Optimization of Metal Can (bottle) Shapes for Maximizing Waste Container Capacity

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Abstract: Effective waste management is key to creating more sustainable cities. This study explores a straightforward but impactful way to enhance waste collection efficiency – by optimizing the compaction of metal cans. Various methods of compressing metal containers, including hand and foot compression (middle, full diameter, and full height), were tested to see how much they could reduce the volume of these cans. Our simulations showed that full-height and full-diameter compression were the most effective, significantly increasing container capacity by minimizing empty space. This approach is not only practical but scalable, offering waste management operators a clear pathway to improving resource efficiency. Beyond the immediate benefits of reduced collection frequency and lower fuel consumption, this method contributes to broader sustainability goals by minimizing the carbon footprint associated with waste management. These findings have wide-ranging implications, from urban policy-making to everyday waste disposal practices, highlighting a simple yet transformative step toward a cleaner environment.

Keywords: selective waste; waste container; capacity utilization

1 Introduction

Efficient waste collection is a complex process, that can be significantly improved through optimization. Simply placing items in a bin without considering their form can lead to inefficient use of space, especially for recyclable materials like metal.

Metal is valuable and recyclable, but when disposed of without being compacted, it occupies far more space than necessary, reducing container capacity and increasing collection frequency. Enhancing waste collection is not just about increasing the number of trucks or the size of bins – it is about better using existing space [1].

In most industries, efficient packing is prioritized, whether in shipping boxes or arranging products on shelves [2] [3]. However, this focus is often absent in waste collection logistics. When items such as cans or plastic bottles are discarded without being compacted, containers fill up with air rather than waste, leading to inefficient use of space. This results in more frequent collection trips, increased fuel consumption, and higher operational costs. Numerous studies have addressed this issue, exploring solutions ranging from improved route planning for collection vehicles [4] to strategies for maximizing container utilization [5] [6].

One critical aspect of optimization involves the management of metal waste. Metal items, including aluminum cans, are among the most recyclable materials, but their large volume, when uncompressed, presents a challenge. Studies have shown that strategic compaction of metal waste can significantly increase the saturation of containers, reducing the need for additional landfill space and enhancing recycling efficiency [7] [8]. According to Eurostat, metal accounts for approximately 6% of all packaging waste in Europe, with 75% being aluminum and 25% steel [9]. Despite this, the recycling rate for metal is only 38%, although best practices could potentially increase this figure to 62% [10].

Container design plays a crucial role in optimizing waste management. Research has demonstrated that rectangular or square containers can store waste more efficiently than traditional cylindrical bins [11]. Additionally, design improvements in metal cans – such as reduced wall thickness and enhanced crushability – can further increase container capacity [12] [13]. Fully compacted metal cans have been shown to improve transport efficiency, allowing larger quantities of waste to be collected in a single trip, thereby reducing greenhouse gas emissions associated with waste transport [14].

Beyond container design, integrating smart technology into waste management systems has emerged as a promising solution. Waste containers equipped with sensors can monitor fill levels in real-time, allowing collection schedules to be dynamically adjusted. This approach ensures that collection vehicles operate at near-full capacity, minimizing unnecessary trips and reducing fuel consumption [15-17]. However, successfully implementing such technology requires community engagement and education, encouraging residents to suitably compact waste items before disposal [18] [19].

Surveys have shown that while many residents manually compress plastic bottles – either by hand or stepping on them – most metal items are discarded without any form of compression [20] (see Fig. 1). This behavior significantly reduces container efficiency, as air takes up a considerable portion of available space. Real-time monitoring systems, such as those proposed by Titrik et al. [21], offer a potential solution by accurately measuring container fill levels by weight, allowing for dynamic route adjustments and improved collection efficiency. However, the high cost of these systems has limited their widespread adoption.

Figure 1
Metal cans placed in the container

Optimizing waste collection requires a multifaceted approach combining efficient gathering methods, enhanced container design, strategic waste compaction, and integration of smart technologies. Particular attention must be given to metal waste, which holds significant recycling value but is often inefficiently collected. As research continues to explore innovative methodologies, waste management systems can evolve to become more efficient, environmentally friendly, and economically sustainable.

In this study, the effects of different compaction methods on container saturation are investigated. The current paper's structure is as follows: Section 2 deals with materials and methods, Section 3 summarizes the results, Section 4 contains discussion, and at the end, the derived conclusions are collected.

