Waste Management 56 (2016) 454–465

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Energy and time modelling of kerbside waste collection: Changes incurred when adding source separated food waste

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ARTICLE INFO

Article history:
Received 2 February 2016
Revised 25 May 2016
Accepted 27 June 2016
Available online 7 July 2016

Keywords:
Kerbside waste collection
Source separated
Food waste
Waste collection model
Biowaste
Municipal waste collection

ABSTRACT

The collection of source separated kerbside municipal FW (SSFW) is being incentivised in Australia, however such a collection is likely to increase the fuel and time a collection truck fleet requires. Therefore, waste managers need to determine whether the incentives outweigh the cost. With literature scarcely describing the magnitude of increase, and local parameters playing a crucial role in accurately modelling kerbside collection; this paper develops a new general mathematical model that predicts the energy and time requirements of a collection regime whilst incorporating the unique variables of different jurisdictions. The model, *Municipal solid waste collect (MSW-Collect)*, is validated and shown to be more accurate at predicting fuel consumption and trucks required than other common collection models. When predicting changes incurred for five different SSFW collection scenarios, results show that SSFW scenarios require an increase in fuel ranging from 1.38% to 57.59%. There is also a need for additional trucks across most SSFW scenarios tested. All SSFW scenarios are ranked and analysed in regards to fuel consumption; sensitivity analysis is conducted to test key assumptions.
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1. Introduction

Food waste (FW) constitutes on average 35–45% by weight of total municipal garbage in Australia, (Melton Shire Council, 2011; New South Wales Environment Protection Authority, 2011; Schacher et al., 2007). Most of this FW is sent directly to landfill, which makes it one of the biggest municipal waste categories discarded to landfill (Randell et al., 2014). Recent attention therefore has been given to policies that divert FW from landfill (ACIL Allen Consulting, 2014; Edwards et al., 2015).

Source separated food waste (SSFW) is the sorting of FW at its point of generation into an exclusive waste stream. It has been shown to increase FW diversion away from landfill and encourage reuse, recycling, and energy recovery (European Commission, 2015; Mazzanti et al., 2009). Because of this, LGA that implement SSFW are now eligible for Australian government financial incentives (Commonwealth Government of Australia, 2015). Whilst this attempts to drive SSFW implementation, a significant barrier is ensuring any collection regime is cost-effective (Zhuang et al., 2008). Information on the magnitude of increase in diesel consumption, and additional trucks required is largely missing from the literature. This is likely because changes to a collection regime are often modelled internally and therefore not made public; or because modelling has proven time consuming and requires a large amount of data; as models are dependent on a number of parameters that can vary drastically due to local conditions (Di Maria and Micale, 2013; Sonesson, 2000). Some of the key variables to consider include; constant stop start driving, distance between bins, constant use of hydraulic lifts, truck capacity, and the speed at which a truck travels when collecting and hauling waste to an unload point (Farzaneh et al., 2009; Huai et al., 2006).

Despite the high number of variables there are existing models. Two commonly used models are Organic Waste Research model (*ORWARE*) and Waste Recycling and Cost Model (*WRCM*). However, problems arise when using these models for contemporary Australian conditions and when trying to reflect geographical, operational and technological changes across LGA, especially as the aforementioned models provide little indication on how to update and substitute the default values used. Moreover, new published

Abbreviations: σ, standard deviation; $\Sigma\ \Delta^2$, sum of squared deviation; BAU, business-as-usual; FW, food waste; GIS, geographical information system; GW, garden waste; LGA, local government area; MCOB, mobile co-mingled organics bin; MFB, mobile food waste bin; MGB, mobile garbage bin; MOB, mobile organics (garden) bin; MRB, mobile recycling bin; SSFW, source separated food waste.

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http://dx.doi.org/10.1016/j.wasman.2016.06.033
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information on the energy consumption of collection truck vehicles in lift, low speed acceleration, and drive modes means models can be improved upon. This research therefore aims, to update and expand upon the *ORWARE* and *WRCM* models by developing a new general model that can be used to predict changes incurred (fuel consumption and time required) by adding SSFW to a collection regime.

The new model, *Municipal Solid Waste – Collect* (*MSW-Collect*), applies scientific methods, including centroid theorem, local street surveys, and census data in a novel approach that better represents critical local parameters specific to their collection area circumstances; parameters which have previously been industry estimates or rule of thumb. Additionally, *MSW-Collect* looks to more accurately represent a collection truck by modelling truck activities that could not previously be included due to a lack of knowledge, e.g. energy requirements of trucks when lifting bins.

This study validates the *MSW-Collect* approach using gathered case study LGA data, and comparing outputs against predecessor models using statistical analysis. Upon validation *MSW-Collect* is used to determine the fuel consumption and trucks required for five common SSFW collection scenarios. The methodology and findings disseminated in this study are intended for LGA that are interested in assessing the cost-effectiveness of SSFW collection, moreover, for waste management decision makers who require accurate energy and material data for a wider analysis of waste management systems, for instance, in life cycle assessment studies.

