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Electric Vehicle Routing Model for Last-mile Logistics in Cities with Steep Streets

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Abstract. The Quito local government aims to establish a low-emission zone in the city's historic center. A key focus is the shift to eco-friendly transportation for last-mile logistics, including electric cargo bikes and other types of light electric vehicles (LEVs). Our research delves into integer programming models to optimize the vehicle routes. We address a variation of the electric vehicle routing problem (EVRP), factoring in vehicle load and street slope for battery consumption and travel times. Moreover, we consider the existence of multiple paths between each pair of customers, which vary in distance and slope, yielding different travel times and battery consumption values. For instance, some paths may have small travel times but require high battery consumption, while other paths may have longer travel times and require less battery consumption. The problem is formulated on a customer multigraph that has one node for each customer and depot, and where parallel arcs are used to represent efficient paths in the original network. Road selection is carried out as part of the vehicle routing. This talk highlights findings on modeling strategies and reports some computational results to examine the impact of some model parameters upon the optimal solutions.

Keywords: Integer linear programming · Electric Vehicle Routing Problem · Steep Slope · Multiple Paths

The literature shows that the study of the problem addressed in this work can contribute new results to the research line of Vehicle Routing Optimization (VRP) with Light Electric Vehicles (LEV) intended for last-mile logistics distribution. To the best of our knowledge, there are few works that consider road network information such as road gradients in route optimization. Additionally, for the case of routing problems for electrically assisted cargo bicycles, there are no known works involving multiple paths and road gradient information for geographical areas with steep slopes.

This research line is motivated by the need to comply with environmental regulations aimed at limiting the generation of greenhouse gases by logistics operators. The evolution and motivation of the VRP problem with electric vehicles are described in the book "Vehicle Routing: Problems, Methods, and Applications" [1] and categorized as Ecological Vehicle Routing. Initially, the aim was to reduce emissions from internal combustion vehicles. However, over time and with the decreasing cost of implementing electric vehicle fleets, this research line evolved towards optimizing routes for electric vehicles.

Various variants of the classic VRP have been studied in the context of electric vehicles. For example, the VRP with time windows was studied by Michel Gendreau [6]. In another relevant work, carried by Schneider, Michael, et al [8], the authors consider the Electric Vehicle Routing Problem with Time Windows (E-VRPTW) and include charging stations for intermediate charges to complete visits to assigned customers on their route, with the objective of minimizing the total distance traveled.

On the other hand, Gonzalo Lera-Romero et al [7] study this variation of the E-VRPTW by adding time-dependent speeds to model congestion. They focus on considering operational aspects such as travel time dependency and battery consumption with traffic management. Additionally, they take into account the nonlinearity of the battery charge function and waiting time for recharging. They present a Branch-cut-and-price resolution algorithm aimed at minimizing the solution cost.

In the Latin American region, taking road network information becomes more relevant due to the continent's topography, with cities having steep slopes in their road networks. This is the case of Quito, which has many steep streets, mainly in its historic center. Regarding the topography of the historic center, it is an important aspect to consider, as it presents streets with very steep slopes. This aspect specific to the area must be considered to build viable routes, as it directly impacts vehicle autonomy. This is because battery consumption depends on road gradients, as well as the load being transported and the speed at which the operation is carried out.

Moreover, Carlos Brunner et al [3], focus on reducing emissions from internal combustion vehicles performing last-mile distribution operations in the city of Valparaíso, Chile, considering the altitude difference between the points the vehicle must visit. This work proposes a mathematical model of Integer Linear Programming (ILP) with a network that discretizes charge levels, from which the cost of arcs, dependencies, and the load transported by the vehicle are determined. Including gradient information in the model is motivated by the relationship between gradients and fuel consumption. This relationship indicates that more fuel is consumed on routes where the vehicle must climb steep slopes. The objective of the work is to reduce operational costs, focusing on both fuel consumption and labor costs as the most relevant aspects of the operation.

On the other hand, Pirmin Fontaine in [5] focuses on the weight dependency on the speed of electrically assisted cargo bicycles. The author proposes a Mixed Integer Linear Programming (MILP) mathematical model for this problem, which is based on discretizing the vehicle's load levels to model the dependence between speed and load. The proposed model assumes the existence of an unlimited number of vehicles and does not consider the maximum battery capacity within the constraints. The model aims to minimize the total travel time.

This work aims to study the problem considering road network information, similar to the proposal in Ben Ticha et al [2], and the impact of street gradients on battery consumption. The objective is to formulate mathematical models that minimize travel time while avoiding overestimating LEV autonomy in geographical areas where roads have steep gradients. Furthermore, it considers the multiplicity of attributes associated with trips (e.g., shorter, faster, and lower battery consumption routes) among clients, generating more than one possible path between each of them, an aspect that is modeled using a multigraph that provides diversity for the composition of the routes comprising a solution.

