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# Utilizing weight data in waste management services

A quantitative analysis of weight and container  
occupancy data

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## ABSTRACT

The objective of this thesis was to provide up-to-date information on the possibilities of utilizing weight data within waste management processes. The objective was approached from three different angles: 1. Client requirements, 2. The potential to enhance waste sorting by utilizing weight data and 3. Recommended actions. The concept of Pay-As-You-Throw pricing model was explored as one strategy to enhance sorting and implementing fair pricing.

In addition to a literature review, a quantitative data analysis was conducted. Data used in the analysis was collected by Pirkanmaan Jätehuolto Oy and consisted of RFID-identified weight data and container occupancy rate data from 660-liter waste containers. Statistical analysis was conducted to determine whether significant differences existed between the mean container weights of sample properties with and without a separate plastic collection on site.

The results indicated no statistically significant differences between the mean weights of the two sample groups. Despite that, the differences in mean weights across the sample properties show that the actual mean weights deviate from the estimated mean weight of a mixed waste container. The data analysis provided an opportunity to consider the prerequisites for collecting consistent data to obtain reliable results. To guide further research, suggestions based on empirical observations were made.

**Keywords:** data analysis, waste management, weight information, pay-as-you-throw

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## 1 INTRODUCTION

This thesis was completed as part of Pirkanmaan Jätehuolto Oy's (PJHOY) "Weight Data as a Service" project. PJHOY is the leading waste management service provider in the Pirkanmaa region and one of the largest in Finland. The goal of the thesis is to provide the client, the city of Tampere, current information about options to optimize the processes of waste management by utilizing weight data. The thesis aims to produce information from three different angles which are: 1. Client requirements, 2. The possibility to enhance waste sorting with the help of weight data, and 3. Recommended actions.

Client requirements are related to the objective of City of Tampere to optimize waste collection processes of the project's pilot client, the municipal service properties. This could mean for example avoiding unnecessary emptying of waste containers or enhancing the sorting of waste at the properties. At the simplest, the City of Tampere seeks to obtain the actual weights of waste generated on the properties.

In addition to client requirements, this study aims to explore the possibility of reaching higher sorting rates through utilizing weight data. This aligns with the second angle of this thesis, which is further connected to broader international circular economy goals, to which Finland has committed to. In 2023, the European Commission (EC) gave Finland a warning, stating that Finland is about to miss the goal of reaching the 50% recycling target of municipal solid waste (MSW) by the year 2025 (European commission 2023). MSW refers to waste generated by households, shops, offices, and public institutions, which is collected by municipal authorities (Eurostat n.d.). To avoid missing the goals, actions are needed.

Taking the warning into consideration, although this paper is first and foremost intended to serve the needs of the City of Tampere, one can see the connection to larger than regional questions. Better sorting efficiency can also be seen as benefiting the City of Tampere in another way, as waste from municipal services is incinerated in the public-private-owned Tammervoima waste-to-energy (WtE)

plant, where the uniform quality of waste influx improves efficiency. According to Tammervoima (2021, 8), WtE covers 15 % of the district heating and electricity production in Tampere.

As a concrete study question, the thesis aims to answer how the City of Tampere can utilize weight data collected during a weight information pilot carried out by PJHOY in 2024 under the “Weight Data as a Service” project. The data includes weight and container occupancy data collected from the pilot client’s waste containers. Based on the results of statistical data analysis, suggestions are made of actions the City of Tampere can take in order to benefit from the weight data collected during the pilot. I will also make suggestions on how the PJHOY can improve data collection in future projects.

## **2 LITERATURE REVIEW**

In the Waste Act (646/2011) Section 6, Paragraph 16 waste management is defined as “collection, transport, recovery and disposal of waste, including the supervision of such operations and after-care of disposal sites”. In waste management, weight data is used in many ways and in many phases of the processes.

With weight data one can examine the quality and quantity of the generated waste, analyze the short trends of waste generation, like seasonal fluctuations, and spot more stable trends. For example, from the Statistics Finland website can be found a diagram describing the recycling, energy and material use, and landfilling rates, and their development in Finland in a ten-year time span (Statistics Finland 2023). From another angle, weight data can be used to analyze compliance with regulations. Although not stated directly in the Waste Act, municipalities are required to provide waste management services according to the population size and waste quantity, a duty that would be difficult to succeed in without parameters to monitor the development of the area and waste generation.

In this literature review, first the most important parts of the Waste Act and other legislation regulating a municipality's role and duties in waste management are reviewed. Not least because they are necessary to take into consideration when contemplating the actions to take based on the data analysis. After that, I will present ways how weight data is used in waste management, focusing on the Pay-As-You-Throw (PAYT) pricing model. The literature review is based on papers published by the Ministry of Environment and the European Commission, and individual research papers appearing in scientific publications.

