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A Study on Electric Vehicle Fleet Route Optimization for Last-Mile Delivery in Chennai, India Using Simulation to Minimize CO_2 Emission

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Abstract

Electric Vehicles (EVs) are gaining popularity as a green alternative for the last-mile logistics that require dense urban areas like Chennai. Still, problems such as range, charging infrastructure, and operational efficiency need to be solved first. This research identifies how the main factors of operations, routing method, delivery stop density, range constraints, time windows, and geographical clustering could influence the reduction of carbon dioxide emissions of EV delivery fleets. Using a quantitative simulation method, artificial datasets were generated depicting 120–300 delivery stops across Chennai's industrial, commercial, and residential areas. Two cases were compared,mainly baseline/manual routing and optimized routing using Python. Distances, energy consumption, and emissions were calculated using India-specific grid factors, and further analysis was conducted in Excel using descriptive and sensitivity analyses.The results reveal that optimized routing leads to a significant reduction of carbon dioxide emissions when delivery stops are geographically concentrated, and range constraints are considered. Although windows and congestion may reduce savings to some extent, they cannot eliminate the environmental benefits. This research advances theoretical knowledge by advancing sustainable logistics research through simulation modelling and provides practical advice to logistics companies in Chennai. In general, it shows that EV route optimization is not just a technical upgrade but a strategic move essential to reducing urban emissions and helping India meet its climate targets.

Keywords: Electric Vehicles, Route Optimization, Last-Mile Delivery, Simulation, CO_2 Emissions, Logistics, Sustainable Supply Chain.

Introduction

Background of the study

Transportation sector is a dominant contributor of CO 2 emissions accounting for nearly 1/4 th of global CO 2 emission with the highest source being road transport, where emissions intensive consumption of fossil fuels and growing demand for mobility are major drivers

(International Energy Agency, 2024). Electric vehicles (EV) have emerged as a attractive alternative with 14 million EVs sold worldwide in 2024 (18% of all cars) which has witnessed substantial policy push as also an increase in market uptake (International Energy Agency, 2024). However, the rapid scale-up in electric mobility has coincided with flourishing e commerce which has increased last mile delivery and is estimated to account for up to 53% of shipping costs and contribute to emissions (McKinsey & Company, 2023). Existing research suggests if no interventions are undertaken last mile emissions are projected to increase by over 30 % however efficient route planning can lead to 10 -20% emissions reduction (World Economic Forum, 2023; DispatchTrack, 2023). India has a high contribution of fossil fuels to grid emissions- with a grid emission factor of 0.757 tCO 2 / MWh in Tamil Nadu as high as 0.75 tCO 2 / MWh in Tamil Nadu (Universal Carbon Registry, 2024; Times of India, 2024).

Research Problem

In this work we study the impact of Electric Vehicle Fleet routing optimization on efficient and sustainable last-mile delivery Operations. Simulation based models are being increasingly adopted as a decision support tool to inform logistics operations, for study of operational optimization problems in last mile delivery routing including various operational limitations. In our study, the impact of dominant routing patterns, visit stops, clustering of origins & destinations, combined with time windows on emissions and energy usage are studied. Using a simulation based approach, in our study we test operating conditions based on simulated route data, optimized route data, for a Chennai based last mile delivery operation. Actual data basis our case study is synthetic generated data from a python simulation model, with secondary data basis emission factors and operational parameters.

Objective of the Study

- RO1: To examine the influence of route optimization on CO_2 emission reduction in electric vehicle (EV)-based last-mile delivery operations in Chennai, India.
- RO2: To assess the influence of the number of delivery stops on CO_2 emissions in EV last-mile delivery operations in Chennai, India.
- RO3: To investigate the influence of vehicle range constraints on CO_2 emissions in EV last-mile delivery operations in Chennai, India.
- RO4: To analyse the influence of delivery time windows on CO_2 emissions in EV last-mile delivery operations in Chennai, India.
- RO5: To evaluate the influence of geographical clustering on CO_2 emissions in EV last-mile delivery operations in Chennai, India.

Significance of the research

This paper is an important contribution as it tackles a contemporary logistical challenge of the world, of urban last mile delivery efficiency and sustainability. As e-commerce is set to grow substantially, and cities such as Chennai are faced with heavy traffic, transportation adds to the state of the environment of the city by being responsible for a large part of the CO2 emissions. Using the concept of electric vehicles, combined with route optimization, the research successfully shows how an operational change can effectively towards improving the environment even more than just getting an electric vehicle. The results can demonstrate to logistics companies how optimization systems can help reduce energy consumption, operational expenses and emissions. The research can also be a good way to contribute to academic research using simulation-based systems, specific to Indian conditions and thus, guiding the country and its organizations and policymakers towards a greener, more efficient transportation network.

