Optimizing mobility in door-to-door waste collection: the case of Benevento

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***Abstract*—Smart Cities promise to revolutionize the way citizens experience the urban setting and consume the services it delivers. In this paper, we evaluate the economic and environmental impact of adopting this paradigm in the field of waste collection by considering the case study of Benevento. The preliminary results obtained reveal a cost saving of approximately 33% with a reduction in polluting emissions estimated at around 24%.**

***Index Terms*—Smart Waste Collection, Route Planning, Optimization, Sustainability**

I. Introduction

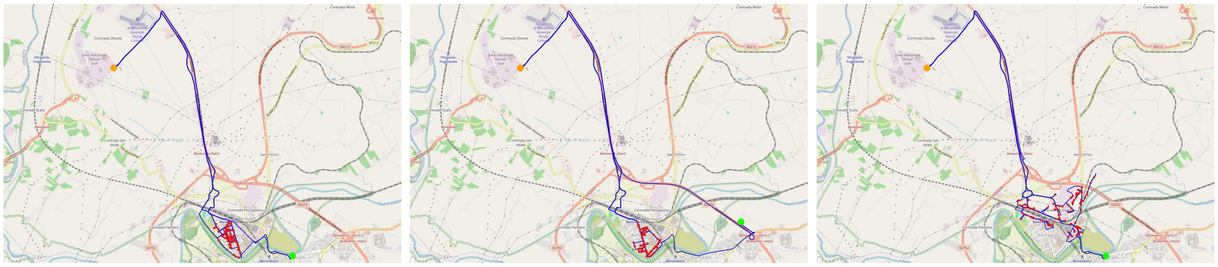
Smart Cities take advantage of the opportunities offered by ICT paradigms and technologies to improve the quality of citizens' lives, reduce the environmental impact of the industrial ecosystem as well as to improve city's sustainability. Smart Waste is of course one of the applications with the greatest implications on people's well-being. The idea is to keep track of waste disposals with the aim of dynamically defining collection strategies that optimize service routes and operational costs, while limiting polluting emissions. In this paper we evaluate the economic and environmental impact of the adoption of a smart city oriented approach by considering the case study of Benevento. In particular, we compare the waste collection system already adopted against a Smart Waste Collection System (SWCS) that comprises *i)* an IoT monitoring subsystem, which exploits Radio-Frequency IDentification (RFID) technology for disposal tracking, and *ii)* a route planning module, which exploits an optimization engine together with a routing engine for path finding.

II. Smart waste collection system

SWCSs rely on IoT technologies to monitor waste disposals. Most of the solutions proposed in literature adopt approaches based on smart bins, *i.e.*, bins equipped with a complete measuring system able to quantify the amount of garbage (or the residual capacity) in real-time [1]. Despite their accuracy, these kind of implementations may be really expensive especially in the case of door-to-door collection, as in the considered case study. For this reason, we thought about a SWCS that exploits a RFID sensing subsystem to track the waste delivered when operators take the garbage bags and throw them into the containers of the garbage trucks. Specifically, the subsystem consists of one or more *readers* mounted on each truck, and a *tag* applied on each bag. Data collected on disposals (where and when they occur, along with their amount) are then used to statistically characterize people's habits, that is to build a behavioural model capable of predicting the amount of waste people will produce in a given day. This is the information we then employ to formulate a Vehicle Routing Problem (VRP) whose resolution produces the set of service routes that operators must follow. Our SWCS in fact includes a Cloud platform that exposes a route planning service built around an optimization engine, implemented with the Vehicle Routing Open-source Optimization Machine (VROOM) [3], and a routing engine, implemented with the Open Source Routing Machine (OSRM) [4]. VROOM is used to solve a Capacitated Vehicle Routing Problem with Pickup and Delivery and Time Windows (CVRPPDTW) [2], a specialization of the general VRP problem in which an heterogeneous fleet of vehicles, *i.e.*, vehicles with different capacities, must complete a set of shipment requests starting from one or multiple depots and returning to them at the end. Each shipment is characterized by *i)* a pickup point, *ii)* a corresponding delivery point, *iii)* an amount of goods, and *iv)* a time window. The objective is to minimize operational costs, which are usually associated with travel distance. This is the modeling that best fits the problem underlying waste collection services. To accomplish its task VROOM needs to know the matrices of actual distances and durations associated with a graph whose nodes are the depots, the pickup and delivery points. This is where OSRM comes in. The latter is indeed in charge of computing shortest paths in road networks using real-world geographic data, primarily sourced from OpenStreetMap (OSM) [5].

