Branch-price-and-cut algorithms for electric vehicle routing problems with time windows

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In this paper we consider different variants of the electric vehicle routing problem with time windows (EVRPTW). All variants considered involve a homogeneous fleet of electric vehicles housed in a single depot, a set of customers, and a set of battery recharging stations. Each vehicle has a limited capacity, a limited battery autonomy, and a battery that is fully charged at the beginning of the day. Each customer has a known demand, s service time, and a time window in which its service must start. All recharging stations offer the same service (same recharging rate and no recharging costs) and differ only by their location. For each pair of locations (depot, customers, and stations), the input provides a traveling cost, a traveling time, and an energy consumption. The EVRPTW consists of determining least-cost feasible vehicle routes such that each customer is visited exactly once. Starting and ending at the depot, a route is composed of a sequence of customer visits interspersed by stops at recharging stations if needed. A route is feasible if the total demand of the visited customers does not exceed vehicle capacity, the service at each customer starts within its time window, and the battery charge is positive when traveling.

We consider four EVRPTW variants: at most one recharge per route/full recharges only; any number of recharges per route/full recharges only; at most one recharge per route/variable recharges; any number of recharges per route/variable recharges. For each problem variant, we propose a state-of-the-art branch-price-and-cut algorithm in which the subproblem is solved by a labeling algorithm. A full recharge incurs a recharging time that depends on the energy consumption since the last recharge. This can be handled relatively easily in the labeling algorithm. However, variable recharges require a more complex labeling algorithm where the time component is a function of the quantity of energy recharged. Surprisingly, the variants with full recharges only are not directly suited for bidirectional labeling while the variable recharge cases are suitable. We show how we can combine the algorithm for the variable recharging cases with that for the full recharging cases to yield a bidirectional labeling algorithm for the latter cases. Finally, we also develop an efficient local search heuristic column generator to speed up the overall solution process. Computational results on benchmark instances will be presented.