## **2.1 Legislation and principles derived from it**

Waste management is regulated in multiple layers from the global level (e.g. United Nations) to regional international actors (the European Union) to national legislation, and regional regulations. Finland being an EU country, the Waste Framework Directive (Directive 2008/98/EC) is the key source of guidance and waste management targets. Since EU directives are implemented into Finnish legislation, EU law is not addressed in this review.

From laws, many principles arise that are widely recognized in the field of waste management. Perhaps the primary principles relevant to this thesis are the polluter pays principle, from which the PAYT model is derived, and the waste hierarchy principle.

### **2.1.1 The Waste Act (646/2011)**

The Waste Act (646/2011) and Government Decree on Waste (978/2021) define the duties and goals relating to waste management in Finland. They are supplemented by regional waste management regulations. Together, these constitute the frame inside which all developmental work regarding waste management services is to be conducted. In this thesis, this is taken into account especially in regards the recommended actions.

According to the Waste Act Chapter 5, municipalities are the authorities assigned to organize waste management in their area. Chapter 9 on the other hand

requires the municipalities to collect a fee from organizing it. The most important provisions in the Waste Act regarding the municipalities' role in the context of this study are presented in Table 1.

Table 1. The essential provisions of the Waste Act (Ministry of Environment 2022).

|                   |   |
|-------------------|---|
| <b>Section 46</b> | <b>Paragraph 1: Duty to organize waste management:</b>  |
|                   | The municipality shall organize waste management for the following waste other than hazardous waste:<br>---<br>2) municipal waste from the municipality's administrative and service activities.  |
| <b>Section 78</b> | <b>Paragraph 1: Duty to levy a waste charge</b>   |
|                   | The municipality shall levy a waste charge for waste management it organizes in accordance with this Act to cover the costs it incurs in carrying out the duty.   |
| <b>Section 79</b> | <b>Paragraph 1: Criteria for waste charge</b>   |
|                   | Criteria for the municipal waste charge include the type, nature and quantity of waste and the number of pickups. The waste collection and transport conditions at the property and in the pickup area, the use of municipal collection equipment and the transport distance when the waste is transported individually may also be taken into account as criteria. The number of persons living in the property, the purpose of use of the property or other equivalent criteria may also be used as criteria for the waste charge if the quantity or nature of the waste is difficult to establish reliably or if necessary to prevent harm to the environment or health or to organize waste management. |
| <b>Section 79</b> | <b>Paragraph 2: Criteria for the basic charge</b>   |
|                   | Criteria for the basic charge include the number of persons living in the property or the purpose of use of the property or another equivalent criterion. The basic charge can be specific to a property or household.  |
| <b>Section 79</b> | <b>Paragraph 3: Municipality's right to determine the waste tariff</b>  |

|                   |  |
|-------------------|--|
|                   | Further provisions on criteria for the waste charge are laid down in the waste tariff approved by the municipality.  |
| <b>Section 91</b> | <b>Paragraph 1: Municipality's right to issue regional regulations</b>   |
|                   | The municipality may issue general regulations applicable to the municipality or part of it that are based on local conditions and necessary for the implementation of this Act. |

In addition to the actual law text, Table 1 includes the information in which Section and Paragraph the provision can be found and a short description of the provision. It must be noted that the quotes in Table 1 may not be stated in full length as written in the law but shortened in order to highlight the relevant parts.

### **2.1.2 Tampere regional waste management regulations**

Based on the Waste Act (646/2011) Section 91, municipalities have the right to issue regional regulations. Regional waste management regulations define more precise frames for waste management, complementing and specifying legislation by taking into notion regional factors and special features. The regulations guide choosing the best practices according to which waste management should be conducted in the area (Tampere Regional Waste Management Committee 2024, 4). The Tampere regional waste management regulations issued by the Regional Waste Management Committee cover 17 municipalities presented in Figure 1.



Figure 1. The municipalities covered by the Tampere regional waste management regulations (The city of Tampere n.d.)

In the regional regulations, broader principles of waste management are defined, such as enhancing waste sorting and promoting environmental protection, as well as concrete instructions for organizing waste management, such as the actors responsible for waste management in the area, suitable storing facilities for waste, minimum waste collection intervals, equipment used in waste collection, and accepted waste disposal sites (Tampere Regional Waste Management Committee 2024, 1–3). The most important regional regulations concerning this study are found in the Waste Tariff regulation issued for 2025 and are listed in Table 2.

Table 2. The essential provisions of the Waste Tariff regulation issued for 2025 (Tampere Regional Waste Management Committee 2025, 2–5).

|                  |   |
|------------------|---|
| <b>Section 4</b> | <b>Paragraph 3: Waste fee of a 660-liter mixed waste container</b>  |
|                  | The waste fee for a mixed waste container consists of collection, transport, processing, a basic charge and the payment for a manually movable waste container defined in |

|                  |   |
|------------------|---|
|                  | waste management regulations. --- The size of a manually movable waste container in accordance with waste management regulations is 140, 240, 360, 660 or 770 liters. |
| <b>Section 8</b> | <b>Paragraph 1: Maximum waste weight per container</b>  |
|                  | A maximum of 60 kilograms of waste may be placed in a 660-liter mixed waste container.  |

Section 4 of the Waste Tariff regulation determines how the price of waste disposal is composed. It can be concluded from the regulation text, that the number of emptyings is the variable affecting the price the most, since collection, transport and processing are all connected to it. Section 8 defines the maximum waste weight acceptable per one mixed waste container.