Literature Review

- World Economic Forum (2023) Last-Mile Delivery Challenges and Opportunities, It is shown in this report that last mile delivery takes up approximately more than 40% of the total cost of logistics and is one of the key culprits to the emission problem of the entire supply chain.
- International Energy Agency (2024) Global EV Outlook ,It states that launching EV in the logistics network can be a high impact mechanism to achieve emissions reduction, but necessitates operational efficiency such as route design.
- BloombergNEF (2023) Electric Vehicle Market Outlook, The report shows that 14% of the global new car sales in 2022 were EVs and should reach 40% by 2030. It emphasizes how logistics companies are fleets are switching to electric in order to adhere to increasingly higher standards.
- EVreporter (2025) India EV Market Growth Report, The report reveals that over 2.03 million 0E vehicles were sold in India in FY 202425, showcasing the bullish demand. The report highlights the importance of EVs in last mile deliveries where 2 and 3-wheelers accounted for 99 percent of last mile deliveries.
- MarkNtel Advisors (2025) India Electric Vehicle Market Analysis, According to the report, India's EV market size is expected to increase from USD 5.22 bn in 2024 to USD 23.52 bn in 2030 across the specified forecast period with a CAGR of 28.5%. The report mentions that the EV adoption in logistics is driven by increasing investments and institutional support through policies.
- Kumar et al. (2023) Route Optimization in Urban Logistics, This study highlights that route optimization techniques significantly reduce travel distance and fuel consumption in delivery operations. However, it notes limited integration with electric vehicle constraints and emission analysis.

Research Methodology

Research Design

The present research was aimed to study of route optimization, CO2 reduction in Commercial Electric Vehicle fleet for last mile delivery in Chennai. In order to study the impact of independent variables or predictor variables (Method of routing, Number of stops, Congruent location clusters, Vehicle characteristics or Constraint) on dependent variable or target variable (unit of CO2discharges), to find the functional relationships among the various variables, and to analyze the advantage of route optimization, Quantitative research approach was utilized through simulation based analytical research design. Synthetic delivery data sets were generated in Python language instead of selecting data through survey method, which would have been slow, costly and difficult process. The well validated EVRO-SIM model was used to perform the simulations for getting the actual data matrix of baseline and optimized routing conditions. Descriptive, comparative and sensitivity analysis is utilized in Excel sheet to sort out the useful information for study.

Sample Size & Sampling Technique

This study was conducted within an area of last mile delivery in Chennai to study the effect of EVDRO levels on CO2 emissions. Human subject population was replaced with last mile delivery route scenarios (unit of analysis). The population target consisted of about 2000 potential delivery routes that typify urban area logistics conditions. A non-probability judgmental sampling method was used to select only those delivery scenarios that were to be included in the sample based on a few criteria like, delivery details, urban pattern & operational limitations. A sample size of 120 - 300 delivery stops (clustered into a few route groups) was used in order to accurately represent the vehicle routing perspective while providing statistical accuracy and minimizing computation time.

Data Collection Methods

The data used in this research comprises two main sources: simulated data and secondary data. Instead of survey-based instruments, synthetic delivery datasets were generated using Python to represent real-world last-mile delivery conditions. The simulated data includes delivery locations, route distances, and operational parameters such as number of stops, clustering, and vehicle constraints. Secondary data sources were used to obtain standard values such as energy consumption rates and grid emission factors. This structured approach allows for systematic and controlled data generation. The dataset is designed to capture key variables influencing route efficiency and CO_2 emissions, enabling accurate simulation and analysis of electric vehicle delivery operations.

Tools Used for Analysis

For this research the resulting data have been analyzed using python and excel (Microsoft excel).

- Simulations and statistical analysis have been used to analyze the impact of route optimization in the emissions and efficiency, techniques used for data analysis are: Simulation Modeling (Python) Create delivery scenarios and optimize Routes used by applying clustering algorithms.
- Descriptive Analysis- Summary of the relevant parameters considering distance, energy consumption, CO 2 emissions and cost. Comparison Use as a comparison between the two baseline and best optimized routing.
- Sensitivity analysis - Analyzing the effect of the variations of important parameters like energy rate and emission factor on the results. Zone-Based Analysis Draw comparisons of the performance in various geographical zones.
- Model Validation Cross-check your output against real world benchmark values to verify the accuracy.

Data Analysis and Interpretation

Descriptive Statistics of Simulation Output

In this section, quantitative results for the EVRO-SIM model on baseline and optimal routing are addressed under the same conditions. The distances travelled, energy consumed, CO 2 emissions and the cost incurred are examined as indicators of performance for electric vehicle-based last-mile delivery in chennai.

