A green logistics solution for last-mile deliveries considering e-cargo bikes and e-vans

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Abstract

The environmental challenges and the initiatives for sustainable developments in urban areas are mainly focused on eco-friendly transportation systems. Therefore, we introduce a new green logistics solution for last-mile deliveries considering synchronization between e-vans and e-cargo bikes, developed as Two-Echelon Electric Vehicle Routing Problem with Time Windows and Partial Recharging (2E-EVRPTW-PR). The first echelon consists of e-vans in an urban zone while the second echelon consists of e-cargo bikes in a restricted traffic zone (i.e. historical centre). The proposed 2E-EVRPTW-PR model aims to minimize the total costs in terms of travel costs, initial vehicles’ investment costs, drivers’ salary costs and micro-depot cost. The effectiveness of the proposed solution has been demonstrated comparing two different scenarios, i.e. the EVRPTW-PR considering e-vans for the first scenario, and the 2E-EVRPTW-PR considering e-vans and e-cargo bikes for the second scenario. The comparison has been carried out on existing EVRPTW-PR instances for the first scenario, and on novel 2E-EVRPTW-PR instances for the second scenario, in which the customers of initial EVRPTW-PR instances have been divided into two zones (urban and restricted traffic zones) by using Fuzzy C-mean clustering. Moreover, results encourage logistic companies to adopt zero-emission strategies for last-mile deliveries, especially in restricted traffic zone.

Keywords: two-echelon electric vehicle routing problem; green logistics; electric cargo bikes; last-mile delivery;

1. Introduction and briefly literature review

City logistics is facing everyday environmental challenges in promoting and developing a cleaner transportation environment focusing on emission, traffic noise and congestion reduction. This raised the concept of “green logistics” in urban areas that enhanced the movement of electric mobility considering various technologies, such as electric vehicles (EVs), e-cargo bikes, hybrid vehicles, etc. The substitution of internal combustion vehicles (ICVs) with zero-emission technologies achieves several benefits for companies such as lower maintenance and operational costs, accessibility in restricted traffic zones, such as historical centres, pedestrian zones, etc. (Taefi et al., 2015). Recently, a novel formulation of the Electric Vehicle Routing Problem introduced the advantages of EVs regarding full recharge solution (Schneider et al., 2014) and partial recharge solution (Keskin & Çatay, 2016). To the best of our knowledge, only a few papers in the literature applied the Two-Echelon Electric Vehicle Routing Problem (2E-EVRP). Breunig et al., (2019) proposed a 2E-EVRP with Time Windows (2E-EVRPTW), where ICVs deliver goods to satellites in the first echelon, while customers are visited with EVs in the second echelon. Jie et al., (2019) proposed a combination of a column generation and an adaptive large neighbourhood search for 2E-EVRPTW considering battery swapping stations (2E-EVRPTW-BSS). Wang et al., (2019) proposed 2E-EVRPTW-BSS with ICVs for the first echelon and EVs for the second echelon. On the other hand, different studies investigated the advantages and performance of e-cargo bikes (Gruber et al., 2014; Nocerino et al., 2016). Moreover, Anderluh et al., (2017; 2019) implemented the Two-Echelon Vehicle Routing Problem (2E-VRP) that involved the synchronization between vans and cargo bikes.
In this paper, we propose a novel formulation for Two-Echelon Capacitated Electric Vehicle Routing Problem with Time Windows and Partial Recharging (2E-EVRPTW-PR) based on Keskin & Çatay, (2016), for the last-mile deliveries that highlight the usage of zero-emission technologies (e-cargo bikes and e-vans). The model aims at minimizing the total costs of two echelons considering travel costs, initial vehicles’ investment costs and drivers’ salary costs. The proposed model highlights the advantages of e-cargo bikes application in restricted traffic zones in terms of energy and investment cost savings, which are scarcely considered in the literature.

2. Model description and preliminary results

In the proposed 2E-EVRPTW-PR model, the first echelon is composed of the depot, set of customers and the set of charging stations, located in the urban area. The second echelon includes the set of customers and the set of charging stations located in the restricted urban area. The connection between first and second echelon is the transhipment point (micro-depot) in which e-vans are delivering goods to the e-cargo bikes according to the request of customers located in restricted traffic zones. Therefore, the transhipment point is the depot for the second echelon, in which e-cargo bikes are parked. The proposed model aims to minimize the total costs of two echelons considering travel costs, initial vehicles’ investment costs, drivers’ salary costs and micro-depot cost, and to optimize the number of used vehicles (e-cargo bikes and e-vans). The constraints are due to the partial charging of e-vans and e-cargo bikes’ batteries, load capacity, remaining cargo level and time windows. The time windows constraints ensure deliveries according to customers’ preferences and prevent the formation of subtours. We compared two different scenarios, i.e. the EVRPTW-PR scenario considering the e-van fleet and the 2E-EVRPTW-PR scenario considering the mixed fleet (e-vans and e-cargo bikes) to evaluate the goodness of the proposed solution. We validated the EVRPTW-PR scenario considering existing instances proposed by Goeke (2019). Then, for comparing the 2E-EVRPTW-PR scenario, we adjusted corresponding instances applying Fuzzy C-mean (FCM) clustering to obtain two clusters of customers related to urban and restricted traffic zones, respectively. We developed FCM in Matlab 2019b, while the proposed mathematical formulation is implemented in CPLEX 12.10 that uses the exact method as a solution approach. The results of numerical applications highlight the advancement of e-cargo bikes in restricted traffic zones considering the minimization of total costs as well as computation time. Moreover, the proposed model could benefit logistics companies as a decision support system to decide the best solution for the last mile deliveries, especially in restricted traffic zone.

References


