Optimization of a Recyclabe Waste Collection System - The Valorsul Case Study

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Abstract This paper studies alternative scenarios for a recyclable waste collection system in order to increase efficiency in their operations. Three alternative scenarios are proposed where two different locations for one or two additional depots are studied. The problem is modeled as a multi-depot vehicle routing problem and a solution approach is developed. The three scenarios are compared with the current solution regarding distance travelled, working hours, amount of recyclable waste collected and vehicle usage. Significant gains are obtained when depots are added to the current logistics system.

1 Introduction

Nowadays, organizations are faced with an extremely competitive environment, which triggers off a search process for efficiency and effectiveness in its processes and operations. Academic research has a role to play in this context as it can be very helpful to reach this purpose allowing scientifically supported analysis of possible alternative scenarios to the current operation.

This paper aims to study the current operation of a recyclable waste collection company – Valorsul, and proposes and analyzes alternative scenarios to improve Valorsul's efficiency. The recent decrease in waste production, the increasing awareness with environmental issues and the need of compliance with the recycling targets imposed by the European Union had motived this kind of studies in companies responsible for the collection of recyclable waste. Such factors enhance the need of making thoughtful decisions that reduce costs and diminish the resources required for the operation. Given that the collection cost, specially the fuel cost, is of great importance in the cost structure of the company, any reduction in the distance travelled in the collection activity will have an immediate impact in the total cost and will improve the company's performance.

Valorsul is responsible for the selective collection in 14 municipalities, covering about 3000 km^2. All vehicles start and end the collection routes at one depot. Long routes are performed given its vast operating service area. There is then a potential space for optimization, where vehicle routes could be optimized through the reduction of the allocated service area. For that, more depots have to be added to the system. These scenarios will be explored in this paper.

The paper is structured as follows: in section 2, the Multi-Depot Vehicle Routing Problem (MDVRP) and its application to waste collection systems are explored. In section 3, the main problem characteristics are presented. In section 4 the solution approach is characterised. In section 5 a set of alternative scenarios is solved and the results discussed. Lastly, in section 6 the conclusions are presented.

2 Literature Review

2.1 MDVRP

MDVRP is a generalization of the vehicle routing problem (VRP) in which, beyond the definition of vehicle routes, it is necessary to determine from which depot customers are to be visited. Over the years, several models for MDVRP have been developed. These models allow finding exact and approximate solutions. However, since it is a NP-hard problem, the existing models in the literature are mostly heuristic but also some exact models have been proposed. On the heuristic procedures, Tillman and Cain (1972) developed an heuristic based on the savings method, modifying the distance formula to enable the existence of multiple depots. Some years later, Golden et al. (1977) proposed two heuristic algorithms which allow solving larger problems. In the first algorithm customers are assigned to depots while the routes are defined. In the second algorithm, the customers are first assigned to depots and then, in a second phase, the routes are defined through a heuristic algorithm for the VRP. Other heuristics have been proposed to solve MDVRP, including those proposed by Renaud et al. (1996) and Crevier et al. (2007). On the exact models, Laporte et al. (1984) and Laporte et al. (1988) developed exact branch and bound algorithms to solve symmetric and asymmetric versions of the MDVRP, but which are only applicable to small instances. More recently, in 2009, Baldacci and Mingozzi (2009) developed an exact method, which is able to solve, among others, the MDVRP.

2.2 Applications to Waste Collection Systems

Regarding waste collection systems, one of the first works was presented by Beltrami and Bodin (1974) where it was developed a heuristic algorithm for a Periodic Vehicle Routing Problem (PVRP) and applied to a waste collection system in New York. Later on Tung and Pinnoi (2000) present a heuristic for a problem of establishing routes and scheduling a fleet of vehicles with multiple time windows. Angelelli and Speranza (2002) developed a model for solving the PVRP, which is applicable to different waste collection systems. Using a tabu search algorithm, the model was applied to an undifferentiated waste collection system in Italy and to a system for collecting paper and organic waste in Belgium. Teixeira et al. (2004) present a heuristic approach divided in three phases to solve a PVRP. These three phases are solved by the development of heuristics. This approach was applied to a real case in Portugal. Recently, Ramos et al. (2014) studied the problem of planning the collection of recyclable waste taking into account economic and environmental factors. In this work, a Multi-Product, Multi-Depot Vehicle Routing Problem (MP-MDVRP) is tackled, where the service areas and vehicle routes have to be defined in a logistics network with multiple depots and multiple products to be collected. A Mixed-Integer Linear Programming (MILP) model is proposed for the MP-MDVRP and a decomposition approach is developed to solve it and applied to a recyclable waste collection system operating in Portugal. The results were the reduction of the distance traveled and the reduction of CO_2 emissions, thus ensuring an improvement both economically and environmentally.