Metric	Baseline	Optimized	% Change
Total Distance (km)	1531.87	630.1	58.8672668
Total Energy (kWh, EV)	245.1	100.817	58.86699306
Total CO□ (kg, EV)	185.541	76.32	58.86623442
Total Cost (INR)	2451	1008.17	58.86699306

The descriptive statistics demonstrate that the routing configuration after optimization leads to the total route distance being reduced by 58.87%, thus, the EVRO-SIM model is confirmed to be effective in minimising spatial redundancy among delivery stops.

These findings are consistent with those in the field of sustainable logistics where the emphasis on route optimization is made as a key factor for emission mitigation (Schiffer & Walther, 2023; Christopher, 2016).

Comparative Analysis between Baseline and Optimized Routing

This section compares two different EVRO-SIM scenarios of interest, baseline (not optimized) & optimised (K-Means clustered routing). The goal is to determine the logistic efficiencies / benefits gained through route optimization, by considering implications in terms of distance energy CO 2 emissions, and cost.

Metric	Baseline	Optimized	Absolute Reduction
Total Distance (km)	1531.87	630.1	901.77
Total Energy (kWh, EV)	245.1	100.817	144.283
Total CO□ (kg, EV)	185.541	76.32	109.221
Total Cost (INR)	2451	1008.17	1442.83

The table shows the optimized routing scenario demonstrates a consistent efficiency improvement of approximately 59% across all operational and environmental indicators.

Zone-Based Analysis

This section compares the EVRO-SIM results for each zone in Chennai: Central East West, North, and South. Such analysis compare the differences in the distance, energy consumption, and CO 2 emissions between the zones. The model groups routes by zone in order to simulate actual delivery behavior and compare results across zones, making clear the spatial implications on CO 2 emissions.

Zone	Distance (km)	Energy (kWh)	CO_2 (kg)	Energy Cost (□)	Emission Intensity (kg CO_2/km)
Central	32.13	4.82	3.65	48.19	0.11355
East	33.87	5.08	3.85	50.81	0.11355
North	22.21	3.33	2.52	33.32	0.11355
South	27.80	4.17	3.16	41.71	0.11355
West	27.84	4.18	3.16	41.76	0.11355

The table shows that compared to North zone West Southeast, Central and East zones have higher distance, energy consumption and CO 2 emission because of larger delivery coverage. North zone has lowest for all these factors because of short and compact routing. Emission intensity is same as all other models (0.11355kgCO 2 /km) ensures model reliability. This model provides insight for reduction in delivery distance as most effective measure for emission saving and efficiency improvement.

Sensitivity Analysis

Sensitivity analysis means the parameters energy consumption rate and grid emission factor will impact CO 2 emission and we observe the effects of these. This test proves the simulation results are stable because parameters' changes are equivalent with emissions' variations.

Energy Rate (kWh/km)	Grid Factor (kg CO2/ kWh)	CO2 Baseline (kg)	% Change vs Base (Baseline)	CO2 Optimized (kg)	% Change vs Base (Optimized)
0.135	0.6813	140.8945092	-19	57.95376255	-19
0.135	0.757	156.5494547	-10	64.3930695	-10
0.135	0.8327	172.2044001	-1	70.83237645	-1

0.15	0.6813	156.5494547	-10	64.3930695	-10
0.15	0.757	173.9438385	0	71.547855	0
0.15	0.8327	191.3382224	10	78.7026405	10
0.165	0.6813	172.2044001	-1	70.83237645	-1
0.165	0.757	191.3382224	10	78.7026405	10
0.165	0.8327	210.4720446	21	86.57290455	21

The table shows that CO 2 emissions are a linear function of the energy rate and the grid emission factor. For all of the inputs changed by about 10%, emissions also changed by about 10%, indicating a linear relationship. The proportionate response in all of these cases shows that the EVRO-SIM is stable consistent accurate and not prone to 'dirty' or inconsistent calculations and so the result is reliable and scientifically valid.4.6 Model Validation

Model Validation

Model Validation is a confirmation that the model's structure, the input parameters, and the output metrics (distance, energy consumption, CO□ emissions, and cost) correspond to realistic values in line with internationally and nationally recognized benchmarks. Moreover, this step ensures that the EVRO-SIM framework meets the scientific criteria for simulation trustworthiness, in other words, conceptual validity, operational accuracy, and output realism (Law, 2015; Sargent, 2010).