### **2.1.3 Waste hierarchy principle**

Waste hierarchy refers to the principle that the first step should always be to avoid waste generation. If waste is generated, it should be repurposed. If it cannot be repurposed, the material should be recovered and used as raw material for something else. Only if none of these stages cannot be applied, should something be considered as waste and be disposed of. Even in the disposal, the waste should be sorted and treated accordingly, whether it's as raw material for energy or heat production, or in the worst case, landfilled. This principle can be found from the Waste act (646/2011) Chapter 2, Section 8.

### **2.1.4 Polluter pays principle**

Polluter pays principle refers to a legislative concept stating that the one generating the waste should be the one financially responsible for its management and disposal. In the Waste Act (646/2011) Chapter 2, Section 20 the responsibility is extended to the current or previous owner of the waste.

## 2.2 Pay-As-You-Throw pricing model

The PAYT pricing model is based on the polluter pays principle (Ukkonen & Saahimaa 2021, 373). In Finland, the waste fee may be based on waste quantity or quality, waste type, number of container emptyings, and the total costs incurred from waste management (Ministry of Environment 2019, 20; Waste act Chapter 9, Section 79). The PAYT pricing model is based on two fees: a fixed fee and a variable fee. This ensures that the collecting company will get a revenue, and that the client gets a fair price relative to the amount of waste generation.

According to the EC (n.d., 11), four conditions must be met to successfully implement a PAYT system. 1. Identification of individual users, 2. Measurement of individual waste quantity, 3. Pricing that induces compliant behavior, and 4. Engagement of residents in order to get them to commit. Szymańska et al. (2021, 97) and Ukkonen & Saahimaa (2021, 373) add implementation of fixed unit prices for waste units or used waste management services to the list.

Pricing models based on weight are typically organized by equipping containers with fixed scales or by utilizing trucks capable of weighing containers on site (Ministry of Environment 2019, 28). The containers can be identified either by a barcode, a QR code or by an electronically readable identifier, like an RFID-transmitter chip, that is operated through radio frequency (Elia et al. 2015, 191). In that way, the identification information is connected with the weight information during the weighing process. The PAYT pricing model as a term is used also when discussing solutions based on volume, such as pre-paid identifiable trash bags (ibid. 191), but in this thesis the focus is on weight-based solutions.

According to the Ministry of Environment (2019, 13), weight-based pricing is known to encourage prevention of waste generation and sorting of waste when compared to pricing models based on emptying frequency and container volumes. According to the EC (n.d., 2), the share of the variable fee is what results to behavior change. These findings are in line with the waste hierarchy principle introduced in Chapter 2.1.3. The PAYT pricing model was also mentioned as a solution in the warning Finland received in 2023. In it, PAYT is

viewed as a good economic incentive to enhance recycling and acting according to the waste hierarchy principle (EC 2023). The potential negative effects of implementing the PAYT model are illegal dumping, littering, and transporting waste to municipalities without a PAYT model, referred to as waste leakages (EC N.d, 6; Ukkonen & Saahimaa 2021, 373).

To explore the effects of the PAYT pricing model, two case studies were reviewed to present positive and negative findings associated with the system. Although studies regarding the model have been conducted globally, this review focused on case studies conducted within waste management systems comparable to that of Finland and in countries with similar recycling rates. Examples can be found from Norway (Heller & Vatn 2017) and Belgium (De Jaeger & Eyckmans 2015). The recycling rates are important to consider in order to avoid over-estimating the effects of the PAYT scheme. The rates for Finland, Norway and Belgium are 43.7%, 41.2%, and 54.7%, respectively (European Environment Agency 2024). It must be mentioned that weight-based pricing is in fact used in Finnish waste management centers, which utilize fixed (truck) scales. Mobile weighing units or container-specific weighing on the other hand have not been widely used in Finland (Ministry of Environment 2019, 13).

### **2.2.1 Case study: Ulsten, Norway**

In the municipality of Ulsten, Norway, Heller and Vatn conducted a survey to research economic incentives to enhance waste sorting. The municipality had implemented a weight-based pricing scheme until year 2011, and the participants answered the survey in 2009 and 2012. According to Heller and Vatn (2017, 280) half of the participants estimated that the weight-based pricing enhanced their sorting efforts, meanwhile half of the participants estimated their efforts remained the same. As a possible negative impact of weight-based pricing, the study highlights the increase in illegal burning or disposing of waste (ibid. 277).