3 Case-study

Valorsul is responsible for the collection of 7807 containers (2542 paper containers, 2378 plastic/metal containers and 2887 glass containers) located at 14 municipalities of Portugal. Valorsul owns a vehicle fleet of 14 vehicles that is based only at one depot, located in *Centro de Tratamento de Resíduos do Oeste* (CTRO), in the municipality of Cadaval. Besides this facility, Valorsul owns six transfer stations located at Nazaré, Óbidos, Peniche, Rio Maior, Alenquer and Sobral de Monte Agraço. Currently, there are 82 routes established, 26 for paper collection, 26 for plastic/metal collection and 30 for glass collection. Considering the collection routes performed between January and September 2013, Table 1 shows the average collection frequency, number of containers collected by route, distance traveled per route and amount of material collected per route for each type of recyclable material. Paper and plastic/metal have similar indicators. The average distance travelled per route is about 136 km and each container is collected, on average, every 8 or 9 days. Glass has the highest time interval between consecutive collections (20,5 days) and longer routes (151 km).

Table 1 – Current indicators for Valorsul routes performed between January and September 2013 (average values)

Recyclable material	No. routes performed	Collection frequency (days)	No. containers collected per route	Distance travelled per route (km)	Amount collected per route (ton)
Paper	816	9,3	82	135,3	2.8
Plastic/Metal	740	8,3	81	137,9	2.1
Glass	342	20,5	83	151,2	9.8

After the analysis of the operation, several constraints that hinder the operation were identified. The size of the service area and also its asymmetry to CTRO location appear as the most important. The time limit of a shift, the location of containers in urban areas and its difficult acess, and uncertainty about the filling levels are also factors than must be taken into account when proposing and analyzing possible alternatives. The alternatives identified as the most suitable to mitigate the currently existing constraints were to add more depots to the system, using the existent transfer stations as depots, i.e., where vehicles would be based to start and end the collection routes. Given the actual asymmetry of the CTRO location, the new potential depots should be located at the north of the actual service area. Therefore, three alternative scenarios were defined. Scenarios I and II study a solution with two depots: CTRO and Óbidos and CTRO and Nazaré. Scenario III considers a solution with three depots, located at CTRO, Nazaré and Óbidos (see Figure 1). It is expected that these scenarios will reduce the route durations and distance travelled. Each scenario will be evaluated and compared with the current solution in order to assess the best alternative to be implemented.

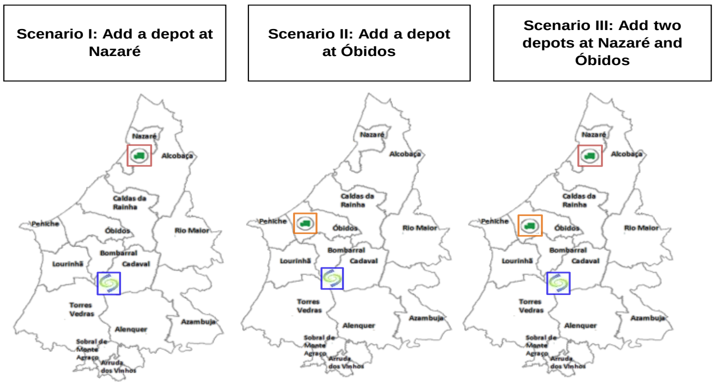

Figure 1 – Proposed scenarios

4 Solution Approach

Given the size of the problem, it is intractable to solve it with an exact algorithm. Therefore, a decomposition approach has been developed, where some constraints of the original problem are firstly removed and the relaxed problem is solved. The solution approach is illustrated at Figure 2. At first, the route duration constraints and the definition of only closed routes are removed. Then, the solution obtained is analyzed and the feasible routes are separated from the unfeasible ones. A feasible route is a closed route with duration less or equal to the maximum time allowed for a route. An unfeasible route is a route (closed or open) with duration superior to the time limit. For the collection sites that belong to the unfeasible routes, a second step is performed where a problem with route constraints is solved. Again, the solution is analyzed and the feasible routes are separated from the unfeasible ones. In this case, the feasible routes are the closed ones and the unfeasible are the open inter-depot routes. For the latter, a step 3 is performed where the original problem is solved, that is, a MDVRP is solve, but only for the sites that belong to the unfeasible routes.

