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Characterization of municipal solid waste collection operations

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ABSTRACT

Solid waste collection contributes to the cost, emissions, and fossil fuel required to manage municipal solid waste. Mechanistic models to estimate these parameters are necessary to perform integrated assessments of solid waste management alternatives using a life-cycle approach; however, models are only as good as their parameterization. This study presents operational waste collection data that can be used in life-cycle models for areas with similar collection systems, and provides illustrative results from a collection process model using operational data. Fuel use and times associated with various aspects of waste collection were obtained for vehicles collecting mixed residential (residual) waste, recyclables, and yard waste from single-family residences in selected municipalities. The total average fuel economy for similarly-sized diesel collection vehicles was 0.6-1.4 km/L (1.4–3.3 mpg (miles per gallon)) for residual waste and 0.8–1 km/L (1.9–2.4 mpg) for recyclables. For residual waste and recyclables collection stops, the average time to collect at each residence using automated collection was 11–12 s and 13–17 s, respectively. The average time between stops was 11–12 s and 10–13 for residuals and recyclables, respectively. A single yard waste route was observed, and all collection times were longer than those measured for either recycling or residual waste. Unload or tip times were obtained or measured at a landfill, transfer station, and material recovery facility (MRF). Average time to unload was 7–9 min at a MRF, 14–22 min at a landfill, and 11 min at a transfer station. Commercial and multi-family collection vehicles tend to have longer stops and spend more time between stops than single-family collection, and a larger portion of fuel is used while driving relative to single-family collection. Roll-off vehicles, which collect more waste per stop, spend longer at each stop and drive longer distances between stops than front-loader vehicles. Diesel roll-offs averaged 2.4 km/L (5.7 mpg) and front-loaders averaged 1.4 km/L (3.3 mpg).

1. Introduction

Waste collection is an integral component of solid waste management (SWM) systems that contributes to both the costs and environmental emissions associated with managing solid waste. Although collection costs vary depending on population, population density, location, labor costs, and many other factors, waste collection has been reported to contribute over 40% of the total cost of municipal solid waste (MSW) management (Chalkias and Lasaridi, 2009). Emissions from collection vehicles vary based on factors such as truck type, fuel type, efficiency, and route characteristics, but collection has consistently been found to be the most fuel-intensive process in SWM systems (NREL, 1995). Therefore, a systematic characterization of the collection process is critical for developing and evaluating MSW management programs that cost-effectively minimize environmental emissions and energy use.

Limited collection process data have been previously reported. Agar et al. (2007) presented collection operation times and fuel

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Table 1
Characteristics of Organizations Providing Waste Collection Data.

Location or organization providing data[a]	Population density (pp/km^2)	% Multi-family units (MF)[b]	People/household	Data Provided or Measured[c,d]
City A	1080	27%	2.7	Obtained monthly fuel consumption and associated tonnage; observed four collection routes (one yard waste, one recyclables, two residual) and recorded distances, times, tonnages [calendar year (CY) 2012]
City B	1180	32%	2.8	Obtained GPS tracking data for 2 diesel and 2 CNG trucks over 4 collection days, for both residual and recyclables collection (route distances, times, tonnages) [CY 2012]
City C	4250	62%	2.2	Obtained monthly fuel use and tonnage for 68–77 residual waste vehicle routes and 45–62 recyclables collection routes [CY 2011]
City D	1160	32%	2.8	Obtained engine control module (ECM) records for residual and recyclables collection vehicles (e.g. fuel efficiency, total distance travelled) [CY 2010]
City E	1110	39%	2.4	Observed unload (tip) times (one day) at a material recovery facility (MRF); obtained tip times for City E tips for several days of operation [CY 2012]
City E	1110	39%	2.4	Obtained tip times for landfill and transfer station for several days of operation [CY 2012]
City F	1110	39%	2.4	Collection vehicle emissions study provided fuel use, mileage, tons per trip, tons per stop and collection activity times and distances for single- and multi-family residential and commercial collection [CY 2013]

[a] All cities are located in the U.S.
[b] Percent of housing units which are multi-family (U.S. Census City Data, 2014).
[c] Collection activity and route data were for single-family residential collection except where noted.
[d] All collection vehicles were diesel except where noted.

use obtained by examining global positioning system (GPS) records of refuse collection vehicles, but this did not include stop duration or time between stops, which are necessary to mechanistically estimate both truck and fuel requirements. Farzaneh et al. (2009) presented data on truck and fuel requirements, as well as durations and distances for all collection activities (e.g., transit to landfill, unloading) for three truck-days of collection. Measurements have been reported on refuse collection vehicles to better characterize emissions (Farzaneh et al., 2009) and engine performance (Ivani, 2007) during different operation, including urban driving, highway driving, refuse collection, and disposal activities. More recently, emissions and fuel use rates were measured for diesel and natural gas automated side loaders (Sandhu et al., 2016), diesel front loaders (Sandhu et al., 2014), and diesel roll-off collection vehicles (Sandhu et al., 2015). Heavy-duty diesel vehicles (HDDVs), a class that includes collection vehicles, have an estimated fuel efficiency of 2.8–3.2 km/L (6.6–7.5 mpg) (US EPA 2006). Since refuse trucks stop and start much more frequently than other HDDVs, they are expected to have lower fuel efficiency. A 2008 model year Autocar refuse collection truck with a Cummins diesel interact system model L (ISL) engine, for example, was reported to average 1.15 km/L (2.94 mpg) (WIH Resource Group, 2010). Values published in the literature for refuse vehicles vary significantly due to many factors including differences in collection vehicle fleet, housing density, and route characteristics. Additionally, fuel efficiencies per distance travelled do not consistently account for the fuel used during loading and unloading of waste, which can also vary significantly.

The objectives of this study were to (1) develop a set of empirical collection data to characterize MSW collection, (2) develop a set of default input parameters for use in mechanistic life-cycle collection models, and (3) illustrate how model parameters can be employed in a specific collection model.

The next section describes the acquisition and analysis of waste collection data. This is followed by presentation and discussion of measured collection data as well as data obtained from collection vehicle fleet operators and waste facility operators. Finally, a default data set for single-family residential collection is described. This data set is employed in the collection process model (Jaunich et al., 2016) of the Solid Waste Optimization Life-cycle Framework (SWOLF) (Levis et al., 2013) and illustrative results are discussed.

2. Methods

Waste collection data were assembled for several cities in the U.S. (Table 1). A number of route parameters for single-family collection of recyclables, yard waste, and residual waste were directly measured for City A. In the U.S., recyclables collection typically includes aluminum and steel cans, glass containers, paper, cardboard, and several types of plastic containers. In addition, data were provided by several municipalities and private collection companies (Cities B–E). Collection activity data obtained during a recent collection vehicle emissions study for City F were also incorporated (Sandhu et al., 2014, 2015).

Total logged distance, waste collected, fuel use, and truck capacity were used to estimate the fuel efficiency (L/kg), fuel use per metric ton (Mg) waste, and effective in-truck density (i.e., Mg/m^3).