Maximizing the Capacity Utilization of Selective Waste Collection Vehicles

Dr. Ádám Titrik, Prof. Dr. habil István Lakatos

Széchenyi István University, Egyetem tér 1, 9026 Győr, Hungary, e-mail: titrika@ga.sze.hu; lakatos@sze.hu

Abstract: Selective Waste Collection is an essential part of recycling raw materials, in order to protect our environment. The waste collection is carried out by using a seriously polluting vehicle, due to the fact that most of the gathering vehicles are using fossil energy sources, like gasoline. High volume of carcinogenic elements are contained in the emitted exhaust gases. The current waste collection methods are just focusing on the load of the selective waste collective vehicle during a collection route. The goal of this research is to find the best solution to use the full storage capacity of the selective waste collecting vehicle with the lowest volume of residual air due to the effectively compressed waste. The closed and uncompressed PET bottles require the largest volume in the waste collecting vehicle. It is essential to minimize the air in the PET bottles to decrease the volume. Different methods have been examined to increase the density of the selectively collected waste. Statistical data have been used to determine the collecting parameters – nowadays, a 15 t waste collecting vehicle, with a 20 m3 load capacity is only gathering 1-1.5 t PET due to the ineffective use of its load compartment. The application of the method herein, enhances the efficiency of the waste collecting vehicle by gathering 4-10 times more waste than currently used methods.

Keywords: selective waste; waste gathering; capacity utilization

1 Introduction

Currently, collecting and reusing materials is common process, especially in case of metals and plastic. In many countries the selective Waste Collecting Vehicles (garbage disposal truck) are using fossil-based energy sources. The engine of these vehicles emit various side-product deriving from the combustion. The exhaust components can cause cancer, birth defects, or other reproductive damages. In order to minimize this kind of pollution, it is important to increase effective payload of the selective waste collecting vehicles. One possible way is to maximize density of the collected waste. The PET bottle is containing too much residual air after the currently applied pre-compression procedure (applied by the user and the vehicle), highly reducing the effectiveness of the waste gathering.

Nowadays the minimization of the air in the waste are reached in the factory/DEPO with different handling technologies. The novelty of this process is the waste density is maximization in the vehicle during its route and not in the factory/ DEPO. Less air in the waste increases the waste density, enhancing the efficiency of collecting by decreasing the frequency of container unloading.

The main topics of the research are:

- Inspecting collecting habits, parameters
- Evaluating statistical data
- Defining and choosing the possible solution
- Testing the possible solution
- Route planning actions with the new method

2 Inspecting the PET Bottle Handling

Investigation of PET collecting habit was carried out on a sample of 150 people, where the results are showed on the following figures. Figure 1 shows that more than 60% of people who collects selectively the PET bottles (polyethylene terephthalate – used for mineral water and soft drinks) put back the cup to the bottle. Some of the Waste Collection Vehicles cannot compress the PET bottles to the minimum possible volume because of the residual air in the closed PET bottles. These PET bottles are working as a spring after the compressing force is reduced in the vehicle, the compressed bottles are expanding back [1].

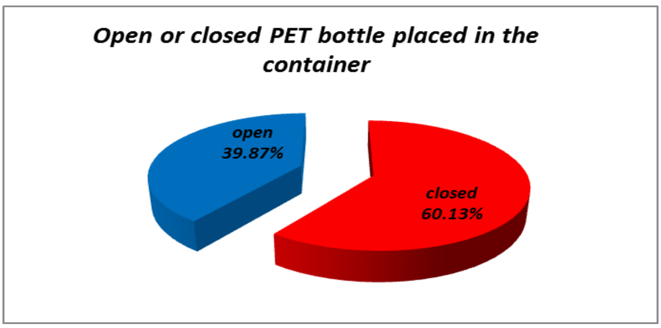

Figure 1
PET bottle handling habits

Volume reduction is applied on the PET bottle with hands predominantly, while 7.33% of the people are not using any compression at all. The distribution of PET bottle volume reduction methods is visualized on Figure 2.

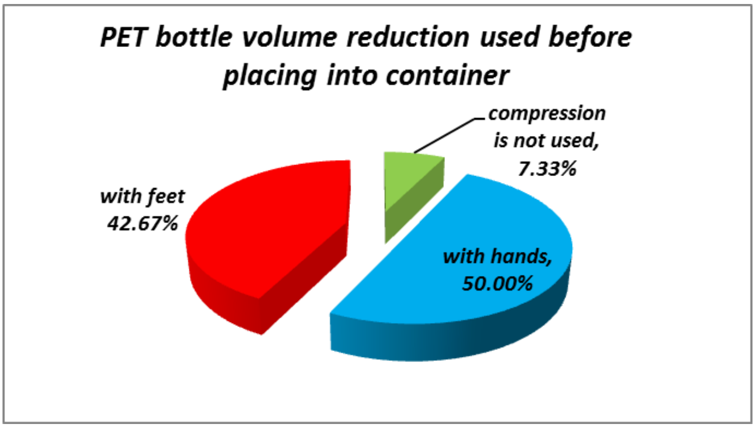

Figure 2
Different volume reduction applied on PET bottle

In Széchenyi István University tests have been made to measure the volume reduction on PET bottle with different type of compression method applied.