For step 1, a MDVRP with Mixed Closed and Open Inter-Depot Routes (MDVRP-MCO) is solved through the model proposed by Ramos et al. (2013), where the constraints regarding route duration were removed. For step 2, the same model is used, but with duration constraints. For step 3, a MDVRP is solved through the model proposed by Ramos et al. (2014). The mathematical formulations used in all models were based on the Two Commodity Flow Formulation proposed by Baldacci et al. (2004). This solution approach is applied to each recyclable material separately (paper, plastic/metal and glass).

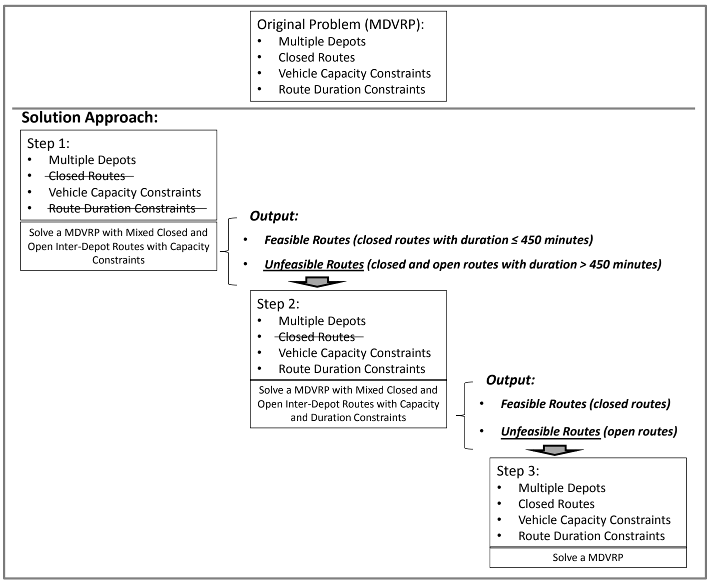

Figure 2 – Solution approach developed

The solution approach goal is to define vehicle routes that minimize the monthly distance travelled in the collection activity, for each recyclable material. The distance travelled also includes the waste transportation from the depots to the sorting station. The problem can be summarized as:

Given:

- Location of depots and sorting stations;
- Locations of collection sites;
- Distance between the different pairs of entities;
- Amount of material to collect at each collection site;
- Collection frequency for each collection site;
- Vehicle capacity to collect each material and vehicle speed;
- Time required to collect a container and to unload a vehicle;

Determine:

- The collection routes;
- The number of collection sites covered by each route;
- The amount of material collected on each route;
- The duration of each route;

So as to minimize the total monthly distance and ensure total waste collection.

5 Results

This section covers the application of the models to the case study described in section 3. The models were implemented with GAMS (General Algebraic Modelling System) language, and solved through CPLEX (23.5.1 version), in an Intel Core i3-2310M CPU, 2.10 GHz. To apply the solution approach, two simplifications were made. The first one was to group the individual containers into clusters so as to reduce the problem size. For that, we consider that all containers located at one locality belong to the same cluster and are collected at the same route. Thus, instead of dealing with 7807 individual containers, we group them into 138 clusters. Each cluster represents a collection site with a given number of glass containers, paper containers and plastic/metal containers. The second simplification regards the collection frequency of each collection site. Each site has a different collection frequency. Based on the real operation we set *a priori* four different collection frequencies (one, two, three and four times a month) and group the collection sites into these frequencies, given the historical data analyzed. The models were run for each group individually. Table 2 shows the number of collection sites that was considered in each step of the solution approach for Scenario I. Figure 3 shows the service areas obtained for each scenario for material paper.

Table 2 – Number of collection sites considered along the solution approach for Scenario I

Recyclable Mat.	Paper		Plastic/Metal		Glass	
Collection Freq.	4x/month	2x/month	4x/month	2x/month	2x/month	1x/month
Step 1: Input	83	56	112	26	5	135
Step 1: Output - No. collection sites belong to feasible routes - No. collection sites belong to unfeasible routes	14 69	0 56	14 98	0 26	5 0	59 76
Step 2: Input	69	56	98	26	-	76
Step 2: Output - No. collection sites belong to feasible routes - No. collection sites belong to unfeasible routes	60 9	56 0	79 19	26 0	0 0	76 0
Step 3: Input	9	-	19	-	-	-