### **2.2.2 Case study: Flanders, Belgium**

De Jaeger and Eyckmans (2015) researched the impacts of gradually introducing a weight-based pricing system in 72 Flemish municipalities. The data was collected during a 6-year timespan. In the study, the amount of residual MSW generated was compared between the 72 municipalities that adopted the weight-based system and between a control group which did not (ibid. 1104). The results of the study indicate that there is a significant reduction in residual MSW when municipalities change to weight-based pricing, but that impact tends not to persist over time. This being said, the authors conclude by stating that to produce more reliable results, a more thorough analysis is needed (ibid. 1111).

## **3 MATERIAL AND METHODS**

To illustrate the potential applications of weight data in waste management, weight data collected from the client's properties was analyzed to determine if on-site plastic waste sorting has a detectable impact on waste weight. To achieve this, a quantitative statistical analysis comparing the weight data of properties with and without a separate on-site plastic waste collection was conducted to determine whether there are significant differences between the groups. In addition, the relationship between waste weight and occupancy rate was studied through correlation analysis. In the process, the actual average weight of a container was calculated and compared with the estimation currently used by the PJHOY.

### **3.1 Data collection**

The data utilized in this analysis was collected by Pirkanmaan Jätehuolto Oy in the timeframe of Feb 5 – May 5, 2024. Weight information was obtained from eleven separate actors representing the pilot client, municipal service properties. Of these, ten properties were used as sample properties in the study, comprising four kindergartens, two libraries, one school, one youth center, one small scale business center, and one business space. The data included the address and utilization purpose of each property, number of waste containers on the property and the types of waste collected on the property.

During the pilot, 660-liter wheel-operated mixed waste containers located on the sample properties were equipped with RFID transmitters in order to collect uniquely identifiable weight data. A waste loading vehicle equipped with a scale weighed the sample containers on site, and the data was recorded in the XTRACK service, where a single weighing could be identified by the RFID number, location identifier (name), coordinates, and address.

In addition to weight measurements, container occupancy rate was visually estimated by the truck operator at the time of weighing. The scale of the occupancy rate ranged from 0% to 100% in 25% increments, and it was reported through a separate interface. Before the pilot, the PJHOY had estimated the mean weight of one container to be 36 kilograms (Pirkanmaan Jätehuolto Oy 2024), and within the dataset the number of containers could be inferred from the total estimated waste weight, be it 36, 72, 108, or 144 kilograms, corresponding to 1, 2, 3 or 4 containers, respectively.

### **3.2 Data processing**

In the dataset, there were four properties without a separate on-site collection for plastic. Plastic, being a material that can have a large volume but a low weight, was identified as a factor that may have a significant effect on the container weight and occupancy rates. Other interesting factors to consider regarding weight as a parameter would be biowaste and metal waste, but since all the sample properties sort biowaste on site, and all except one of the properties have a separate metal waste container on site, those factors were excluded from the study.

Before the statistical analysis, an observation matrix was made with the aim to define the container weight, number of containers, the container occupancy rate, RFID-number, and whether there is on-site plastic collection or not for each weighing.

### 3.3 Weight in relation to on-site plastic sorting: Independent variable t test

To determine if on-site plastic sorting affects the weight of mixed waste containers, the mean weights associated with sample properties with a separate on-site plastic collection (Group 1) were compared with the mean weights of sample properties without separate on-site plastic collection (Group 0). To determine if the differences are statistically significant, a t test was performed. It was chosen, since it was assumed that the group means follow the normal distribution. Because there are two independent sample groups to be tested regarding the continuous variable, mean weight, the test was conducted as an independent variable t test (Nummenmaa et al. 2019, 200–201).

The test was conducted as two-sided, meaning, that differences in both ends of the normal distribution are considered in the result (Nummenmaa et al. 2019, 176). Although it might be intuitively logical to assume (plastic being a lightweight material) that Group 0 has a higher mean weight than Group 1, it would be equally meaningful regarding this study to discover the opposite. In the dataset, there were 84 datapoints representing Group 0 and 164 datapoints representing Group 1.

The Independent variable T test formula is as follows:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (1)$$

|       |  |                    |
|-------|--|--------------------|
| where | t = t value                            | [-]                |
|       | $\bar{x}_1$ = mean of the first group  | [kg]               |
|       | $\bar{x}_2$ = mean of the second group | [kg]               |
|       | $s_1^2$ = variance of the first group  | [kg <sup>2</sup> ] |
|       | $s_2^2$ = variance of the second group | [kg <sup>2</sup> ] |
|       | $n_1$ = sample size of the first group | [-]                |
|       | $n_2$ = sample size of the first group | [-]                |

The null hypothesis was that  $H_0$  = there is no significant difference between the means of the two groups, and the alternative hypothesis was  $H_1$  = there is a significant difference between the averages of two groups. In this test, the significance level was set at  $\alpha < .05$ , which means that there is a 5 % error marginal in the test. If the p value obtained from the test exceeds .05, the null hypothesis cannot be rejected (Nummenmaa et al. 2019, 176).

