. Each trip is solved as a separate sub-model with the initial battery level updated from the remaining capacity of the preceding trip. Binary variable X captures routing decisions and continuous variable Y tracks real-time battery state at each node

III. Results And Discussion

A. Optimal Routes

The MTEVRP model achieved a globally optimal solution for all five operational trips of the TransMedan electric buses. LINGO 18.0 confirmed Global Opt status with Infeasibility = 0 for every sub-model. Two principal route patterns emerged consistently:

Route 1: 1 – 7 – 6 – 5 – 4 – 3 – 2 – 13 (serving Harmonika to Mongonsidi, nodes 7→2)

Route 2: 1 – 8 – 9 – 10 – 11 – 13 (serving Simpang Sejati to Simpang Sutomo, nodes 8→11)

TABLE II. Optimal Routes and Costs per Trip

Trip	Route	Path	Cost (IDR)
1	1	1 – 7 – 6 – 5 – 4 – 3 – 2 – 13	121,370
	2	1 – 8 – 9 – 10 – 11 – 13	
2	1	1 – 7 – 6 – 5 – 4 – 3 – 2 – 13	121,370
	2	1 – 8 – 9 – 10 – 11 – 13	
3	1	1 – 7 – 6 – 5 – 4 – 3 – 2 – 13	121,370
	2	1 – 8 – 9 – 10 – 11 – 13	
4	1	1 – 7 – 6 – 5 – 4 – 3 – 2 – 13	**148,460**
	2	1 – 11 – 10 – 9 – 12 – 8 – 13 *Charging station	
5	1	1 – 7 – 6 – 5 – 4 – 3 – 2 – 13	121,370
	2	1 – 8 – 9 – 10 – 11 – 13	
Total			**633,940**

Note: *charging station visit included in Trip 4, Route 2.

B. Battery Consumption Analysis

Battery capacity decreases progressively and consistently across trips. Starting from a full charge of 303 kWh, trips 1 through 3 each consume 64.8 kWh (equivalent to 54 km of total travel), leaving 238.2, 172.8, and 108.0 kWh respectively at the end of each trip. A detailed summary is given in Table III.

TABLE III. Battery State Summary per Trip

Trip	Initial Battery (kWh)	Final Battery (kWh)	Remark
1	303.0	238.2	Normal – no SPBKLU visit
2	238.2	172.8	Normal – no SPBKLU visit
3	172.8	108.0	Normal – no SPBKLU visit
4	108.0	287.4	Charging station visited (node 12) – battery restored to 303 kWh
5	287.4	222.6	Normal – no Charging station visit

Trip 4 represents the critical scenario: with only 108.0 kWh remaining, the model autonomously decided to include a charging station visit at node 12 within Route 2, following the path 1 – 11 – 10 – 9 – 12 – 8 – 13. After swapping the battery, energy was restored to 303 kWh, enabling the vehicle to complete the trip with 287.4 kWh remaining. This decision raised the Trip-4 cost to IDR 148,460 (vs. IDR 121,370 for other trips), but prevented operational failure demonstrating that the model intelligently balances cost minimization with operational feasibility.

Trip 5 returns to the standard pattern with the restored battery, confirming the model's ability to plan long-horizon multi- trip operations by seamlessly integrating normal trips with battery-swapping trips.

C. Model Strengths and Limitations

Strengths: (1) Globally optimal solutions are guaranteed not merely locally good because Branch and Bound explores all viable sub-problems through thousands of iterations. (2) The model handles mixed-type decisions simultaneously: binary variables for routing and continuous variables for battery state. (3) All parameters (battery capacity, charging station location, operational costs) reflect real-world conditions, making results directly applicable. (4) The LINGO implementation is flexible and readily extendable with additional constraints such as time windows or heterogeneous fleets.

Limitations: (1) Computation time grows with problem size; very large instances may require heuristic or metaheuristic algorithms. (2) Battery consumption is assumed proportional to distance only (constant rate 1.2 kWh/km), ignoring speed variations, road gradient, and passenger load. (3) Precise model formulation requires careful definition of all variables, parameters, and constraints errors in formulation directly affect solution quality.

IV. CONCLUSION

This study successfully applied an MILP model with the Branch and Bound method to the Multiple Trips Electric Vehicle Routing Problem (MTEVRP) for the TransMedan electric bus fleet. The key findings are:

1. The MILP–Branch and Bound model solved via LINGO 18.0 achieved global optimality for all five trips, yielding a minimum total operational cost of IDR 633,940.00.
2. Trips 1, 2, 3, and 5 each cost IDR 121,370 following two consistent route patterns, while Trip 4 incurred IDR 148,460 due to a necessary charging station battery swap that prevented operational failure.
3. The model autonomously and optimally decided when and where to swap the battery, demonstrating its capability to manage energy constraints intelligently across multiple trips.
4. Future research should incorporate time windows, dynamic traffic conditions, heterogeneous fleets, and multi depot scenarios, and may explore hybrid metaheuristic exact algorithms for larger scale instances.

ACKNOWLEDGMENT

The author gratefully acknowledges the support of the Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, as well as the Medan Transportation Agency for providing the operational data used in this study.

REFERENCES

[1]Angeline. (2014). Application of Branch and Bound method for integer programming. Journal of Science and Mathematics, 22(1), 45–52.

[2] Dantzig, G. B., & Ramser, J. H. (1959). The truck dispatching problem. Management Science, 6(1), 80–91.

[3] Indrayani. (2016). Application of Branch and Bound algorithm in intelligent traffic-light systems. Journal of Technology and Computer Systems, 4(3), 87–94.

[4] Keskin, M., & Catay, B. (2016). Partial recharge strategies for the EVRP with time windows. Transportation Research Part C, 65, 111–127.

[5] Laporte, G. (2009). Fifty years of vehicle routing. Transportation Science, 43(4), 408–416.

[6] Prayogo, K. W., & Santi, I. H. (2024). Distribution route optimization at J&T Express using Branch and Bound algorithm. Journal of Operations Research and Transportation, 9(2), 101–112.

[7] Schiffer, M., & Walther, G. (2017). The electric location routing problem with time windows and partial recharging. European Journal of Operational Research, 260(3), 995–1013.

[8] Zhou. (2018). Electric vehicle routing and battery swap station location optimisation for automotive assembly lines. International Journal of Computer Integrated Manufacturing, 31(10), 978–991.