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Optimization of recyclable waste collection using real-time information.

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Abstract This paper addresses the recyclable waste collection problem in urban areas. The work focuses on the recyclable glass bins collection, but with the peculiarity that these are provided with a device that sends fill level data daily to the control center. With this additional real time information we propose a collection policy that minimizes the length of the routes of vehicles on two levels, one daily and other for a larger planning horizon. This proposed policy is compared to the one used in the current literature and only optimizes the daily routes. Several simulations of the two policies are performed on a model of the city of Seville. Results show the proposed policy achieves better results in terms of meeting demand and better utilization of resources.

Keywords: waste collection, vehicle routing, real time data, optimization

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1. Introduction

Trying to solve the problem of waste collection in cities is not a new problem. Already in the 70 authors can be found attempting to address the problem, either from a mathematical point of view (Marks & Liebman, 1970), either modeling and solving a vehicle routing problem or VRP (Beltrami & Bodin, 1974; Turner & Hougland, 1975). This problem is not easy to solve because it is included within the family of problems called Vehicle Routing Problem (VRP), as ever known, they all fall under the classification of NP-hard.

The increased levels of consumption and associated waste generation, environmental considerations and sustainability of cities have led to the emergence of new European and national policies regarding the management of municipal waste. An example is the National Integrated Waste Plan implemented in Spain in 2009, which is to continue the anterior National Urban Waste Plan (PNRU), and, among other things, forces municipalities with more than 5000 inhabitants to ensure proper separation for selective collection of waste. Such measures make to consider new challenges to municipalities, even more so in the economic recession framework in which we live. Different types of containers, different types of waste, containers location, pollution, energy consumption, cost reduction, are any of these challenges. Thus authors that address the problem from the consumption of fuel (Sonesson, 2000), until which encompass environmental and economic goals can be found in the literature.

Nowadays with the emergence of new technologies and the lowering of its price give researchers new tools to solve this problem. Examples of these new technologies are Geographic information system (GIS), volumetric sensors, radio frequency identification (RFID). Using this technology the issues can be addressed as eliminating unnecessary stops, fleet reduction and balancing according to demand, pollution impact reduction, operating costs reduction, etc. In this direction it works in recent years (Chang et al., 1997; Nuortio et al., 2006), and in which there is great potential for future work.

And it is in this direction that this work moves. In this paper we address the problem of waste disposal in urban areas with the real-time level data of the containers. In particular we focus on the collection of glass containers. We describe in this work the problem to solve; we present the proposed collect policy, and compared with other classical optimization algorithm. Finally, we show the results obtained and present the conclusions of the work.

2. Problem description

We consider a capacitated vehicle routing problem on a graph: $G: [N, A]]$, where N is the set of nodes and L is the set of links communicating them. The set of nodes

N contains one node d with a positive level of demand (depot), a subset C of nodes with a positive level of supply (containers), and another subset $\bar{C}$of nodes with zero levels of supply and demand, so that $N = (C \cup \bar{C}) \cup d$.The supply level of containers in subset C is time variant, and is known daily.

A number V of vehicles (where V is a variable) will travel through the graph visiting the different containers, only one vehicle per container. We consider capacity restrictions on vehicles (Q) equal for all of them.

The problem is defined inside a predefined time horizon, N days, and the objective is to minimize the number of vehicles that need to be used and the cost (in time units) of transporting waste from the containers of C to the depot d, crossing along the way the necessary nodes of the subset $\bar{C}$.

We also define a set T of time costs associated to the different links in the graph. These costs depend only on the transit of vehicles through links, and not on the amount of waste carried by those vehicles. In general, we will incur in cost t_{ij} when travelling from node i to node j. We will also compute the loading time at each customer as a time cost tr, incurred every time a vehicle visits one of the nodes contained in C.

3. Proposed Solution

We propose a collection policy based on three stages: calculation, estimation and optimization. Previously we fixed the fill level (RL) of containers which are to collect.

In the first stage, we calculate the routes needed to minimize the travel length after knowing the containers to collect in a day t with the volumetric sensor data and the fixed RL. In the next stage, we estimate the containers to be collected over the next N days $(\mathrm{t}+1, \ldots, \mathrm{t}+\mathrm{N})$. We use its current fill level and its daily fill rate. The necessary routes are also calculated for those N days. In the last stage and seeking to reduce the number of kilometers traveled in the planning horizon, we look for the possible containers, from those N days, which can be collected on day t. Obviously the fill levels that have these containers in the day t is lower than the value RL fixed by the policy, so the proposed decision rule takes into account that not exploited container capacity.