2 Materials and Methods

The worst case is to place the can in its original form. Different compression methods have to be tested (see Fig. 2):

- Hand compaction: The compression is done in the middle part of the metal can. The compression occurs at the diameter and flattens the container, while the rest retains its original shape. This type of compaction gives the user "peace of mind" that something is done to protect the environment.
- Foot compaction (diameter, middle): the metal container is compressed in the diameter. During compression, the can takes on a flat shape in the middle, but the ends stay "original".

- Foot compaction (diameter full): the metal can is loaded to the full diameter on the full height. During compression, the can takes on a flat shape on the entire surface.
- Foot compaction (height): the metal can is properly stepped on and compressed over its full height. During compression, the can takes on a flat shape.

By hand

By foot, middle (diameter)

By foot (diameter)

By foot (height)

Figure 2

Different compression methods applied to a 0.33 ℓ metal can

The next phase of the test is modeling the cans once the compression processes have been completed. Accurate dimensions can be obtained through digitization; however, compression cannot be achieved twice with the same result. Sketches were used to perform reverse engineering on top of the photograph (Figure 3). A simplified model was created to reduce the computation, and the bottom of the can was stripped of its radius and design components.

The data on the different compressed metal cans are in Table 1.

The tested metal cans were the following:

- 0.33 ℓ
- 0.5 ℓ

Four different simulations were made:

- No compression applied: the metal can is in its original condition. The CAD model's shape and volume are the same as the original can.
- Hand compressed: the metal can is loaded in the middle of its height (diameter). The cap and bottom of the can stay original.
- Foot compressed in the middle: load is used in the middle of the metal can in diameter. The metal can is flattened in the middle.

- Foot compressed in the height: load is used on the height of the metal can. The metal can is getting flattened, so its height is reduced.
- Foot compressed by diameter: load is used on the can diameter. The metal can is getting entirely flattened.

Fig. 4 and Table 2 summarize the different conditions of metal cans of different volumes to better visualize the data. The data were measured with ~10 repetition tests, and here are presented the average data.

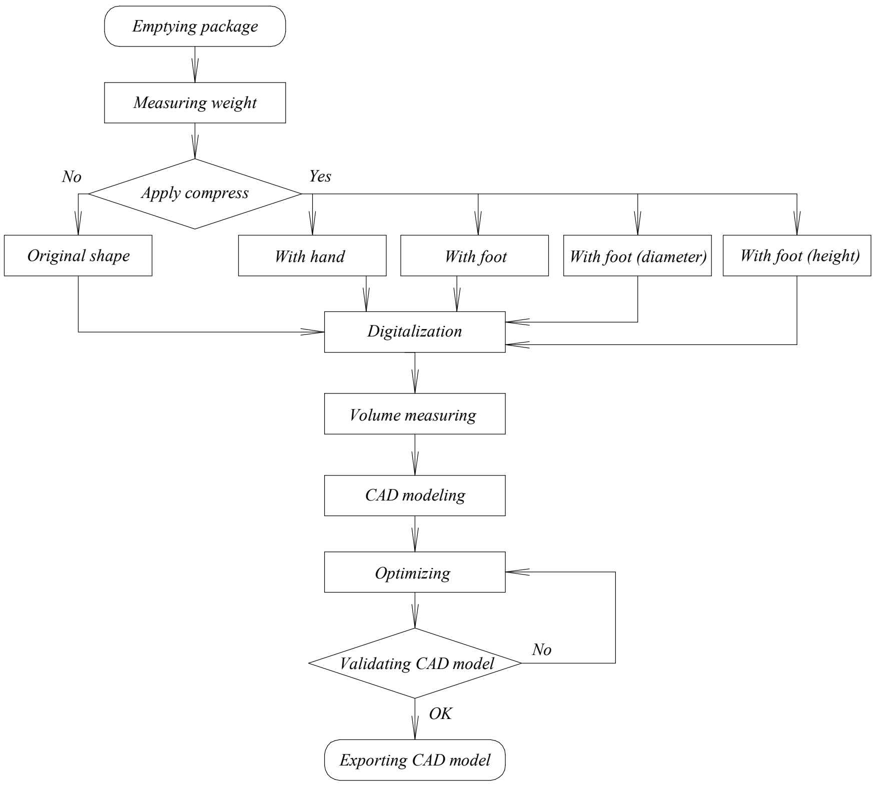


Figure 3
Reverse engineering steps of a compressed metal can

Table 1
Measuring different metal cans

	0.33 ℓ metal can				
Used comp.	-	*with hand*	*with foot*	*with foot (dia. full)*	*with foot(height)*
					