### **3.4 Weight in relation to container occupancy: Pearson correlation test**

In order to define whether there is correlation between waste weight and container occupancy rate, a Pearson correlation test was performed. There were 86 data points, in which both the weight and container occupancy rate were marked definitively with unique RFID identification numbers. From these data points, one was dismissed from the study since its container weight was 0 kilograms and the occupancy rate was 100%, which should be impossible. Four markings exceeding 10 kilograms in weight, but with a 0 % occupancy rate were left untouched, since the gap from 0% to 25% in the occupancy rate is quite wide, and it is possible that the driver had estimated that 0% is more accurate than 25%, although the container has waste in it.

The Pearson correlation coefficient is used to determine if there is a linear relationship between two variables and how strong said relationship is. The result will be a number between 1 and -1. A positive number indicates that the two variables are connected so that when the other variable's values increase, the other one's values increase linearly. A negative number indicates that as one variable's value increases, the other variable's values decrease linearly. (Nummenmaa et al. 2019, 214–215.)

Table 3. Degrees of correlation in the Pearson correlation test based on r value (Nummenmaa et al. 2019, 227).

| Degree of correlation | r value                       |
|-----------------------|-------------------------------|
| Perfect               | $\pm 1$                       |
| High                  | Between $\pm 0.5$ and $\pm 1$ |
| Low                   | Below $\pm 0.5$ and 0         |
| No correlation        | Near 0                        |

Table 3 illustrates the degree of correlation in the Pearson correlation test. The closer the correlation coefficient, or r value, is to zero, the weaker is the correlation between the variables (Nummenmaa et al. 2019, 215).

The Pearson correlation coefficient formula stands as follows:

$$r = \frac{\Sigma(X_1 - \bar{X})(Y_1 - \bar{Y})}{\sqrt{\Sigma(X_1 - \bar{X})^2 \Sigma(Y_1 - \bar{Y})^2}} \quad (2)$$

|       |   |      |
|-------|---|------|
| Where | $r$ = Pearsons correlation coefficient        | [-]  |
|       | $\bar{X}_1$ = mean of the X values            | [kg] |
|       | $X_1$ = individual data points for X variable | [kg] |
|       | $\bar{Y}_1$ = mean of the Y values            | [-]  |
|       | $Y_1$ = individual data points for Y variable | [-]  |
|       | $\Sigma$ = summation across all data points   | [-]  |

The null hypothesis was  $H_0$  = there is no correlation between the variables. The alternative hypothesis was  $H_1$  = there is correlation between the two variables. In this test, the significance level was set at  $\alpha < .05$ .

#### 4 RESULTS

The mean weight of the group without on-site plastic separation was 33.29 kilograms whereas the group with on-site plastic collection averaged 29.12 kilograms. The combined mean weight across both groups was 31.21 kilograms. The obtained means differ from the standard weight that the PJHOY has

calculated for a 660-liter container, which is 36 kilograms. The mean and median weights for each of the ten sample properties are presented below in Table 4.

Table 4. Mean and median weights of the sample properties' waste containers and the number of datapoints.

| <b>Sample property</b> | <b>Mean weight (kg)</b> | <b>Median weight (kg)</b> | <b>Number of data points</b> |
|------------------------|-------------------------|---------------------------|------------------------------|
| Property 1             | 26.73                   | 25                        | 15                           |
| Property 2             | 34.21                   | 30                        | 19                           |
| Property 3             | 35.31                   | 40                        | 16                           |
| Property 4             | 34.71                   | 30                        | 34                           |
| Property 5             | 27.34                   | 25                        | 47                           |
| Property 6             | 8.33                    | 10                        | 6                            |
| Property 7             | 35                      | 45                        | 17                           |
| Property 8             | 38.68                   | 35                        | 34                           |
| Property 9             | 20                      | 20                        | 23                           |
| Property 10            | 28.92                   | 30                        | 37                           |

The four properties without on-site plastic collection are referred to as Properties 1–4 in Table 4. From these findings can be concluded that the mean weight that the PJHOY has calculated is quite high, exceeding the actual mean weight considerably in some cases. For example, the actual weight was 27.67 kilograms lower than the estimate in case of Property 6 and 16.00 kilograms lower in case of Property 9. Property 8 on the other hand averaged 2.68 kilograms over the standard weight. None of the weights exceeded the maximum weight defined for a 660-liter mixed waste container in the Waste Tariff regulation Section 8 (Tampere Regional Waste Management Committee 2025, 5).

#### **4.1 Weight in relation to on-site plastic collection: Independent variable t test**

Based on the t test, there could not be detected a statistically significant difference in the mean waste weights between the sample properties which had

on-site plastic collection (Mean = 33.29, Standard deviation = 17.78) and of those which did not (Mean = 29.12, Standard deviation = 16.04);  $t(246) = 1.867$ ,  $p = .63$ . Since the critical t value for samples containing over 200 degrees of freedom (meaning data points) is 1,972 (Nummenmaa et al. 2019, 340), and the obtained test t value was below it, the null hypothesis ( $H_0$  = there are no significant differences between the sample groups) could not be rejected. This could be also concluded by the p value being  $>.05$ . This means that whether a property has on-site plastic collection or not has no significant effect on the weight of the containers.