This policy is compared with another used in the literature (Nuortio et al., 2006; Johansson, 2006; Faccio et al., 2011), which simply collects the containers with the fixed fill level.

Below clarifies the nomenclature used in the description of the implemented algorithm for simulating policies.

- $L\ (r)$ denotes the length of route r, in time units.

- The used operators are known (Bräysy & Gendreau, 2005). These are: Insertion Operator, Local Search Operator, 2-Opt, OR-Opt, 3-Opt, Exchange, Relocate, 2-opt*, CROSS-Exchange and GENI-Exchange.
- Parameter that we use as decision rule to determine which containers with fill levels lower than RL are collected at day t is defined as follows:

$$P(i) = \left(1 - Nll(i)\right) \cdot tr \cdot k \tag{1}$$

  – Being $NLL\ (i)$ the fill level of each container at the current moment, and k a parameter as a weight of not exploited container capacity in the decision rule. The simulation uses different values of k in search of its optimal value.

Below we present the pseudo-code of the algorithm used by the proposed policy. This algorithm calculates the routes needed for a particular day, but as discussed above, it will be simulated continuously for three months in order to compare the overall results.

```
Calculate containers to collect day t (real-time data)
for d1 = 1:N Estimate container to collect in day t + d1 (historic data)
end
for d2 = 1:N + 1 Build collection routes (Operators already mention)
end
for d3 = 1:N for each day since t + 1 to t + 7 and considering the capacity
constrains
   for each container j in each route r  at day t
      for each container i in each route s  at day t + d3
         if    L(r with i between j and j + 1) + P(i) + L(s without i) <
         L(r) + L(s)
         Save container iin containers to collect in day t
         end
      end
   end
end
for build day t routes with the new containers
   while the length of routes improves
   end
end
The algorithm to simulate the policy to compare:
Calculate containers to collect day t (real-time data)
for build day t routes (Operators already mention)
   while the length of routes improves
   end
end
```

4. Case study

We consider the problem of collecting recyclable waste containers in the city of Seville, in particular glass containers. These containers are located throughout the city so dispersed. These containers is not necessary to collect daily because of non-degradable nature of the glass, the rate of generation of this type of waste which is not very high and the capacity of the containers (in the case of Seville is 3 m^3).

Currently it used a policy that combines on the one hand the collection of containers according to estimates of historic filling rates and on the other the containers collected after receiving a call from a neighbor alerting the complete filling of any of them.

The implementation of automated sensors that emit a signal to the waste management center with the fill level data in the containers of this type of waste is a trend seen in recent times (Nuortio et al., 2006; Johansson, 2006; Faccio et al., 2011).

And assuming that such sensors have been implemented in the city of study the problem to solve is:

- A model of Seville consisting of a graph: $G: [N, A]]$, with $N = 1217$ nodes and $N = 4510$ arcs. The cost associated with each arc is in t_{ij} kilometers.
- It assumes the existence of a sufficient fleet to service. The capacity of the truck was fixed in terms of number of full containers that can contain. Each vehicle can collect $Q = 7$ full containers. Associated with vehicles is also fixed in $tr = 2.5$ minutes the time required to collect each container (the mechanical collection of glass containers in Seville requires a crane). The estimated average speed of vehicles was fixed at 20 km / h.
- A single depot (d) from which the vehicles begin and end collection routes is considered.
- Distributed by the graph are located containers (subset C) to be collected. The number of containers was fixed at 300. It is considered that each container has a volumetric sensor that provides daily the fill level of each of them. In addition to its exact location, two data have associated to each container; one is the current filling level (%) and the other a daily filling rate (%), different for each. This rate is assumed to follow a normal distribution (Johansson, 2006), with an average value 0.1428, the standard deviation value is a parameter in the experiments (0.5 or 1).
- The problem is to solve for a planning horizon of $\mathrm{N} = 6$ day, although the proposed policy aims to minimize the number of kilometers within a time of three months, so there will be a rolling-horizon procedure for that time.

4.1 Results

After these we present and analyze the results of the implementation of two policies to the problem.

Several experiments on the model of Seville from the two policies were conducted to compare.

As parameters to study the sensitivity on the results we used the standard deviation (σ) of the containers daily rate of filling and the fixed RL in both cases. And the value of k in proposed policy. For a better comparison we added the value of k in the cost function of both policies.

As service satisfaction index we used the demand met daily. Unmet demand is considered, and therefore is not accounted for in the index, the estimated amount of glass arriving to the container once it is full. This amount of waste is not collected.

