MODELLING FUEL CONSUMPTION IN KERBSIDE SOURCE SEGREGATED FOOD WASTE COLLECTION: SEPARATE COLLECTION AND CO-COLLECTION

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ABSTRACT. A mathematical model was developed to calculate the fuel consumption of kerbside source segregated food waste, co-mingled dry recyclable and residual waste collection. A hypothetical city of 20,000 households was used and nine scenarios were considered with different combinations of collection frequencies, vehicle types and waste types. The results showed that the fuel saved by weekly and fortnightly co-collection of household waste ranges from 7.4% to 22.4 % and 1.8% to 26.6% respectively, when compared to separate collection. A compartmentalised vehicle split 30:70 always performed better than one with two compartments of equal size. Weekly food waste collection with alternate weekly collection of the recyclables and residual waste by two-compartment collection vehicles was the best option to reduce the overall fuel consumption.

Keywords: *Waste collection, collection vehicle, fuel consumption, food waste*

Introduction

Food waste is a major component of municipal solid waste in developed and developing countries. Disposal of food waste in landfills has adverse effects on the environment and the economy [1]. In view of this, the food waste issue is a growing concern for governments of different countries all over the world. In Europe, the EU Landfill Directive (1999/31/EC) has created a momentum to separate out food waste from the household waste stream. As one example of a response to this, in 2012 the Scottish government amended its Waste (Scotland) Regulation and the new regulation bans the disposal of household bio-waste including food waste to landfill. It drives local authorities to provide segregated food waste collection to households, which has to be fully implemented by all authorities by the end of 2015 [2]. This will have an impact on the practice of household waste collections in Scotland.

Currently, there are 71 local authorities in the United Kingdom offering a weekly food waste collection [3]. In most cases an additional food waste collection service is simply added to the existing waste collection, with food waste being collected in a single-compartment vehicle. In some cases local authorities use multi-compartment collection vehicles for the combined collection of food waste and recyclables or residual waste [4]. Information on how to select a suitable collection vehicle and implement source segregated food waste collection is scarce. The aim of this study was to identify options that maximise collection efficiency and reduce fuel consumption. A mathematical model was constructed to support decision-making on selecting the optimal collection system based on minimum fuel consumption.

This research compared the differences in fuel consumption for the single collection and co-collection of household waste, to allow selection of the optimal collection system and the best refuse collection vehicle (RCV) at varying capture rates.

Materials and Methods

Description of the model

A mathematical collection model was set up in a Microsoft Excel spreadsheet based on Everett's and Sonesson's model but taking the service time, the volume and load capacity of the collection vehicle into consideration [5, 6]. This model is divided into four parts: Composition of kerbside household waste, determination of limiting factors, determination of collection rounds and fuel consumption. The round size and the number of rounds are calculated to estimate the total travelling distance in transportation and collection stages. The round size is determined from the maximum amount of waste collected from each household by the collection vehicles or from service assignment time per working day. The minimum round size based on three factors (loading, volume or time) is selected as the constraint for the calculation of number of collection rounds, by dividing the total number of households by the round size. The travelling distance in the collection area is found by multiplying the distance between collection points and the total

number of households, while the total distance in transportation is calculated by multiplying the number of collection rounds and the average distance between collection area and transfer station.

Regarding fuel consumption, the equations presented in the European Environment Agency EMEP Emission Inventory Guidebook [7] were used to calculate the fuel consumption of refuse collection vehicles. These take into account the gross weight of the vehicle, road gradient and type of engine. When calculating fuel consumption, the travelling distance, average speeds and percentage laden of vehicle in the collection and transportation stages were considered.

The input of the model includes: number of households setting out waste, amount of food waste collected per household, number of collectors, collection frequency, productive and non-productive working time, time spent per pick-up, speed in collection and transportation stages, distance between collection points and to treatment facilities. The outputs are fuel consumed per tonnage of waste collected, total mileage, utilisation of compartments in terms of volume and load, total number of collection routes, total time spent and the number of collection vehicles required. In this study, only the fuel consumption is reported.

Composition of kerbside household waste

Table 1. Composition of kerbside household waste used in the modelling.

Waste type	Composition (%)
Paper and card	24.85
Food	24.1
Garden & other organic waste	13.45
Plastics	10.92
Glass	6.23
Metals	3.3
Wood	0.84
Textiles	2.93
WEEE	1.03
Others	12.35

According to the UK municipal waste composition report [8], on average each household generates a total of 869.4 kg of kerbside waste annually, equivalent to 2.38 kg per household per day. The quantities of food waste, recyclables and residual wastes collected were estimated from the composition of household waste and the capture rates, as shown in Table 1. In this study, recyclable waste means paper, card, plastics, glass and metals that are collected co-mingled. The residual waste is a mixture of different waste materials that have not been captured in the food waste and recycling bins.

Scenarios for the collection systems

A hypothetical city of 20,000 households was used for the case study. It was assumed that the kerbside household waste is collected by a single-compartment or compartmentalised collection vehicle on a weekly or fortnightly basis. The specification of each collection vehicle is shown in Table 2.

Nine scenarios were considered according to the different combinations of collection frequencies, vehicle types and waste types (see Table 3). Each scenario was run with different capture rates for food waste and recyclables. In this study, only weekly source separated food waste was considered as this is widely accepted practice in the United Kingdom.

