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Towards an integrated approach for demand forecasting and vehicle routing in recyclable waste collection

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Extended Abstract

Solid waste collection is a complex logistical problem that arises in every municipality. According to various studies, transportation costs represent approximately 70 to 80% of all operational costs in waste collection. Therefore even small improvements in the collection routes may lead to substantial savings, which directly affect households, the municipal budgets and the collection companies' bottom lines. From a different point of view, the increased entry of monitoring technologies, such as GPS and RFID, and the growing availability of off-the-shelf routing software has begun to exert pressure on collection companies, which are used to static periodic collection schedules, to implement active tour planning and optimization. Yet, the particular features required by collectors or imposed by the collection areas are usually not present in the routing solutions available on the market.

In this work, we consider a complex recyclable waste collection problem that extends the class of vehicle routing problems with intermediate facilities by integrating a heterogeneous fixed fleet and a flexible assignment of destination depots. Several additional side constraints, such as a mandated break period contingent on tour start time, multiple vehicle capacities and site dependencies are also included. This specific problem was inspired by a real-world application and does not appear in the literature. The motivation for this research is two-fold. Firstly, waste collection VRP assumes homogeneous fleets, while, on the other hand, heterogeneous fleet VRP problems often omit other important features present in our problem, such as intermediate facilities and complex temporal and operational constraints. We thus bridge the gap in the literature between the waste collection VRP with intermediate facilities and the heterogeneous fixed fleet VRP. Secondly, our case study features both urban and sparsely populated rural regions, where the latter require the need for efficient tours that need not finish at their origin depots. Few papers consider such a setup and report significant cost savings for a similar flexible depot assignment.

Our VRP is modeled as an MILP which is enhanced with several valid inequalities. Due to the richness of the formulation, a commercial solver like Gurobi is only able to tackle instances of small to medium size. To solve realistic instances, we propose a local search heuristic capable of systematically treating all problem features and general enough to respond to the varying characteristics of the case study regions for which it is intended. The results show that the heuristic achieves optimality on small random instances, exhibits competitive performance in comparison to state-of-the-art solution methods for special cases of our problem,

and leads to important savings in the state of practice. We achieve an average cost reduction of 15%, which can be extrapolated to 300'000 USD annually, for tours executed in the canton of Geneva, Switzerland, and this is only by optimizing each tour separately. The savings from allowing a flexible assignment of destination depots are analyzed and highlighted on benchmark data from the literature.

The operational relevance of the routing algorithm depends on the forecast container levels at the time of collection. To this end, we develop a non-linear model which uses past level data available from ultrasound sensors mounted inside the containers to make short term forecasts. It is based on a discrete mixture of count data models representing populations depositing different quantities in the containers, thus reflecting a realistic underlying behavior. This approach appears to be better at explaining the observed in-data variance compared to a dynamic panel linear regression, machine learning, and hurdle models using Poisson and negative binomial distributions. Comparing the mixture of count data models to a simple count data model implying only one deposit quantity, we establish that the former exhibits better in- and out-of-sample performance, thus defending the motivation to mimic the underlying data generation process. Moreover, it still maintains relative simplicity by considering a very small set of discrete disposal quantities and has few other exogenous assumptions.

After discussing the performance of the routing and forecasting model, we explore the methodological framework for their integration into an inventory routing problem with dynamic periodicity. The integrated framework solves simultaneously the container selection problem based on forecast demand and the efficient routing of the fleet in a rolling horizon context. The advantage of this strategy is the fuller and more balanced utilization of the available fleet. For each day of the rolling horizon, containers are selected by counterbalancing a penalty for early or late collection and the effect of the container selection on the overall routing cost. Tests are based on synthetic and real data coming from collectors in Switzerland and France.

Keywords: Iliya Markov, waste collection, vehicle routing, demand forecasting, demand-supply integration, inventory routing