Weight	*12 g*				
Volume	*360 cm³*	*163 cm³*	*144 cm³*	*160 cm³*	*81 cm³*
Volume reduction	-	*–55%*	*–60%*	*–56%*	*–77%*
Average density	*0.0333 g/cm³*	*0.07362 g/cm³*	*0.08333 g/cm³*	*0.075 g/cm³*	*0.14814 g/cm³*
	0.5 ℓ metal can				
Used comp.	-	*with hand*	*with foot*	*with foot (dia. full)*	*with foot(height)*
					
Weight	*15 g*				
Volume	*535cm³*	*316 cm³*	*211 cm³*	*195 cm³*	*168 cm³*
Volume reduction	-	*–41%*	*–61%*	*–63%*	*–68%*
Average density	*0.02803 g/cm³*	*0.04746 g/cm³*	*0.07109 g/cm³*	*0.07692 g/cm³*	*0.08928 g/cm³*

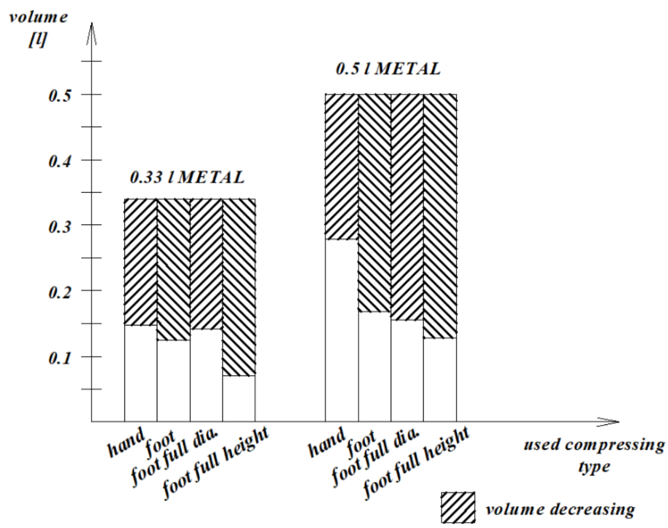


Figure 4

Volume decreasing on metal cans using different compressing types

Table 2

Tabular summary of metal can measurements

Can volume	*Can weight [g]*	*Original volume [cm^3]*	*Compression type*	*Compression volume [cm^3]*	*Volume reduction [%]*
0.33 ℓ	*12*	*360*	*hand*	*163*	*55*
			foot	*144*	*60*
			foot (dia. full)	*160*	*56*
			foot (height)	*81*	*77*
0.5 ℓ	*15*	*535*	*hand*	*316*	*41*
			foot	*211*	*61*
			foot (dia. full)	*195*	*63*
			foot (height)	*168*	*68*

Waste container saturation test

In the following simulation, differently pressed metal cans have been used. Therefore, the authors will find answers to the question of how the compression modes affect the saturation of the containers. The variation of the metal cans, the different compaction modes, and the different container saturation states will have an impact on the amount of waste that can be placed in the container.

Eq. (1) is the equation for the number of cans (n) that can be held in the container:

$$n = \left[\frac{k \cdot V_c}{V_b}\right] \quad (1)$$

where:

V_c – container volume [ℓ]

V_b – the volume of a compacted can [ℓ]

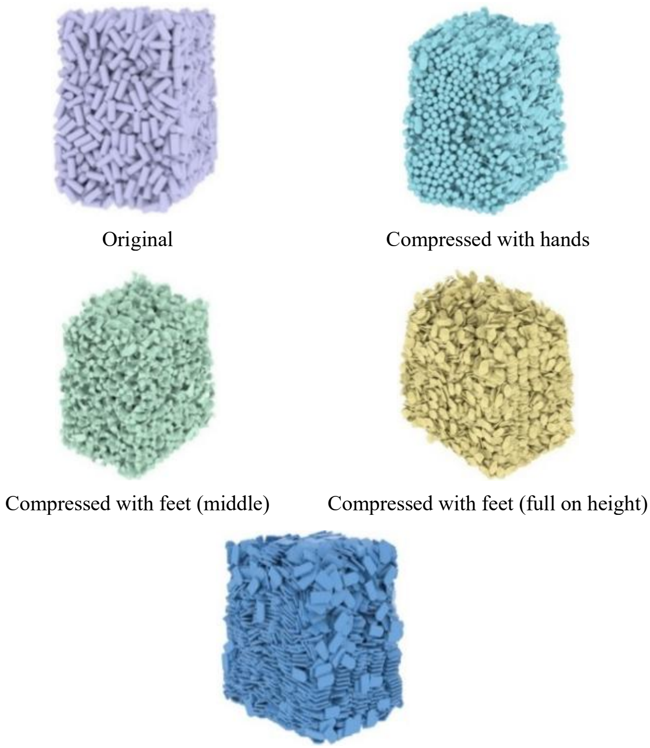
k – fill factor ($0 < k < 1$) accounting for empty space