The cost function used is:

$$CT = \left(\frac{Kilometers}{Average\ speed}\right) + Number\ of\ collected\ containers \cdot tr \cdot k \qquad (2)$$

Table 1 Proposed policy results

σ	*RL*	*Km*	*Nº R*	*Nº RT*	*NllMV (%)*	*DS (%)*	*k*	*CT*
0.5	0.95	19611	548	3759	91.7%	94.7%	0.5	63532
0.5	0.95	19337	547	3657	91.6%	94.9%	1	67154
0.5	0.95	19222	542	3568	92.5%	94.5%	3	84426
1	0.95	22935	655	4478	93.2%	91.6%	0.5	74401
1	0.95	22647	651	4409	93.6%	91.5%	1	78965
1	0.95	22629	646	4310	94.1%	91.4%	3	100213
0.5	1	22293	586	4664	91.3%	99.3%	0.5	72710
0.5	1	22133	592	4503	90.1%	98.6%	1	77656
0.5	1	21608	581	4331	91.3%	98.3%	3	97308
1	1	27309	728	5880	91.6%	98.5%	0.5	89276
1	1	26842	725	5752	91.6%	98.3%	1	94907
1	1	26699	725	5640	91.4%	97.9%	3	122396

σ ≡ Standard deviation, RL ≡ fixed fill level, Km ≡ Total distance traveled in kilometers, Nº R ≡ number of routes, Nº RT ≡ number of collected containers, NllMV ≡ vehicles fill level, DS ≡ met demand, CT ≡ total cost (depending on the value of k in table 2)

- Table 1 show that the proposed policy is better suited to the different scenarios with $k = 0.5$, because gets the best percentages of met demand with lower costs.

- It is also noteworthy that the proposed policy is better suited to larger values of σ with the $RL = 1$, because gets percentages of met demand very high, although with higher costs.
- The proposed policy is in general more expensive, although in small percentages, than the other policy, but also gets a significantly higher percentage of met demand, so more garbage is collected.
- Even with the above, the distance traveled in proposed policy routes is not significantly greater than the other. So in environmental and economic considerations would be considered more balanced.
- Under the proposed policy gets better resource use and more optimized, because collected greater number of containers with less number of routes, so that the average fill level of the vehicle is higher. This may lead to a reduction in the fleet of vehicles needed.

Tabla 2 Results from experiments on the model to compare policy

σ	*RL*	*Km*	*Nº R*	*Nº RT*	*NllMV (%)*	*DS (%)*	*CT k=0.5*	*CT k=1*	*CT k=3*
0.5	0.94	19565	552	3582	91.53%	95.05%	63174	67651	85561
1	0.94	22762	656	4318	93.10%	91.97%	73685	79082	100672
0.5	0.96	20054	583	3694	89.94%	98.98%	64778	69396	87866
1	0.96	22351	651	4226	92.37%	90.62%	72336	77619	98749
0.5	0.98	18907	541	3424	89.95%	92.17%	61000	65280	82400
1	0.98	21971	660	4146	89.68%	89.22%	71095	76277	97007
0.5	1	18702	605	3397	80.08%	91.03%	60352	64598	81583
1	1	21975	720	4121	81.68%	87.96%	71076	76227	96832

5. Conclusions

We have built a route optimization procedure to recyclable waste collection using real-time information about the containers fill level.

In order to do it we propose a collection policy based on three stages: calculation, estimation and optimization. In the first stage, we calculated the routes needed to minimize the travel length after knowing the containers to collect in a day t with the volumetric sensor data and the fixed RL. In the next stage, we estimated the containers to be collected over the next 6 days ($t+1, \ldots, t+6$). We use its current fill level and its daily fill rate. The necessary routes are also calculated for those 6 days. In the last stage and seeking to reduce the number of kilometers traveled in the 90 days, we look for the possible containers, from those 6 days, which can be collected on day t. And we recalculated the necessary routes with the new containers. Thus the proposed procedure using real data optimizes routes on two levels, daily and within a larger planning horizon.

The proposed policy has been compared to policies currently used in the literature which only takes into account the daily optimization.

According to the conclusions drawn, the policy with which we compare could be optimal from the point of view of the concessionary company, because it has lower costs, in general, with met demand that could be considered within the acceptable levels.

And the policy proposed in this paper could be adopted by the municipalities, because while having higher costs it has higher levels of met demand and uses resources more optimally, using fewer vehicles.

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