2. Description and review of existing models ORWARE and WRCM

ORWARE, developed in the mid-1990s in Sweden, is a software package that assesses organic and inorganic waste management scenarios using a life cycle perspective. The component of *ORWARE* dealing with kerbside waste collection is described in detail by Sonesson (2000, 1996), however a brief description is as follows. *ORWARE* separates the kerbside collection process into three distinct modes based on a collection truck's activity; (1) the haul (the time when the truck is transporting collected waste from the collection area to the unload point), (2) stop-collect (the time at which the truck is stopped and emptying kerbside bins or waiting to empty kerbside bins into the truck body), and (3) drive-collect modes (the time driving between stopping and emptying kerbside bins). Within each mode energy consumption and time are calculated and are summed to give total energy consumed (MJ/year) and time required (h/y). Input data parameters involved in the model are; average speed in haul mode, distance between collection area and unloading, amount of waste, average truck load, distance between stops, average speed collecting, time per stop, number of households, collection frequency, households per bin, energy used (stop), and energy used (driving). *ORWARE* does require data from the user that may be difficult to obtain accurately (Sonesson, 2000). However, this can be overcome by using default values provided for; average speed in haul mode, average truck load, distance between stops, average speed collecting, time per stop, energy used (stop), and energy used (driving).

WRCM is an Australian model developed in the late 1990s by the *Co-operative Research Centre for Waste Management and Pollution Control*. Similar to *ORWARE*, *WRCM* aims to be a general model with a minimal amount of data input requirements by using default generalised figures. *WRCM* divides kerbside collection into two distinct phases; truck collection and truck haul for separate parameter estimation, calculation and then summation. The required parameters are LGA classification (metropolitan, or non-metropolitan), the number of households serviced by the LGA, waste per household, waste density in truck, collection area, collection frequency and distance from collection to unloading point. Along with these parameters is a list of assumptions, which can be altered if data is available, but otherwise simplify the model. These assumptions are; traffic congestion – and consequently average road speed, participation rate of households, set-out rate of bins, fuel consumption rate, collection time per household, truck capacity, and truck emptying time.

The use of default data allows both *ORWARE* and *WRCM* to be attractive to an LGA for estimating energy and time consumption. However, *ORWARE*, given its application in Sweden, mean defaults are not typically applicable to other regions, as population density and town design vary. For example the crucial variable of distance between bins in ORWARE is 0.11 km for an urban environment, whilst in WRCM the average is 0.02 km. Not having applicable default data means this distance needs to be estimated. The *ORWARE* model does not provide a method to calculate replacement data for this and other parameters. Some data may be possible to obtain from contractors or LGA, however in conducting this research it has been found that data provided in this way is typically a rough 'rule of thumb' estimate by an operator or manager. *WRCM* does provide means to estimate distance between bins. It applies a corresponding distance in increments of five meters to the calculation of collection area divided by the number of households in the collection area. This is a more sophisticated approach; however this is translated into defaults of five meter intervals, which is unlikely to be accurate enough when modelling a collection regime that visits over 50,000 dwellings every week.

WRCM also simplifies the fuel consumption of a collection fleet into litres per hour (L/h) without pinpointing what activity of collection is responsible for the fuel consumption. This may explain discrepancies in predicting fuel consumption as different collection activities have different energy requirements, for example hydraulic lifting of a bin can consume approximately 2.3 g of diesel/s whilst freeway driving can consume up to 9.7 g of diesel/s (Farzaneh et al., 2009; Sandhu et al., 2014). This is important when considering the logistics of a collection regime. One collection area may require many bin lifts, but smaller driving distances to the waste disposal site, whilst another necessitates the opposite. *ORWARE* divides energy consumption into that used in the stop mode and that used in the drive mode, which distinguish between a truck's energy requirements for the hydraulic lifting of a bin, and from the energy required to haul waste to the unload point. In *ORWARE* it is not detailed how the default figures for energy use of 2.5 MJ/stop and 9 MJ/km were derived. It could be assumed that 2.5 MJ/stop is the average energy required to lift the average amount of bins per stop. Whilst the 9 MJ/km is noted as being from the consumption rate of 0.25 L/km, however this fuel consumption rate is comparably low to other literature sources which range from 0.36 to 1.17 L/km (Di Maria and Micale, 2013; Gala, 2015; Huai et al., 2006; Sandhu et al., 2014).

3. Description of the MSW-Collect model

A schematic of *MSW-Collect* and a typical operation is provided in Fig. 1. The truck at the start of the day leaves the depot (*start/end*) and travels to the collection area along urban roads observing urban speed and driving restrictions. Once in the collection area the truck activities are divided into '*stop/go*' (represented by the *stop/go* sign) which refers to the acceleration/deceleration a truck makes as it drives between stops, and '*lifting*' (represented by the up and down arrows), which refers to the hydraulic lifting of one kerbside bin. As can be seen in Fig. 1 *stop/go* and *lifting* continue until collection is complete. Furthermore, *lifting* may include multiple bins before *stop/go* begins again, as bins from apartment dwellings are grouped together. Once the truck is full, or the

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