As this is a discrete optimization problem, the following methodological framework is followed:

- Formulation of the proposed ILP model in the study.
- A benchmark model is established based on an existing model in the literature [3] closely related to the problem addressed by the proposed model. The MILP model is then brought to an equivalent formulation as the proposed ILP model.
- Experimental tests are conducted between the proposed model and the benchmark, using restricted instances for comparison. Both models consider a single path between nodes, slope, and load for battery consumption calculation, limit the fleet of vehicles, and differ from each other in their modeling approach; the proposed model is formulated with an extended network, while the benchmark model is formulated compactly.
- From the computational experiments, the performance of the proposed model is determined under the aforementioned assumptions.
- The proposed model is then enriched by considering the existence of more than one path between network nodes, thus implementing the multigraph in the model, and its performance is evaluated again through computational tests.

This study addresses the VRP issue for LEV in last-mile deliveries in CHQ and contributes to reducing the resistance that logistics operators may have regarding the adoption of this new technology in their operations. This is a recurrent issue and is also mentioned by Diego Carracedo in Hamid Mostofi in [4]. Additionally, the model contributes to this line of research by implementing models that can utilize road network information to establish the best paths between network nodes, considering multiple criteria. The model incorporates a battery consumption model that factors in the impact of street gradients and the load carried by the LEV, as proposed in the literature. In practical terms, it contributes to the study and utilization of this mode of transportation for the last mile in CHQ. Developing a model for VRP with LEV for last-mile merchandise distribution in cities with irregular topography, considering road network information and multiple paths between network nodes.

Methodologically, a model of ILP for VRP with LEV for the last mile will be formulated and implemented, which will consider road network information including street gradients. Subsequently, computational tests will be conducted with respect to a benchmark model to evaluate the performance of the proposed model. This model will be adapted to consider more than one path between each pair of network nodes, using a multigraph. Finally, after adding this diversity of paths to the model, its performance is evaluated. The study has the following objectives:

– Obtain evidence of the impact of considering or not considering slope in the mathematical modeling.
– Formulate and implement the proposed model considering only one path between each pair of network nodes.
– Evaluate the performance of the proposed model compared to a benchmark model.
– Formulate and implement the proposed model considering more than one path between each pair of network nodes, in order to capture different optimization criteria (shortest distance path, fastest path, path with lowest battery consumption, etc.), by including a multigraph.
– Evaluate the impact of using the multigraph in the proposed model.

References

1. Vehicle Routing: Problems, Methods, and Applications, Second Edition. Society for Industrial and Applied Mathematics (Nov 2014). https://doi.org/10.1137/1.9781611973594
2. Ben Ticha, H., Absi, N., Feillet, D., Quilliot, A.: Vehicle routing problems with road-network information: State of the art. Networks **72**(3), 393–406 (Feb 2018). https://doi.org/10.1002/net.21808
3. Brunner, C., Giesen, R., Klapp, M.A., Flórez-Calderón, L.: Vehicle routing problem with steep roads. Transportation Research Part A: Policy and Practice **151**, 1–17 (Sep 2021). https://doi.org/10.1016/j.tra.2021.06.002
4. Carracedo, D., Mostofi, H.: Electric cargo bikes in urban areas: A new mobility option for private transportation. Transportation Research Interdisciplinary Perspectives **16**, 100705 (Dec 2022). https://doi.org/10.1016/j.trip.2022.100705
5. Fontaine, P.: The vehicle routing problem with load-dependent travel times for cargo bicycles. European Journal of Operational Research **300**(3), 1005–1016 (Aug 2022). https://doi.org/10.1016/j.ejor.2021.09.009
6. Gendreau, M., Ghiani, G., Guerriero, E.: Time-dependent routing problems: A review. Computers amp; Operations Research **64**, 189–197 (Dec 2015). https://doi.org/10.1016/j.cor.2015.06.001
7. Lera-Romero, G., Miranda Bront, J.J., Soulignac, F.J.: A branch-cut-and-price algorithm for the time-dependent electric vehicle routing problem with time windows. European Journal of Operational Research **312**(3), 978–995 (Feb 2024). https://doi.org/10.1016/j.ejor.2023.06.037
8. Schneider, Michael Stenger, A..G.D.: The electric vehicle-routing problem with time windows and recharging stations. Transportation Science (48), 500–520 (2014), http://www.jstor.org/stable/43666939