Table 1
Achievable volume reduction with different compression method

Bottle volume (PET)	Bottle weight [g]	Original volume [cm^3]	Compression method	Reduced volume [cm^3]	Volume reduction [%]
0.5L	18	520	with hands	470	10
			with feet	390	25
			hand comp.*	440	16
1.0L	28	1030	with hands	540	48
			with feet	276	73
			hand comp.	595	42
1.5L	30	1555	with hands	920	40
			with feet	470	69
			hand comp.	775	51
2.0L	37	2045	with hands	930	54
			with feet	444	78
			hand comp.	930	54
2.5L	45	2540	with hands	1230	52
			with feet	590	77
			hand comp.	960	62

*manual PET bottle compressor

The results clearly show that applying hand operated volume reducer (compressor) does not minimize the PET bottle volume. Nearly the same reduction ratio can be achieved with only hands. By all means, the best volume reduction can be achieved with feet compression (stomping).

Uncompressed and closed PET bottles are the worst for waste collecting vehicles, due to the spring effect of the residual air inside the bottles.

2.1 Collecting Parameters Based on Statistical Data

The statistical data needs to be evaluated for this research, which leads us to define optimized solution for elective waste collection. The examined ~3500 waste container with the capacity of 2.5 m^3, (the data provided by waste handling company, no further parameters can be published) give us the following important data:

- Average filling was 70.4% of the available capacity
- Average selective PET weight was 28.9 kg
- Average density was 11.56 kg/m^3

The fill level and weight of the PET waste is showed in Figure 3, in case of 2.5 m^3 selective waste container (50 pieces, randomly chosen sample from 3500 containers, where the filled level is 100%). The diagram shows that the fulfilled container average weight is ~45 kg. The container max. payload is 900 kg, so the waste density can be increased up to 20 times.

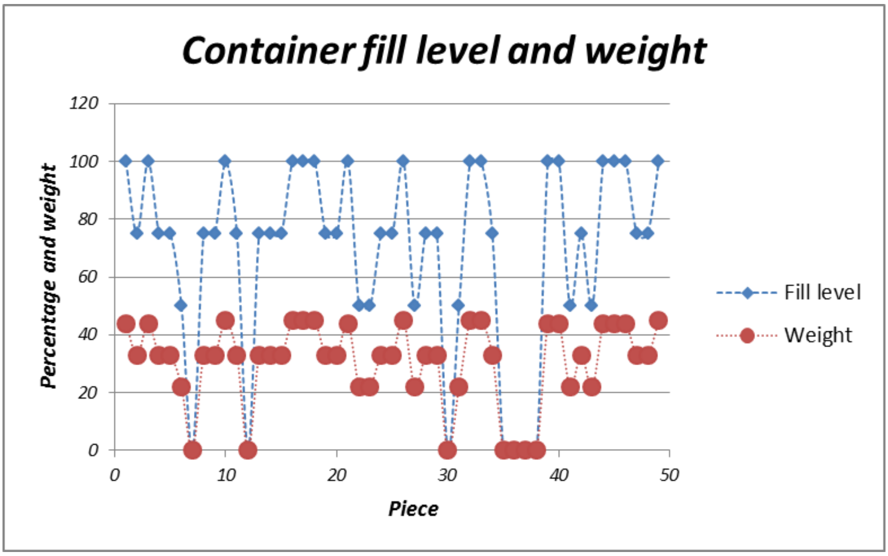

Figure 3
Container fill level and weight relation (PET)

The waste collecting vehicle can gather 35-45 pieces of 2.5 m^3 selective waste container, depending on the collected PET bottle waste density. According to this data, the selective waste collecting vehicle of 20 m^3 capacity can only gather 1000-1300 kg PET waste.

There are two ways for capacity utilization:

- In the container
- In the Waste collection Vehicle

The best solution would be to maximize the waste density at the content of the container. Perforations and volume reduction on the PET bottle can be applied, when it is placed into the container. The applying of shredder is also viable option. Both solutions need external energy to reduce the volume of the PET bottle, however the first solution can use human force through container attached mechanism. It also has to be considered that the usage of human manual labor is trending to minimize. The sufficient energy to operate the container volume reducer is enormous, therefore using a shredder on the vehicle could be a better option.

