Pickup and delivery with a fleet of electric vehicles and a local energy production unit

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1 Introduction

A set of capacitated Battery Electric Vehicles (BEVs) carry out pickup and delivery operations with time windows constraints. The energy needed to recharge the batteries of these vehicles is produced in a production unit (p.u.) not far from the area where these vehicles operate. Additional batteries are available at the p.u., where vehicles can go and swap their batteries. Pickup and delivery operations must be planned over a time horizon divided into periods. In each period it must be decided how much energy to give to the batteries that are at the production unit. Also, if the energy produced is in excess of that required by the batteries, this excess can be sold to the general network at a profit. If the energy required by the batteries is greater than the energy produced, an unlimited amount of energy can be bought from the general network. The objective of the problem is to plan vehicle routes to meet all pickup and delivery demands while maximizing the profit that is made from the energy sold over the time horizon. We now briefly cite the relevant literature. [4] is one of the first papers to study pickup and delivery problems with a mixed fleet of BEVs and Internal Combustion Engine Vehicles. In [5] the electric Pickup and Delivery Problem with Time Windows (E-PDPTW) is studied. In the context of people transportation, one of the first studies on Dial-a-Ride problems with electric vehicles is [2]. In [6] the authors address the DARP with electric vehicles and a battery swapping policy. Since our problem deals with the management of the energy produced, it can be seen as an integrated problem sharing similarities with the Inventory Routing Problem (IRP) [3] or the Production Routing Problem (PRP) [1].

2 Problem description, modelling and solution method

The problem is modeled on a complete directed graph $\mathcal{G} = (\mathcal{N}, \mathcal{A})$, where $\mathcal{N}$ is the set of nodes and $\mathcal{A} = \{(i, j) : i, j \in \mathcal{N}, i \neq j\}$ is the set of arcs. The set of nodes $\mathcal{N} = \{0, 2n + 1\} \cup \mathcal{P} \cup \mathcal{D}$ consists of the vehicle depot $(0, 2n + 1)$, the set of pickup nodes $\mathcal{P} = \{1, \dots, n\}$, the set of delivery nodes $\mathcal{D} = \{n + 1, \dots, 2n\}$ and the production unit (p.u.) $2n + 2$. Every route begins at node 0 and ends at node $2n + 1$. n requests must be served over a planning horizon $\mathcal{H}$ of H periods $\{1, \dots, H\}$, each of duration τ. With every arc (i, j) is associated a cost e_{ij} and a travel time τ_{ij}. V BEVs are available at the depot, each of capacity Q. Batteries are swapped at the p.u.. Vehicles move at constant speed. K batteries of capacity Q_e are available, V batteries located on the vehicles and $K - V$ located at the p.u.. In each period h, p_h is the energy produced, available at the beginning of the period. Batteries swapped in period h can be recharged in period $h+1$ and get available from period $h+2$. γ is the recharging rate. All batteries are half-charged at the beginning. Every request specifies an origin s_i, a destination t_i, a time window $[r_i, d_i]$ and a demand q_i. Each user node must be visited exactly once, while the p.u. may be visited multiple times. The time window to visit the p.u. is set to $[0, T]$, where T is length of the planning horizon ($T = H\tau$). Moreover, we assume that the number of stops that a vehicle can make to swap its battery is not limited. In each period h, p_h must be split among the batteries and sold to the general network. Energy can also be bought from the general network. The objective is to satisfy all transportation requests at maximal revenue, defined as the difference between the energy sold to and the energy bought from the general network.

We divide the problem into two sub-problems: the routing sub-problem and the energy management sub-problem. The routing sub-problem is solved heuristically by generating a restricted number of trips. We call trip a couple $t = (r, h)$ where r is a path between two nodes and h is the starting period of the path. There are four kinds of trips, based on the starting and ending node: trips in $\mathcal{T}_1$ start from the depot and arrive to the p.u., trips in $\mathcal{T}_2$ start from (and end to) the p.u., trips in $\mathcal{T}_3$ start from the p.u. and end at the depot, trips in $\mathcal{T}_4$ start from (and end to) the depot. Trips are generated by taking into account the time constraints for the requests and the capacity constraints for the vehicles. We denote the set of trips with $\mathcal{T} = \{\mathcal{T}_1 \cup \mathcal{T}_2 \cup \mathcal{T}_3 \cup \mathcal{T}_4\}$. The energy management sub-problem is solved by formulating it as a MILP where in each period it must be decided how much energy to give to the batteries, how much energy to sell or buy and which trips are used. The solution method consists of three steps: the routing sub-problem is solved, then the MILP is solved and finally the solution is possibly improved by modifying the routes of some vehicles.

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