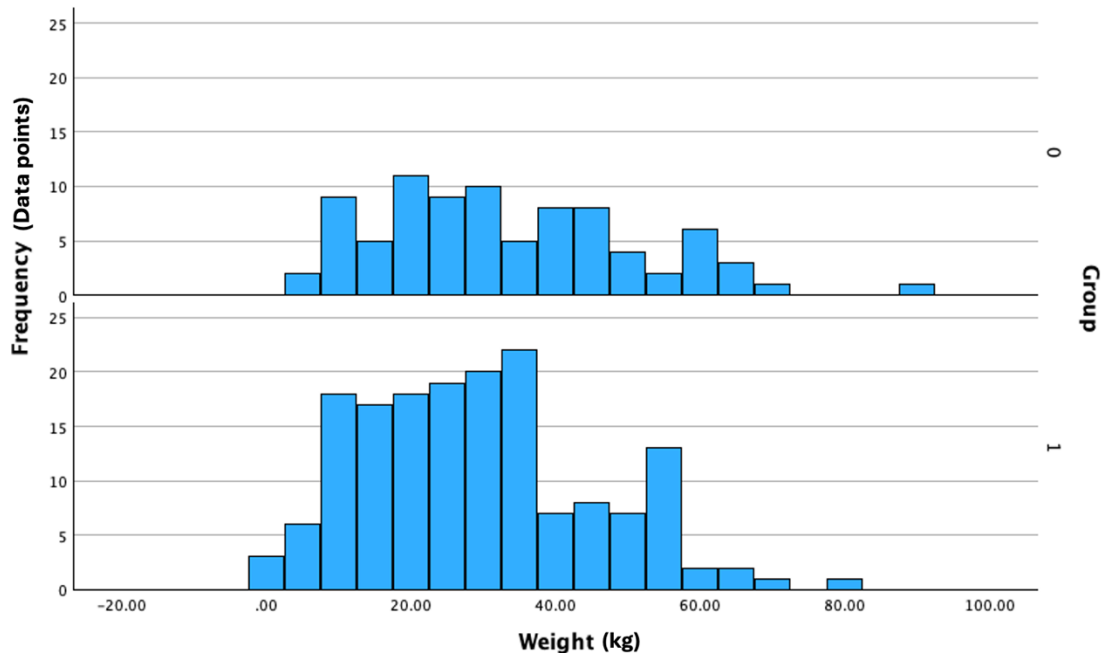


Figure 2. Histogram of waste weight (kg) distribution across different weight ranges.

The two histograms in Figure 2 display the distribution of waste weight. The x-axis represents weight ranges with intervals of 5 kilograms, the y-axis the frequency of data points within those ranges. The histogram on the top displays the Group 0 distribution, referring to the sample properties without separate plastic waste collection. The lower histogram displays the weight distribution of Group 1, the sample properties with an on-site waste plastic collection. As can be seen, the Group 0 distribution is more symmetrical than Group 1 distribution, which is concentrated between ranges 10 to 40 kg. Nevertheless, both of the histograms are similarly skewed to the right around the average weights, 29.12

and 33.29, respectively. The relative height difference of the bars between the histograms is explained by Group 1 having 80 datapoints more than Group 0.

#### 4.2 Weight in relation to container occupancy: Pearson correlation test

The Pearson correlation test result indicates that the tested variables have a positive relationship,  $r(85) = .37$ ,  $p < .001$ . Referring to Table 3, since the  $r$  value is  $.37$ , the waste weight and container occupancy rate have a weak positive relationship, meaning that when the waste weight value increases, the container occupancy value increases linearly.