Of course, for the best result, the percentage of empty places has to be decreased, which is from:

- Compressed can
- Between cans placed in the container

3 Results

For the optimal solution, simulations have to be run that give the result for this question. The results are illustrated in Fig. 5 and Table 3 and Fig. 6 contains the number of additional metal cans that can be stored with different compression types.



Original

Compressed with hands

Compressed with feet (middle)

Compressed with feet (full on height)

Compressed with feet (full on diameter)

Figure 5

1500 ℓ container filling test with different compressed 0.33 ℓ metal cans

Table 3
Waste container characteristics for metal cans with different compaction

Container size	***Waste type***	***Compression type***	***Can pieces***	***Bulk weight [kg]***	***Bulk density [kg/m³]***	***Utility rising [%]***
1500 ℓ	*0.33 ℓ metal can*	*original*	*~2341*	*~28.09*	*18.72*	*-*
		hand	*~2833*	*~33.99*	*22.66*	*+17.4*
		foot	*~2956*	*~35.47*	*23.64*	*+20.8*
		foot (full. dia)	*~4848*	*~58.17*	*38.78*	*+51.7*
		foot (height)	*~4093*	*~49.11*	*32.74*	*+42.8*
1500 ℓ	*0.5 ℓ metal can*	*original*	*~1552*	*~23.28*	*15.52*	*-*
		hand	*~1832*	*~27.48*	*18.32*	*+15.3*
		foot	*~1942*	*~29.13*	*19.42*	*+20.1*
		foot (full. dia)	*~4531*	*~67.96*	*45.31*	*+65.7*
		foot (height)	*~2959*	*~44.38*	*29.59*	*+47.5*

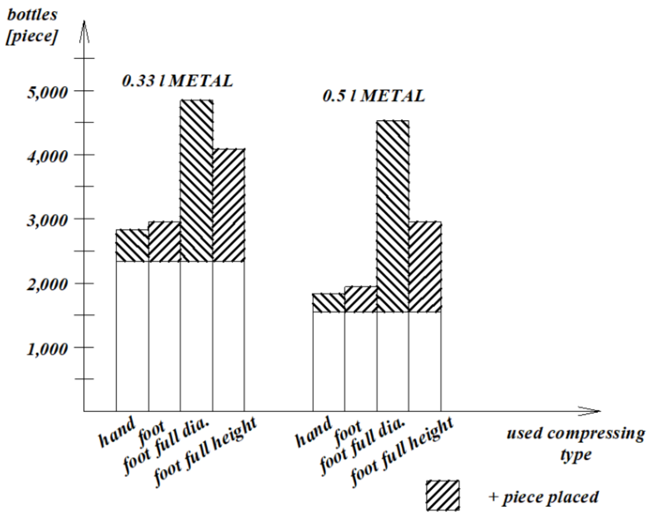


Figure 6
The number of additional metal cans that can be placed with different compression

4 Discussion

Examining the measured data (Tables 1-2) and simulation data (Table 3), it can be concluded that the metal can compression shape, has a significant impact on the saturation of the waste container:

- Using foot compression (middle of the can on the diameter) is not a good solution. Although the can's volume has been reduced, in this case, the shape of the can is undesirable for the saturation of the container.
- In a smaller package, the hand compression leads to a bad result because the can shape in one direction gets wider, which creates problems for the optimum container filling.
- For the best result, the full diameter or full height compression should be applied. In this case, the utility goes up to ~65%.

The results show that, with the appropriate compaction method, twice as much waste can be placed in the container, thus halving the number of reasonable empties. However, this would require the use of educational tools. A study has shown that visual aids in education helped about 75% of the people interviewed adopt the proper method [22]. Since only the same type of waste is placed in a container, having the correct compaction diagram on the side of the container for the type of waste is not a problem. Continuous development and people's positive attitude towards the environment provide an opportunity to use the container adequately, i.e., to perform the best compaction on metal waste.