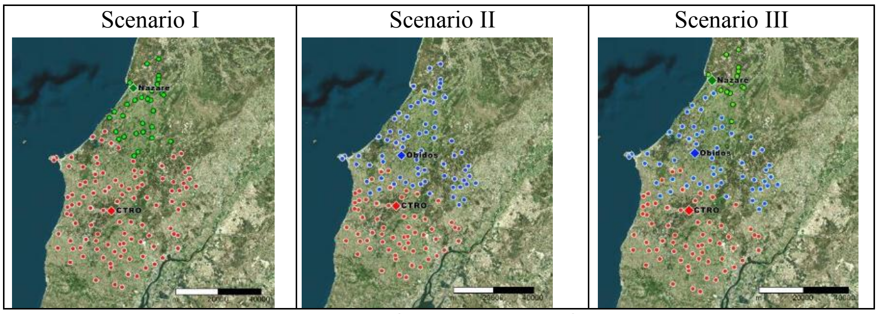

Figure 3 – Service areas for material paper for each scenario

In order to compare the scenarios three key performance indicators (KPI) were considered: vehicle usage rate, amount of material collected per kilometer and amount of material collected per minute.

Figure 4 shows the comparison between the three scenarios and the current solution for the amount of material collected per kilometer and per minute indicators. Regarding the first indicator, scenario I reveals an improvement only for material paper. On the other hand, scenarios II and III lead to improvements for paper and glass and maintains the values for palstic/metal when compared to the current scenario. For the second indicator, it suffers an improvement in all alternative scenarios and for all materials.

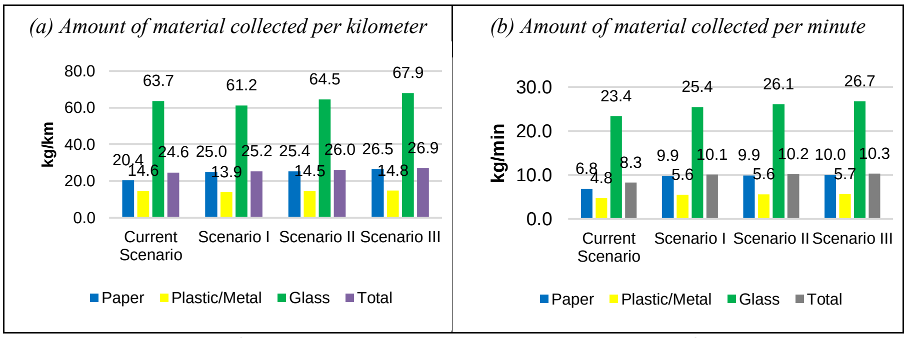

Figure 4 – Amount of material collected per kilometer and per minute for each scenario

In order to assess which is the best alternative scenario, the percentage between the scenarios and the current solution for the KPIs was computed (see Table 3). Material paper suffers the greatest improvement in all KPIs for all scenarios. Scenario I lead to a total improvement of 2.4% regarding kg/km and 22% regarding kg/min. Scenario III increases those results to 9.3% and 24%, respectively. Therefore, Scenario III, where two more depots are added to the current network, is the best scenario amongst the three. However, adding two more depots could be more difficult to implement than adding just one depot. If Valorsul concludes that the complexity inherent to the implementation of two more depots in relation one just depot, not worth the gains, then Scenario II should be implemented (adding a depot at Óbidos).

Table 3 – Comparison of the percentage improvement between alternative scenarios and current scenario

	Scenario I				Scenario II				Scenario III			
KPIs	P.	Pl.	G.	Total	P.	Pl.	G.	Total	P.	Pl.	G.	Total
Vehicle usage	28.5 %	3.0 %	-1.3 %	n.a.	21.4 %	3.0 %	7.8 %	n.a.	21.4 %	0.0 %	1.3 %	n.a.
kg/km	22.6 %	- 4.8 %	-3.9 %	2.4%	24.5 %	-0.7 %	1.3 %	5.3%	29.9 %	1.4 %	6.6 %	9.3%
kg/min	45.6 %	16. 7%	8.6 %	22.0%	45.6 %	16.7 %	11. 5%	23.0%	47.1 %	18. 8%	14. 1%	24.0%

Note: P. (Paper); Pl. (Plastic/metal); G. (Glass)

6 Conclusions

In this paper a new way of managing the recyclable waste collection system of Valorsul is analysed. The problem was modelled as a MDVRP and a decomposition technique to solve it was developed. The results indicate that the implementation of new depots will improve the current collection operation.

As future work the studied problem should be analysed by extending the used model to a location-routing problem where aspects such as: lengthening the shift duration, using open inter-depot routes in the operation, using a more accurate method to estimate the containers filling level and allowing different collection frequencies should be studied.

7 References

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