Recyclables' Collection Planning using Sensor-based Information for Bin Fill Levels: Methodology and Application

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1 INTRODUCTION

The collection of municipal solid waste (MSW) is a complex operation especially when it involves large regions, multiple vehicles based at several depots, and numerous bins. Until quite recently, the collection routes were typically fixed for a given period (e.g., the days of a month) and defined considering historic bin fill rates, calculated based on the fill levels registered manually by vehicle drivers over time (see, e.g., Teixeira et al., 2004). Today, owing to the evolution of sensor technologies and the decrease of their prices, actual bin fill levels can be known in real time, and the collection routes can be defined accordingly, varying every day. Planning these variable routes to optimize collection operations is, however, a challenging problem, as we make clear below.

In this paper, we present a study where the net benefits of sensor-based recyclables' collection are analyzed. For this purpose, we have set up a methodology and applied it to data on bin fill levels provided by ERSUC, the company responsible for MSW management in the Litoral Centro area of Portugal (6,700 km^2, 1 million inhabitants, 36 municipalities). These data, gathered by vehicle drivers during the collection operations, were assumed to be the same that sensors placed inside the bins would make available in real time.

2 METHODOLOGY

The methodology we have designed to address the recyclables' collection planning problem described above is outlined in Figure 1. As can be seen there, it comprises two phases: in Phase 1, a look-ahead heuristic is applied (every day) to decide when to perform collection routes within a given planning horizon (e.g., 5 or 10 days); and, in Phase 2, an optimization-based or a hybrid metaheuristic approach is applied to decide which routes to perform in the next day. The need to consider two distinct approaches is because the former can only handle small-size instances (involving, say, 200 bins at most) while ensuring a short time difference between the reception of the fill level data and the completion of route calculations (say, two hours at most).

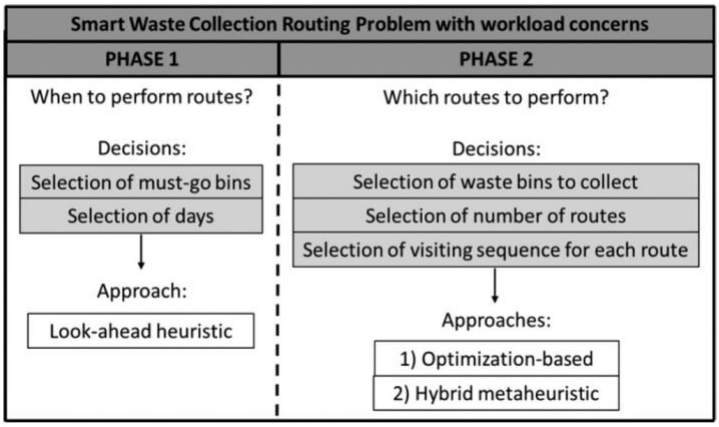

Figure 1 – *Methodology outline*

The look-ahead heuristic uses real-time information on existing bin fill levels and fill rate forecasts to identify the bins that, in order to avoid waste overflows, must be mandatorily collected between the current day and the expected next collection day – designated as must-go bins. This procedure allows to avoid unnecessary collection routes.

The optimization-based and the hybrid metaheuristic approaches were developed for the Smart Waste Collection Routing Problem (SWCRP) introduced by Ramos et al. (2018) extended with workload concerns. Specifically, two such concerns were taken into account: maximum and minimum duration of collection routes; and fair effort distribution across collection vehicles (and respective teams). The SWCRP is a Vehicle Routing Problem with Profits wherein the decision on which bins to visit in addition to the must-go bins depends on whether they are profitable to collect or not (Archetti et al., 2014). In our case, profit was defined as the difference between the revenue generated from selling the collected waste and the cost of collecting it (considered as a linear function of the distance travelled).

The optimization-based approach is applied to the model representing the SWCRP with workload concerns considering the must-go bins as well as any other bins characterized by a fill level above a predetermined threshold. The hybrid metaheuristic approach consists of a simulated annealing algorithm and a neighborhood search algorithm performed sequentially, and includes a procedure to eliminate intersections between route segments whenever they occur. The neighborhood search algorithm allows to further explore the vicinity of the simulated annealing solution, ensuring that, at least, a local optimum is found. This metaheuristic is presented and evaluated in detail in Jorge et al. (2022).

3 APPLICATION

For assessing the net benefits of changing from fixed-route (blind) to variable-route (smart) operations, we performed a study on the collection of paper and cardboard during a period of 28 days (April 2 to 29, 2019) in three ERSUC municipalities served by the same depot (Vil de Matos): Coimbra, a urban municipality located close to a depot (610 bins, 15 km from the depot); Condeixa, a suburban municipality more distant from the depot (121 bins, 28 km); and Soure, a rural municipality relatively far from the depot (98 bins, 38 km). Specifically, we compare here the current ERSUC operations with those corresponding to the methodology application scenarios identified in Figure 2.