Paragon software was used to carry out the tests. During the collection of metal waste, access to the rural sites – 177 containers – can be achieved by 3 routes, considering the capacity (Figure 7). During the test, the vehicles covered ~1,100 km. According to the emptying schedule, waste collection occurs every 2 weeks, so the vehicles cover a total of ~ 27,500 km a year. Based on the study of the data, 1/3 of the containers were 100% full, 1/3 were 75% full, and 1/3 were 50% full.

The main costs of waste collection are as follows:

$$\sum C = C_v + C_w + C_{cm} \quad [€] \tag{2}$$

where:

- C_v – the vehicle operational cost [€]
- C_w – workers cost [€]
- C_{cm} – container maintenance cost [€]

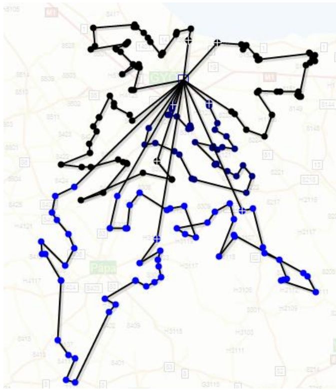


Figure 7
Route planning for 177 containers with Paragon software (different colors mean different routes)

With the correct compaction method, twice as much waste can be placed in the containers, but with a minimum of 25% extra waste placement for safety reasons. If the container was 100% filled in 2 weeks without compaction, it would take 3 weeks to fill the container using compaction. Based on the modification of the emptying plan, it can, therefore, be assumed that instead of 25 collections per year, 17 collections will be performed, during which the vehicles will cover 18700 km. It is important to emphasize that the primary aim of selective waste collection is to protect the environment. However, it should be noted that diesel vehicles of various EURO classifications are currently used, their exhaust fumes are carcinogenic, so any reduction in collection mileage, has a major impact on a healthy lifestyle.

Conclusions

This research demonstrates that optimized metal can compression methods significantly enhance waste container capacity and collection efficiencies. Our findings indicate that full-height and full-diameter compression techniques are the most effective, maximizing space utilization and reducing the frequency of waste collection trips. This improvement can help cities lower fuel consumption and carbon emissions, contributing to the broader sustainability goals.

Public education is essential for further enhancing container efficiencies. Teaching residents how to compress waste properly can be achieved through clear labelling on containers, community awareness campaigns and school educational programs. These initiatives can cultivate better waste management habits, leading to more efficient use of storage containers.

Policymakers can further optimize waste management systems by integrating smart technologies, such as sensor-equipped containers that monitor fill levels in real-time, enabling dynamic route optimization for collection vehicles. This approach transforms waste management from reactive to proactive, enhancing resource efficiency and minimizing environmental impact.

Future research will build on these findings in several areas:

- **Advanced statistical modelling of waste data [23-25]:** developing correlation analyses and pattern recognition techniques for automated waste collection simulations, incorporating proven methodologies in material property optimization and statistical analysis.
- **Experimental validation through controlled testing [26]:** designing hybrid physical-digital testing protocols to verify simulation accuracy under various waste collection conditions, adapting techniques from railway track settlement studies.
- **Model refinement through real-world feedback [27][28]:** implementing vibration-based calibration methods for digital twins inspired by optimization techniques used in rail damper systems, ensuring alignment between virtual models and actual waste collection performance.
- **Material-based analysis for durability [29]:** predictive algorithms for container and waste degradation in diverse environments.
- **Energy optimization through data-driven workflows [30]:** applying energy consumption strategies derived from railway systems to waste management operations, enhancing energy efficiency.
- Considering and integrating cognitive sustainability during the related research [31-33].
- Taking into account other research aspects in the examination of garbage collection [34] [35], as well as special mathematical algorithms for optimization [36-38].
- Applying finite element and discrete element simulations to provide more accurate results in the compaction tests [39][40].
- **Cross-disciplinary knowledge integration:** combining statistical rigor, experimental validation, and industry-specific insights to develop adaptive, self-optimizing waste management systems that minimize reliance on expert intervention while maximizing operational efficiency.

These future research directions aim to enhance the efficiencies of waste collection systems, contributing to a more sustainable urban development.

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