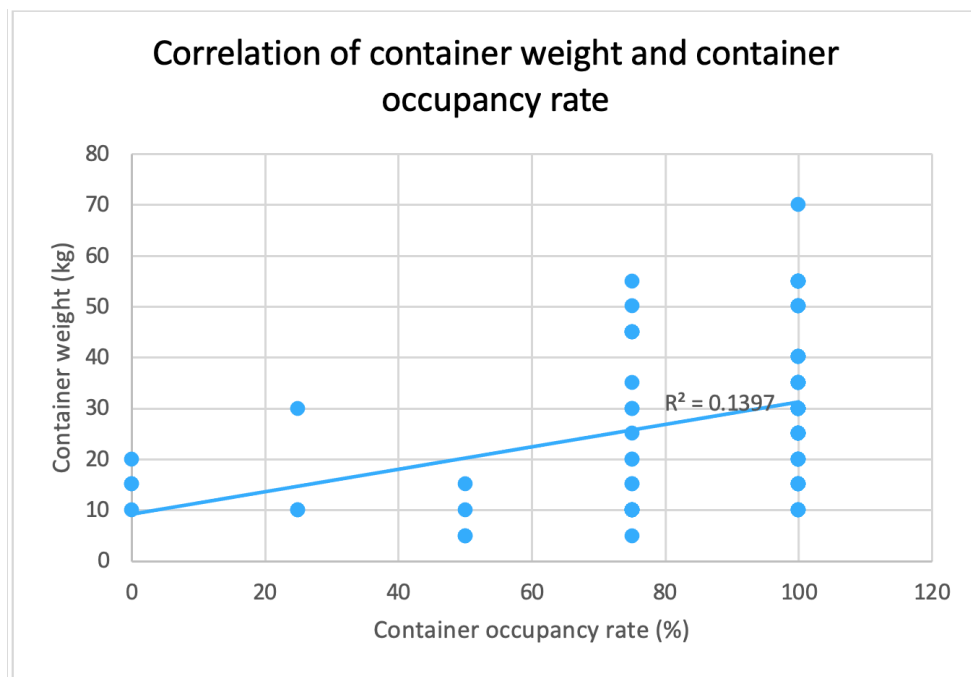


Figure 3. Scatter plot of container occupancy rate (%) and container weight (kg).

Figure 3 presents a scatter plot of container occupancy rate and container weight. The trendline shows a positive linear correlation between  $x$ , container occupancy rate, and  $y$ , container weight. The data points are scattered widely around the trend line, which indicates a weak correlation, as concluded from the  $r$  value.

## **5 ANALYSIS**

Arguably, the most significant and reliable findings of this study are the mean and median container-specific weights presented in Table 4. The differences in weights suggest a difference in container occupancy rates, as proven by the Pearson correlation test. Nevertheless, when a client is charged a fixed fee depending on the number of emptyings, neither of these factors are accounted for at their full potential. It might lead to an unfair situation for the clients, if one generates 10 kilograms of waste on average and another generates 38 kilograms on average, but the pricing is based solely on the emptying interval.

### **5.1 Weight in relation to on-site plastic collection**

There was a small difference in weight between Group 0 and Group 1, but based on this study, separated plastic waste collection did not affect waste weight on a level that would be statistically significant. Some of this might be explained by the size of the dataset.

The sampling period was only three months long, which means that on average there was 25 collections per property. Considering this, for example a renovation or a holiday might have a considerable effect on the quality and quantity of waste generated and thus skew the results. Should a more detailed analysis be warranted, it may be necessary to determine if the activities at the sample sites during the study period are representative of typical operations, considering factors such as renovations or variations in opening hours. Subsequently, it should be assessed whether the ongoing activities are relevant in terms of waste generation and the objectives of the study at hand.

Since the properties are utilized for different purposes, the composition and quality of waste generated varies between sites. For instance, kindergartens generate diaper waste, which the other sample properties are not likely to do. To obtain more reliable and valid results of the effects of on-site sorting, waste generation should be monitored either across properties with comparable

utilization patterns or by measuring waste generation before and after a property has implemented separate plastic waste collection.

## **5.2 Weight in relation to container occupancy**

The data analysis of the 85 RFID-identified data points indicated a correlation between container occupancy and weight data. However, the statistical analysis can only prove that there is correlation, not establish causality. Furthermore, the container occupancy rate was not assessed for individual containers but instead was an estimated average of all containers on one sample property emptied simultaneously, with the number of containers on site varying from 1 to 5. So, although there is correlation, the result should be interpreted critically, considering the limitations of the data and the method of analysis.

The initial objective was to conduct a comparative analysis of weight data and container occupancy rate data across the whole dataset. However, after data processing it became evident that only 85 data points out of 248 contained complete information for weight, container occupancy rate, and RFID identification. By using data lacking proper identification, the reliability of the analysis would be compromised and therefore only data points with consistent information were included in the statistical analysis. It is debatable whether 85 data points collected during a three-month sampling period are enough to obtain reliable and generalizable conclusions of the relationship of the two variables.

## **5.3 Challenges of the study**

The primary challenges when conducting the study included several inconsistencies within the dataset and the difficulty to assess the extent of human errors in data reporting.

### **5.3.1 Inconsistent data**

The data was not reported consistently. To identify a certain weighing event from the data, four variables were cross-checked: property name, RFID number, address, and coordinates of the sample property. The major issue was that many

weighings were not connected to an RFID identification number. The lack of RFID data alone might not have made the data unreliable, but some entries lacked also the property name. In such cases, the weighings were identified by the address. Identifying a sampling site solely by the address was also proven challenging. The sample properties 1 and 2 were located virtually in the same place, and for a couple entries the addresses were misattributed. Since the weighing report obtained from the XTRACK service included weighing data from multiple other sites beyond the designated sampling sites, processing it manually would require reviewing 21 072 entries. This would have been extremely time-consuming, and therefore not suitable for this thesis.

To further complicate the matter, the weight data and occupancy rate estimations were recorded in separate datasets, and upon data processing, it became evident that on many occasions the reporting dates between the two variables did not match. The occupancy rate records lacking corresponding weight data were left unassessed, and with that decision a considerable portion of data became excluded from this study.

