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Intelligent Household Garbage Management: An Alternative Path to Climate-Neutral Europe

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Abstract

We consider intelligent household garbage management, where the management is driven by real-time data about the levels of garbage in residential collection points. More specifically, by using such data, we first study deciding which points can be scheduled for garbage collections. We then minimise the number of garbage trucks that could be assigned to as many scheduled points as possible. We then look into routing such trucks so that their emissions are minimised. Finally, we analyse fair allocations of garbage costs to households.

1. Overview and motivation

Greenhouse gas emissions are among the main factors for climate change. To reduce such emissions, in 2015, the UN introduced the 2030 Agenda for Sustainable Development [1]. One well-understood path towards solving this challenge is to recycle garbage within circular economies. In fact, the EU has started several programs to pave the foundations of such economies: the Circular Economy Package [2]; the Circular Economy Action Plan [3]; the European Green Deal [4]. Nevertheless, despite the significant efforts and CO_2 reductions in the last years, the European Environment Agency expresses concerns about reaching the agenda goals by 2030 [5]. In response, we consider an alternative and less-understood path to climate-neutral Europe: *intelligent household garbage management*. For example, in 2014 in Berlin, the CO_2 emissions related to households were nearly 65% of all CO_2 emissions related to households, transport, and industry [6]. Household garbage management is therefore crucial for minimising these emissions. It has three main steps: (a) the collection of garbage from residential collection points, (b) the transportation of the collected garbage to sorting plants, and (c) the burning of sorted non-recyclable garbage at incineration plants. Some works studied garbage collection and sorting optimisations [7,8]. However, they motivate households to separate garbage more carefully, but not to generate less garbage. For this reason, we ask the question: *How can we motivate households to generate less garbage?*.

2. Methodology, results and main contributions

Household garbage generation relates to lack of awareness, space limitations on recycling methods, inadequate policy, and lack of time and priority [9]. Hence, minimising the amount of garbage generated due to these factors lies at the source of the household garbage management steps (a-c). Our methodology to tackle this problem is to design an IoT solution of wireless sensors (e.g. WILSEN.sonic.level), being installed on the top lids of garbage containers at collection points, and wireless connections to sensors (e.g. via Sigfox Germany), transferring data in real-time about the garbage levels in such containers. Our solution is for Germany where garbage trucks run on fixed schedules and households pay fixed garbage costs. We thus ask: *Given real-time data about the levels of garbage in collection points, how can we dynamically schedule collection points for service, efficiently assign scheduled points to garbage trucks, optimally route garbage trucks through the locations of their scheduled and assigned points, as well as fairly allocate garbage costs to households?* In our work, we take the first steps towards answering this question. Our conceptual contribution is that our solution can (1) improve the awareness of households by keeping them in the loop, (2) provide to them adequate feedback about their levels of generated garbage, and (3) allocate to them costs that are proportional to these levels. We hope that thus households can self-reflect on and become more cautious about their garbage generating behavior, thus giving higher priority to lowering their garbage levels and saving related costs in the future.

Our technical results can be divided into three parts. Firstly, we propose a new formal model for intelligent household garbage management, where *n* trucks collect garbage from *m* points over some fixed day horizon $T=\{1,\ldots,t\}$. Garbage comes in types from $K=\{1,\ldots,k\}$. Secondly, based on sensor data, we formulate (Problem 1) the scheduling of points for collections, (Problem 2) the assignment of the minimum possible number of trucks to the maximum possible number of scheduled points, (Problem 3) the 2-approximate computation of a green route of low CO_2 emissions for each truck through its assigned locations, and (Problem 4) the proportional allocation of costs to households. Thirdly, we design Algorithms 1-4 for solving Problems 1-4, respectively.

Problem 1: scheduling collections per day	Problem 2: assigning collections per day	Problem 3: routing trucks per day	Problem 4: allocating costs to households per day
Algorithm 1: $O(m.k)$	Algorithm 2: $O(m^3.k^2.n)$	Algorithm 3: $O(m.(n+m.k))$	Algorithm 4: $O(m^2.k)$

Table 1: The running times of Algorithms 1-4 for *n* trucks, *m* points, *k* types, and $t=365$.

Our scientific approach combines methods from multiple domains. For Problem 1, we use time-series and predictive analyses, based on historic data. For Problem 2, we give a polynomial-time reduction from the social-welfare maximisation problem in economic theory. For Problem 3, we engineer optimisation based on minimum spanning trees from graph theory. For Problem 4, we adapt proportionality concepts from fair division. Our future hypothesis is that if households generated less garbage over the course of the year, then trucks could visit less often sorting and incineration plants. In practice, we might therefore expect to observe reductions in the CO_2 emissions of plants, as well as the garbage costs of households. Finally, we give more details in the full paper.

3. Conclusion and future works

We proposed a new digital model for intelligent household garbage management and gave for it some algorithms with nice theoretical guarantees. In the future, we will study achieving fairness and equitability for garbage personnel teams (i.e. collectors and drivers) based on their shift preferences (e.g. work in the time window 4 a.m.-10 a.m. but not outside this time window) and location preferences (e.g. work in one area but not in another area). For some given time horizon (e.g. a year), equitability would guarantee that each team is more or less equally busy with work and fairness would guarantee that the profit of each team for their services is at least as much as the profit of any other team for their services. Finally, we will also implement a demo version of our solution, that can be used for simulating our current approach and validating our future hypothesis.

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