3 Applying Shredder on PET Bottles

The test was carried out in the Széchenyi István University with the available plastic shredder machine made by F.lli Virginio Srl (Fig. 4). The shredder is not directly suitable for bottles, so the PET bottles have been divided into 3 or 4 pieces for the test.

Figure 4
Applied shredder

Figure 5
Consistency of the shredded PET bottles

Figure 6
Shredded PET volume reduction test

Test parameters and results

- 3 pieces of 1.5l PET bottles
- Total usage of the shredder was 8 minutes

The applied machine is not optimal for shredding PET bottles. The best shredding performance was not achieved by the used 3 bottles. The placed PET bottles could not be fully shredded because the intake pulling force was decreasing with the size reduction of the bottle pieces. The third of the placed 3 PET bottles stayed in the shredding machine, but the 55 g grinded PET bottle was enough to calculate the result (Fig. 5). The average size of the shredded PET bottles was ~5x5 mm.

The result of the shredding is small plastic pieces, where the size is depending on the parameters of the shredding machine. A measuring bottle was used for analyzing the result, which was filled with shredded plastic pieces to 200 ml without any compression.

Test parameters:

- Waste density for 200 ml shredded PET bottle weights 35.5 g
- Shredded PET waste density is 177.5 kg/m^3
- The shredded PET waste density is 177.5 kg/m^3 compared to the original 11.6 kg/m^3
- Further tests have been made for compressing the shredded waste to 85% (Fig. 6)

Compressing parameters:

- Uncompressed volume: 200 ml
- Compressed volume: 170 ml
- Diameter: Ø72 mm
- Surface: 72*3.14/4=56.52 mm^2
- Applied force: 23 N→ 0.41 N/mm^2

Results in waste vehicle:

- PET waste density 11.6 kg/m^3 →compressed 46.4 kg/m^3 (applying 1:4 volume reduction in waste vehicle)
- PET waste density 177.5 kg/m^3 →compressed 195 kg/m^3 (applying 10% volume reduction in waste vehicle)

According to the results a waste collecting vehicle with 20 m^3 capacity equipped with shredder can gather ~4-10 times more load.

4 Integrated Shredder to Selective Waste Collecting Vehicle

The shredder should be placed on the top of the loading slot of waste collecting vehicle (Fig. 7, red line).

Figure 7
Possible way to attach the shredder to the Waste Vehicle

For the best performance the shredder parameters should be designed to minimize the shredding time and energy consumption. From environmental point of view, the external electrical energy for shredding is better, than using the energy from the internal combustion engine of the vehicle.

4.1. Gathering Plan and Properties of the Shredding

In case of using a shredding unit the route plan will change. In the following section alternative solutions are presented:

Original route plan (Fig. 8):

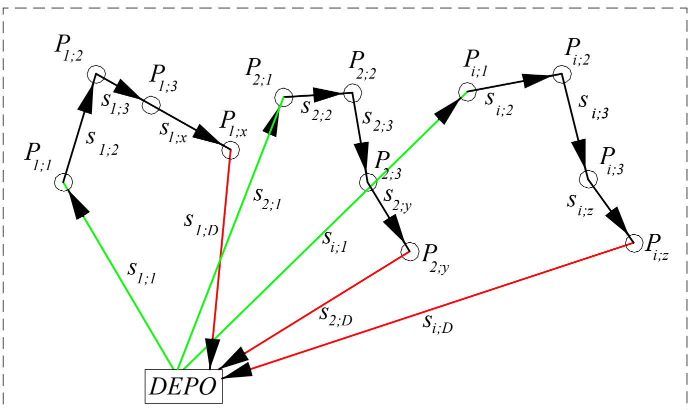

Figure 8
Original gathering plan

Where:

$P_{1;2}$ – P-PET container, $_1$- first route, $_2$- second container

$s_{1;2}$ – s-distance, $_{1;2}$ from 1st to 2nd containers

$$\Sigma S_{original}=s_{1;1}+s_{1;\,1+i}+s_{1;D}+\ldots+s_{i;1}+s_{i;i+1}+s_{i;D}$$

In the original route plan the vehicle collects the container which are alongside the collecting route. The vehicle goes back to the DEPO to empty the waste, when it gets fully filled. After the procedure the vehicle gets back to the next container in the gathering plan. The waste from the container can be compressed up to 25%.

Route plan with shredder equipped vehicle:

In this case the waste vehicle is equipped with shredder, and it can gather more container during its route (Fig. 9).