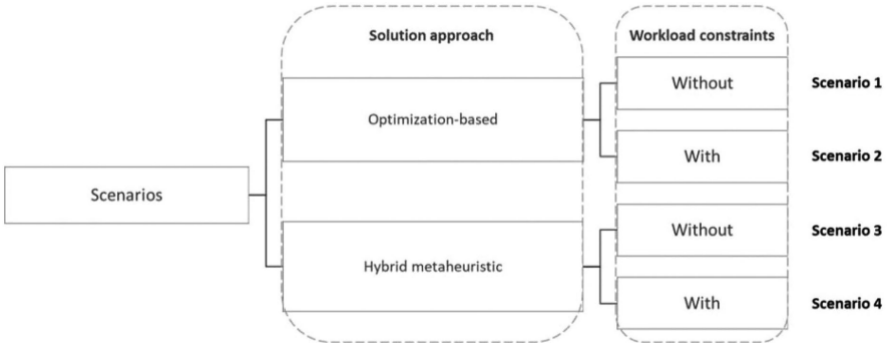

Figure 2 – *Methodology application scenarios*

In Figure 3, it is shown how the current total profit (over the 28-day period) could increase by moving from recyclables' blind collection operations to smart ones (using the proposed methodology). In Soure, profit could become positive (341 €) instead of being negative (-86 €). In Condeixa, it would approximately double (increasing from 599 € to 1,117 €). In Coimbra, the rate of profit increase would be much smaller (around 23%), but the value of the increase would be substantial (almost 2,000 €). It should be noted that these gains would be achieved while fully taking into account workload concerns (as the figure shows, if they were not taken into account, then profits could be slightly higher in the three cases).

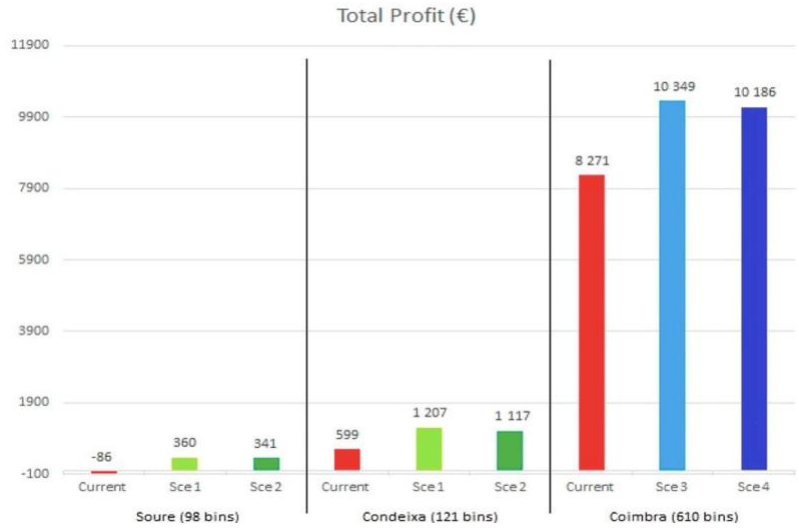

Figure 3 – *Total profit of collection operations*

In the calculation of profits, we did not account for the substantial investment costs involved in the installation of sensors. However, even considering a cost of 200 € per sensor (and a 10% discount rate), the net benefits of sensor-based recyclables' collection would be quite large: the benefit-cost ratio in Soure and Condeixa would be 2.6, decreasing to 1.9 in Coimbra.

Information on several other performance indicators examined in this study (e.g., number of collection days over the period analyzed; number of routes performed, usage of vehicle capacity, and quantity of waste collected per unit of distance travelled) is provided in De Morais et al. (2023).

4 CONCLUSION

The results presented in this paper (and many more) were obtained in the framework of a research project already completed, and disseminated in a workshop attended by representatives of various MSW management companies. Possibly also for this reason, several of these companies are now seriously considering to install sensors in their recyclables' bins or, as is the case of the company operating in the Lisbon region (VALORSUL), are already doing so. In this context, a new research project was recently launched to analyze the quality of sensor data, improve the efficiency of the approaches used within the proposed methodology, and make the planning process fully integrated (from the collection of sensor data to the communication of routes to vehicle drivers) and automated. If successful, this recent project will certainly contribute to a rapid transition to smart recyclables' collection operations in the companies directly involved in the project, as well as in any others willing to become more profitable.

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