Last-mile Robot Deliveries with Access Restrictions

Shaohua Yu[1], Ann Melissa Campbell[2], Jan Fabian Ehmke[3], Jakob Puchinger[4]

[1] School of Intelligent Manufacturing, Nanjing University of Science and Technology, Nanjing, China
shaohua.yu@njust.edu.cn

[2] Business Analytics Department, Tippie College of Business, University of Iowa, Iowa City, USA
ann-campbell@uiowa.edu

[3] Business Analytics Group, Universität Wien, Vienna, Austria
jan.ehmke@univie.ac.at

[4] EM Normandie Business School, Métis Lab, Clichy, France
Université Paris-Saclay, CentraleSupélec, Laboratoire Génie Industriel, Gif-sur-Yvette, France
jpuchinger@em-normandie.fr

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1 Introduction

In recent years, the improvement of quality of life in cities through the reduction of local pollutant emissions and traffic has been an increasingly important topic for city planners and researchers. This leads to classical practices such as using vans for deliveries to be restricted and other modes preferred in some areas such as campuses, pedestrian zones or inner-city districts. Recent technological developments and experiments point to the potential of automated last-mile deliveries using small battery-powered robots. We therefore investigate a two-echelon hybrid van-based robot delivery system for last-mile logistics operations.

In existing research, using robots for second-echelon delivery has been considered. For example, a two-echelon delivery model (2EVRP) is proposed in [1]. At the first echelon, vans transport packages from a large depot to small local robot hubs. At the second echelon, robots deliver items to customers. A van-based robot delivery model (VRD) concept with time windows is studied in [2]. Here, robots are transported in the vans to perform second-level route deliveries. According to a sensitivity analysis performed in [3], each of these delivery models have their advantages. Depending on fixed costs of vans, robots or satellites, as well as other factors, one of the models may perform better than the other.

We propose a hybrid delivery model to select the optimal distribution strategy considering conventional vans, inner city hubs with robots, and delivery vans carrying robots, potentially improving distribution efficiency. We model the problem as mixed-integer program and propose an adaptive large neighborhood search (ALNS) to solve large instances efficiently. We conduct computational experiments to evaluate how our proposed model performs and how different characteristics (size, time) of the access restrictions impact its performance. We also evaluate how different characteristics impact solution structure.

2 Problem Description

We propose to combine the models in the literature to build a hybrid van-based robot delivery model (HVRD). This model lets the distribution system optimize the distribution strategy (using hubs, parking nodes or a combination of the two) to improve distribution efficiency.

A central depot, vans, vans carrying robots, robot hubs, and parking nodes are all given. The vans or vans carrying robots move along the first-level routes, serve customers, or visit parking nodes to drop off/pick up their robots, or visit hubs to unload goods. Robots start from parking nodes or hubs to handle deliveries along second-level routes. Two kinds of customers are considered : *van customers* can be visited by either the van or the robot, whereas *robot customers* can only be visited by a robot. They correspond to the customers in access-restricted van no-go areas.

Customers must be visited exactly once and have a service time and a time window. We assume parking nodes are used for the van to drop off/pick up and replenish its onboard robots, and hubs are used to store robots and goods. Each hub can only be visited once and contains a maximum number of robots ; it can also act as a parking node. Parking nodes can be visited multiple times. We also assume the depot is equipped with a sufficient number of vans.

Robots have a maximum battery capacity, which determines the distance they can travel, but there is no set maximum travel distance restriction for vans. There is a maximum capacity for vans and robots. We assume that when the robot is on board the van, the van and its robot's total load cannot exceed the van's maximum capacity. The robots can visit multiple customers during their trips. The onboard robots cannot leave the depot to serve customers directly and cannot go back to the depot independently.

For recharging, we assume every time a van picks up its robots, the battery is swapped. We assume an onboard robot can be replenished with goods from its corresponding van at parking nodes or hubs, and a hub robot can be replenished with goods at hubs. Note that hubs can be replenished with goods from vans, and vans' freight must be loaded at the depot.

The objective is to minimize the total cost, consisting of travel costs, equipment usage costs, and labor costs.

3 Results and Conclusions

We solve the HVRD model using CPLEX and an ANLS approach. We compare our HVRD model with a two-echelon vehicle routing model (2EVRP) and a van-based robot delivery model (VRD) to evaluate how our proposed hybrid model performs. Our research shows that the number of solvable cases of the HVRD model is larger than that of VRD and 2EVRP models with our instances. Even for the instances where all the customers are feasible for three models, the outputs of the HVRD model outperform those of the 2EVRP and VRD model. Therefore, allowing the system to select the appropriate distribution mode automatically can help the enterprise's distribution accessibility and efficiency.

For sensitivity experiments, we explore the impact of van no-go areas and van no-go area time windows. Our experimental results show that as the van no-go area shrink, the cost of the distribution system is significantly reduced. Besides, as the length of the access time window increases, their impact gradually decreases.

With regards to the increasing importance of an on-demand economy and same-day deliveries dynamic versions of the HVRD problems might also be of interest for future research.

Références

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