Results and Discussion

Best and the worst collection system based on fuel consumption

Scenarios 1-9 looked at the effect of using single-compartment or split compartment vehicles and of collection frequency on the fuel consumption. Figure 1 shows the fuel consumed in the whole household waste collection per scenario at different capture rates of recyclables and food waste. In general, the fuel consumption for collecting the complete household waste stream decreases when the capture rates for co-mingled recyclables and for food waste increases. Scenario 9 has the lowest fuel consumption at the 30 to 100% capture rates, while scenario 1 has the highest in all situations.

Scenario 1 was used as a baseline to show the difference between co-collection and single collection: the co-collection option with the lowest fuel consumption is compared with the fuel consumption in scenario 1 for each capture rate. The fuel saved by weekly co-collection of household waste ranges from 7.4% to 22.4 %. Scenarios 2, 4 and 9 were compared to show the difference between the single collection and co-collection once a fortnight using single-compartment and two-compartment RCVs. Scenarios 4 and 9 use respectively 1.8-9.8% and 8.1-26.6% less fuel than scenario 2 at capture rates of 30% or more.

Table 3. Nine scenarios for kerbside household waste collection systems

Scenario	Description
1	Weekly separate collections of recyclables, residual and food waste by single-compartment RCV
2	Alternate fortnightly collection of recyclables and residual waste and weekly collection of food waste and by single-compartment RCV
3	Weekly co-collection of recyclables and residual waste by compartmentalised RCV, weekly collection using single-compartment RCV for food waste
4	Fortnightly co-collection of recyclables and residual waste by compartmentalised RCV, weekly collection using single-compartment RCV for food waste
5	Weekly co-collection of recyclables and food waste by compartmentalised RCV, weekly collection using single-compartment RCV for residual waste
6	Weekly co-collection of recyclables and food waste by compartmentalised RCV, fortnightly collection using single-compartment RCV for residual waste
7	Weekly co-collection of residual waste and food waste by compartmentalised RCV, weekly collection using single compartment RCV for recyclables
8	Weekly co-collection of residual waste and food waste by compartmentalised RCV, fortnightly collection using single compartment RCV for recyclables
9	Weekly food waste collection with alternate weekly collection of residual waste and recyclables

The results showed that using a compartmentalised vehicle for collection does not always lead to lower fuel consumption. The collection frequency affects the outcome. Using the compartmentalised vehicle to co-collect any type of waste every week with weekly single collection for the rest of the waste (Scenarios 3, 5 and 7) always has higher usage of fuel than the single collection of recyclable and residual waste every fortnight with weekly food waste collection (Scenario 2). Putting aside public acceptance of the reduction in frequency of the household waste collection service, the local authority could provide alternate weekly collection of the recyclable and residual waste with weekly food waste collection to minimise the fuel consumption as well as to maximise the life-span of the collection vehicle.

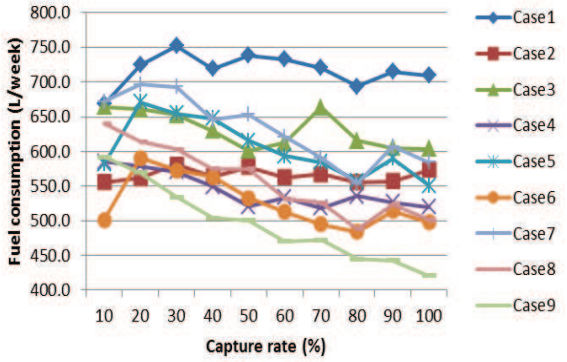

Fig.1. The optimum collection option on the fuel consumption of the household waste collection

Best refuse collection vehicle

The selection of the best collection vehicle is based on the minimum total fuel consumption of household waste collection per week. As expected, a small collection vehicle is ideal for the collection of small amount of waste, such as food waste, at each pick-up point at the low capture rates; while a larger collection vehicle such as the 26-tonne RCV is well suited to residual waste collection. The study also showed that the two-compartment RCV is not always fully utilised and is usually limited by the volume of the compartment rather than the vehicle payload during co-collection of household waste. Therefore, when selecting a suitable collection vehicle, the volume and the split ratio of the compartments must be considered. Comparing all collection systems, it is observed that the performance of the pod vehicle is better than the rear split collection vehicle in terms of fuel consumed. Among the pod vehicles, the Duo3 collection vehicle is the best option at most capture rates for recyclables and food waste. In order to further improve collection efficiency, it is suggested that the split ratios should be kept at 30:70 and volumes of both compartments should be increased. In addition, increasing the vehicle payload by the use of a lighter material for the compartment body could improve performance. When deciding to use a larger compartmentalised collection vehicle, however, several factors should be considered such as the width of the road. Also, the balance between the size of compartment and the collection time must always be considered unless shift working is practiced.

Conclusions

The fuel consumption of the collection of co-mingled recyclables materials, source segregated food waste and the residual waste was investigated. It was concluded that:

Weekly food waste collection with alternate weekly collection of the recyclables and residual waste by two compartments collection vehicle is the best collection system in most situations.

In some cases, the single separate collection of the household waste could consume less fuel than the co-collection by compartmentalised vehicle, when the collection frequency is reduced to fortnightly collections.

A pod vehicle with a large compartment capacity and split into 30:70 is always better than the rear split collection vehicle.

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