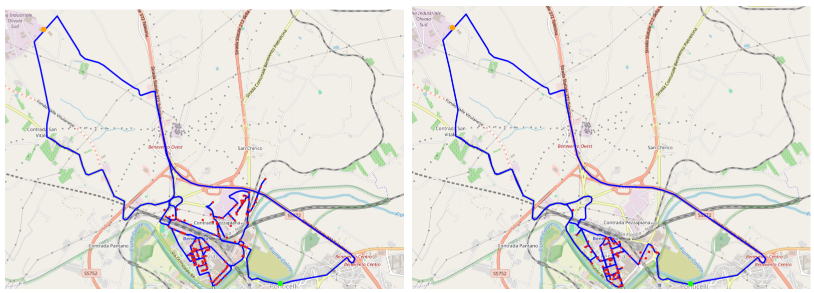
III. Impact analysis

To evaluate the impact of the conceived SWCS, we first processed the data provided by the company responsible for the waste collection service in Benevento with the aim of calculating *i)* the number of trucks employed, *ii)* the total distance traveled, *iii)* the total amount of costs, which is obtained as the sum of the fixed (operators' salary) and variable (fuel) costs,



(a) Truck #1. (b) Truck #2. (c) Truck #3.

Fig. 1: Routes followed in the waste collection system currently used. The green and orange points are the depot and the delivery point, respectively, whereas the red ones are the pickup points.



(a) Truck #1. (b) Truck #2

Fig. 2: Optimized routes. The green and orange points are the depot and the delivery point, respectively, whereas the red ones are the pickup points.

	In-use Waste Collection				Smart Waste Collection			Percentage gain
# of trucks	3				2			$\approx 30\%$
Truck	Truck 1	Truck 2	Truck 3	Total	Truck 1	Truck 2	Total	
Distance (km)	52.99	52.82	49.83	155.64	50.77	67.83	118.59	$\approx 24\%$
NO_x emissions (g/km)	6.36	6.34	5.98	18.68	6.09	8.13	14.22	$\approx 24\%$
CO_2 emissions (g/km)	26.49	26.41	24.91	77.81	25.38	33.91	59.24	$\approx 24\%$
Cost (€)	377.80	377.76	377.01	1132.57	377.25	381.52	758.77	$\approx 33\%$

TABLE I: Current vs. Smart waste collection system.

and *iv)* the estimate of NO_x and CO_2 emissions, which are obtained by taking into account the characteristics of the trucks (emissions per kilometer) and the distance covered. These are indeed the criteria we used to compare the performance of the existing service with that of the proposed SWCS. Currently, operators use three trucks and follow the routes reported in Figure 1. The SWCS, however, suggests that two trucks following the routes reported in Figure 2 are sufficient. Note that in both cases, due to the limited capacity of the trucks, operators reach the delivery point multiple times, since they have to deliver the accumulated waste before they can proceed with other pickup operations. However, in the former a delivery is performed only when truck capacity runs out. This is not true for the latter. In fact, given the position of a truck, the residual amount of waste to pick up, and the elapsed time, the optimizer may find convenient to perform a partial delivery, still without violating temporal constraints. This is one of the optimizations that characterize CVRPPDTW problems. Table I summarizes the values of the previously mentioned metrics, also reporting the percentage gain. Adopting a SWCS leads to a significant reduction of the distance traveled, quantified at approximately 24%. As a direct consequence, also the polluting emissions decreases by the same factor. From a cost perspective, the shorter distance, together with the use of one less vehicle, brought down operational costs resulting in a performance gain close to 33%.

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