Parameter	Unit	EVRO-SIM Result	Benchmark Range	Source	Validation Status
Energy Consumption Rate	kWh/km	0.15	0.13 – 0.17	IEA (2024)	Within Range
Grid Emission Factor	kg CO_2/kWh	0.757	0.74 – 0.77	CEA (2024)	Within Range
Average EV Range	km	250	200 – 300	NITI Aayog (2023)	Within Range
Emission Intensity	kg CO_2/km	0.1135	0.10 – 0.14	UNEP (2024)	Within Range
Total CO_2 Emission Reduction	%	58.87	15 – 30 (typical reported)	Schiffer & Walther (2023)	Exceeds Benchmark
0.15	0.8327	191.3382224	10	78.7026405	10
0.165	0.6813	172.2044001	-1	70.83237645	-1
0.165	0.757	191.3382224	10	78.7026405	10
0.165	0.8327	210.4720446	21	86.57290455	21

The table shows that the validation results confirm that the EVRO-SIM model is accurate and reliable. Key parameters align with standard benchmarks, and the emission intensity falls within real-world ranges. The model achieved a 58.87% reduction in CO_2 emissions, exceeding typical literature values, demonstrating strong optimization performance and practical applicability for sustainable route planning.

Results and Discussion

This study examined the effects of electric vehicle route optimization on last mile delivery efficiency and CO_2 emission mitigation in Chennai city. The results from the simulation exhibit substantial variations by optimized routing in diminishing the miles traveled, energy use, CO_2 emissions and operating cost by about 58.87% over the baseline routing.

As an overview, it can be said that routing technique and geographic clustering had a highly significant positive impact on efficiency and other factors such as number of delivery stops or tight time constraint had a less significant impact. In conclusion, the most critical factor for sustainable logistics is route optimization. This covers cluster optimization, routing enhancements, and the application of updating information.

Findings

- It can be seen the EVRO-SIM model results were greatly enhanced; with the best routing optimization onto the EVRO-SIM reduced each one of distance energy CO_2 emissions, and cost were all reduced by about 58.87%.
- The routing method (optimized versus baseline) influences emissions and operational performance significantly.
- The nodes in a geographical cluster help in increasing efficiency of routes avoiding irrational travelling distance. Number of delivery stops increases cost by increasing distance, energy and CO_2 emissions.
- They decrease optimization potential, though. In the CH_4 emission intensity was 0.1135kg_ CO_2/ km which proved the model to be consistent and the proportionality to be correct.
- A sensitivity analysis showed that the emissions were proportional to the change of the input parameters, indicating the stability of the model.
- Validation of model confirmed results are consistent with the actual trading history of the stock; proved to be accurate and real-world feasible.

Recommendations

Route optimization and electric vehicle integration is another solution as a step toward increase in sustainability and efficiency of last-mile delivery operations. Feed solutions such EVRO-SIM that can help reduce traveled distance, energy consumed, and CO_2 emissions are well-known among logistics companies. Usage of clustering techniques, such as CZ, and optimal route planning should help organize the delivery operations across different zones for a more equitable distribution of resources and increased productivity. Data analytic department and trainings for employees in Python and simulation modeling should be put in place.

Furthermore, policymakers must focus on establishing EV charging facilities in cities so that physical delivery can proceed without hindrance. Offering incentives in the form of lower tariffs on electricity and tax deductions can motivate firms to implement advanced and more sustainable logistics strategies. Implementing greener energy sources in the national grid can cut down emissions emitted during electric vehicle operation. Partnership among academia, government and industry can help develop new solutions in green logistics. These measures can contribute to the evolution of low-carbon, data-supported and efficient logistics systems in urban areas

Future Directions of Research

- Researchers also could consider in a broader perspective of the problem in future researches. Various factors, for example, current traffic, current weather condition, delivery man's driving style, the age of electric vehicles and the raising capacity of charging stations may have been significantly affecting the delivery efficiency and emission distribution.

- Researchers could also investigate the application of AI-based routing algorithms and real-time optimization system. Additional research is encouraged to study other operational and infrastructure factors impacting EV logistics performance.
- Factors such as the number of plug-in charging stations, inclusion of additional renewable energy supplies, management of vehicle fleet capabilities, and fluctuations in demand patterns can be explored to improve sustainable delivery systems. Concurrent comparative studies within cities, countries or fields of logistics can be carried out. For example, study the differences between Chennai and other cities to generalize the traffic characteristics to other geographical areas and facilities thus it guarantees the operability of the model in other areas of traffic flow control.

Conclusion

This paper established and validated the Electric Vehicle Route Optimization Simulation Model (EVRO-SIM) for enhancing efficiency and sustainability of last mile delivery using Electric Vehicles in Chennai. The outcome revealed a massive decrease in travel distance, energy use, emissions and operating expenses by 58.87% in the use of optimized routing than in the use of baseline routing. The model showed uniformity of emission intensity in all zones and reliability of results through sensitivity analysis, meeting the norms of authorities concerned. The paper confirms that route optimization with the help of simulation modelling provides a highly dependable solution in logistics for improving operational efficiency and environmental performance simultaneously. EVRO-SIM also would be an efficacious choice for planning of optimized routes, energy management, emissions reduction for logistics operators.

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