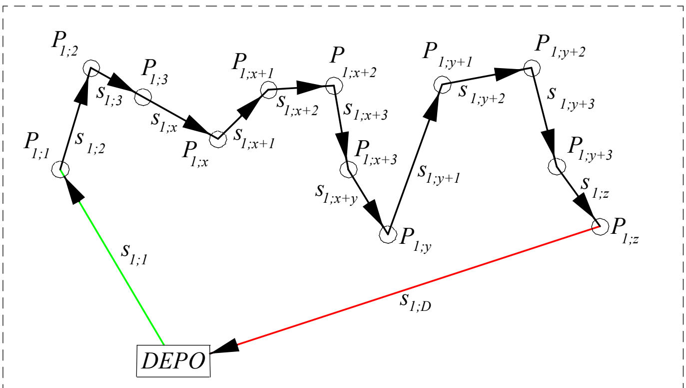

Figure 9
Gathering route with vehicle equipped with shredder

$$\Sigma S_{shredder}=s_{1;1}+s_{1;\,1+i}+s_{1;D}$$
$$\Sigma S_{shredder}<<\Sigma S_{original}$$

The distance of the covered route plan is decreased by using the proposed vehicle shedder method, as the vehicle is able to collect more waste without getting back to the DEPO to empty the collected waste. The traffic load, air and noise pollution are also decreased due to this approach.

Using double sized container at same place for original route plan (Fig. 10):

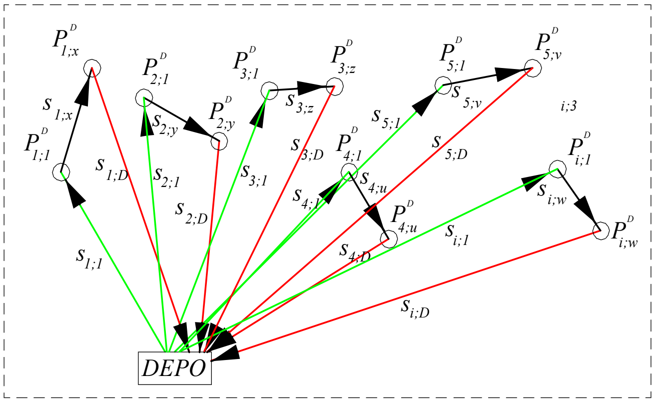

Figure 10
Original gathering plan, double container used

Where:

$P_{D1,2}$ – P-PET container, $_D$- double sized container; $_1$- first route, $_2$- second container

$$\Sigma S_{original,DOUBLE}=s_{1;1}+s_{1;\,1+i}+s_{1;D}+\ldots+s_{i;1}+s_{i;i+1}+s_{i;D}$$

$$\Sigma S_{original,\,DOUBLE}=2*\Sigma S_{original}$$

In this scenario double sized PET container was used in all cases. On the one hand the gathering period duration is decreased by 50%, but on the other hand the waste collecting vehicle is going to be full two times faster. This also doubles the way back to DEPO and to the upcoming container as well.

Gathering route with shredder equipped vehicle, double sized container used:

The waste collecting vehicle can collect 4-10 times more container by using the shredder, although the energy savings can be maximized when double container is used (Fig. 11).

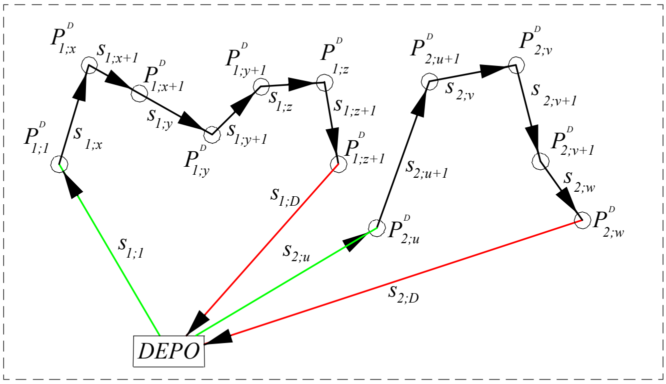

Figure 11
Gathering route with shredder equipped vehicle, double sized container used
$\Sigma S_{shredder,\ DOUBLE}=2*\Sigma S_{shredder}$

In this case the gathering period is decreased by 50%, while the route is getting longer because of the use of shredder (more gathered container). The way back to DEPO and back to upcoming container will be reduced which is both important for environment protection and traffic load reduction.

Conclusions

This work presents a viable solution to maximize the capacity utilization for Waste Collection Vehicles. Reasonable and satisfying result was achieved by the test, where the waste collecting vehicle was able to empty 4-10 times more containers, than in the original gathering solution. The waste density was increased up to 10 times, compared to current traditional methods. In our future work, calculations and optimizations aimed at developing the gathering methods and maximization of energy savings will be researched.

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