As stated before, the container occupancy rate was not reported for individual containers. If the sampling site had for example three containers, out of which two had 100% occupancy and one had a 25%, the driver reported an estimation of the mean occupancy rate of the three containers together. This kind of estimation is not a specific one and makes it challenging to compare the weight and occupancy rate in detail.

### **5.3.2 Possible human errors**

Since the container occupancy rate was assessed visually by a human, there is a substantial potential for human error and retrospective evaluation of the accuracy of the assessment is quite challenging. The errors may result from lack of experience, inconsistency with estimations, and things as simple as environmental conditions, such as bad lighting. Additionally, the weighing dates not matching the occupancy rate records might also be due to human error. For

example, the occupancy data might not have been reported on-spot because it was forgotten, or it could have been mistakenly assigned to a wrong date.

## **6 DISCUSSION AND FINAL RECOMMENDATIONS**

Based on the literature review and data analysis, two recommendations for future actions can be given. The first one is aimed to provide suggestions on how to improve data collection with the target of enhancing waste sorting. The second one concerns the possibility to implement the PAYT pricing model.

### **6.1 Container specific occupancy rates**

To continue research on waste weight in relation to the degrees of sorting, the container occupancy estimations should also be made container specific and preferably be marked at the same time as the container is weighed. With accurate weight and volume data for each emptying, it would be possible to assess the composition of the waste by comparing it to mean weights found in literature or weights of a control group. Doing so, it would be possible to discover if significant quantities of, for example, plastic or biowaste are discarded into the mixed waste containers and to take actions to prevent that.

To succeed in reporting the weight and volume data consistently, the waste truck driver needs to be trained and instructed properly and provided a user-friendly interface for reporting. During the PJHOY weight data pilot, it was established that the weighing equipment works properly (Pirkanmaan Jätehuolto Oy, 2024). It is harder to determine how complicated it is for the person operating the scale and the reporting interface to spot missing RFID information, site names or addresses. In the best scenario, reporting the weight and occupancy rate would happen through the same interface, with easy access to the user.

### **6.2 Pay-as-you-throw pricing model**

The case studies presented in Chapter 2 give inconclusive information about the potential of weight-based pricing models to enhance sorting of waste and recycling. The negative findings are contrary to the views of the EC (2023) and

the Ministry of Environment (2019, 13), who state that weight-based pricing enhances sorting of waste. Nevertheless, as it was established in this study that the actual waste weight differs from the weight estimation in both directions, a weight-based pricing should not be neglected as a potentially fair solution to clients. In addition, Ukkonen & Saahimaa (2021, 379) emphasize its potential in implementing the waste hierarchy principle as well as reaching the EU-wide recycling targets.

According to the Ministry of Environment (2019, 21), implementation of a container specific pricing system is possible by amending regional regulation and the municipality's waste tariff. In addition, when implementing a PAYT system, at least the Data Protection Act (1050/2018), the Act on Public Procurement and Concession Contracts (1397/2016), and the Administrative Procedure Act (434/2003) should be considered in the case of municipal properties, which do not, however, restricts its implementation (ibid. 15). To be fair and monetarily justified, the system should be applied with a broad scale (ibid. 21). As concluded by Elia et al. (2015, 193–194), implementing PAYT pricing model should be approached holistically, taking into notion the economic, environmental, social, and technological factors. That being said, doing so might result in a larger change in operations than was intended when initiating the weight information pilot.

To determine the associated costs of implementing the PAYT pricing model within the context of the City of Tampere, further research is required. No relevant tools or case studies were found to provide definitive cost estimates for such implementation. Factors such as the level of advancement of existing infrastructure and technologies, the current pricing model, and extent of administrative and legislative modifications required impact the costs of the possible implementation (Ukkonen & Saahimaa, 379). The inherent uncertainty of these factors makes it challenging to predict the costs with precision.

## 7 CONCLUSION

The three aims of this thesis were to produce information according to client requirements, explore the potential to enhance waste sorting by utilizing weight data, and to provide recommendations for actions. The objectives related to client requirements and recommended actions could be successfully addressed. The potential to enhance waste sorting based on the data analysis could not be determined due to inconsistencies within the datasets.

The specific study question was to determine how the City of Tampere could utilize the data collected during the weight data pilot. The findings proved that weight data can be analyzed and interpreted from multiple angles. Given that the results of the statistical tests were in many ways debatable, the most reliable and useful results of this analysis were the container-specific actual mean weights. The analysis revealed the differences between estimated and actual waste weights for sample properties with and without separate plastic waste collection, recorded as 36, 29.12, and 33.29 kilograms, respectively. This, and the observed substantial variations in the mean weights across different sample properties can be used to support decision-making related to selection of collection equipment and optimization of collection frequency.

In order to continue research on how to utilize weight information and its role in enhancing waste sorting, precise planning should be done in advance, and the objectives should be defined clearly.

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