Transportation Research Part E 62 (2014) 34–54

Contents lists available at ScienceDirect

Transportation Research Part E

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

Economic and environmental concerns in planning recyclable waste collection systems

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ARTICLE INFO

Article history:
Received 18 January 2012
Received in revised form 8 February 2013
Accepted 10 September 2013

Keywords:
Greenhouse gas emissions
Service areas
Vehicle routing problem
Multiple depots
Multiple products
Recyclable waste collection

ABSTRACT

This paper addresses the planning of recyclable waste collection systems while accounting for economic and environmental concerns. Service areas and vehicle routes are defined for logistics networks with multiple depots where different products are collected. The problem is modeled as a multi-product, multi-depot vehicle routing problem with two objective functions: distance and CO_2 emissions minimization. A decomposition solution method is developed and applied to a real case study. Six scenarios regarding different service areas and objective functions are studied. Savings of up to 22% in distance and 27% in CO_2 emissions are achieved, exceeding economic and environmental goals.

1. Introduction

Recycling involves the processing of used materials into new products, assuming that the product life cycle does not terminate upon product use or consumption. A new cycle then begins in which the primary objective is to recover the remaining value of these products by reinserting them into a forward supply chain (Rubio et al., 2008).

To achieve recycling targets, different collection systems must be built to accommodate the products involved. In Europe, the recycling targets imposed by the European Union have forced member states to develop new collection systems. The traditional routes defined for municipal generic solid waste did not fit the particularities of recyclable materials, for which different vehicles, collection rates and bin locations are required. This context frames the creation of two different waste collection systems—selective and undifferentiated—for recyclable and non-recyclable products. Manufacturers of recyclable products are responsible for providing an adequate destination for their products when they outlast their usefulness. However, this responsibility is often transferred to waste management companies that need to create new collection systems to comply with this responsibility.

The most common recyclable waste collection systems are those related to goods packaging, using materials such as glass, paper, plastic and metal. Different logistics systems can be designed to forward these materials to the recyclers. Variants of recyclable collection systems include systems based on the source separation of each material by the end user or systems based on post-separation at sorting stations. In addition, collection can be based on a single material by non-compartmented vehicles or based on multiple materials using multi-compartmented vehicles. Furthermore, the collection strategies can be based on curbside or drop-off systems, whereas their coverage may be municipal or multi-municipal.

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http://dx.doi.org/10.1016/j.tre.2013.12.002

Regardless of the variations mentioned above, transportation and sorting always appear as the core activities in managing recyclable waste systems.

Although recycling contributes positively to the environment (see Craighill and Powell (1996) for the environmental benefits of recycling), the activity of collecting recyclable waste is a transportation activity. Therefore, the collection generates greenhouse gas (GHG) emissions (such as CO_2, CH_4, HFCs and NO_x), resource consumption, land use, acidification, toxic effects on ecosystems and humans, noise and other negative impacts on the environment. Because GHG emissions are quite harmful (particularly CO_2 emissions), companies are seeking transportation solutions that minimize CO_2 emissions without compromising their economic goals.

The present work addresses the abovementioned concerns and aims to develop the basis for a decision support tool that can aid decision makers in planning recyclable waste collection systems. Specifically, the minimization of variable costs and CO_2 emissions are studied. The former is considered as a function of the traveled distance, whereas the latter is assumed as a function of the consumed energy.

This research has been motivated by a real recyclable packaging waste collection system operating in Portugal. The goal is to restructure its current service areas and vehicle routes to decrease the variable costs and CO_2 emissions. This case describes the concern of many companies operating in this field and is representative of the decision process in managing recyclable packaging waste collection systems.

Recyclable packaging waste collection systems typically collect three types of packaging materials within a geographic area: paper, glass and plastic/metal (see Fig. 1). Each system provides three types of specific bins scattered over a given area for the consumer to dispose of packaging waste. These materials are then often collected on separate routes because the vehicle fleet is not equipped with compartments. The collection routes are defined for a planning horizon because the recyclable materials have different collection frequencies. Each route is constrained by vehicle capacity and by duration of a working day. Depending on the facilities owned by the system and how the operations are planned, the collected materials can either be consolidated at a transfer station (depot) for later transport or they can be directly unloaded at the sorting station. The transfer stations (depots) act as storage points where the separated packaging materials are stored until there is sufficient quantity to fill a larger truck to be transported to the sorting station. After the sorting operation, the separated materials are baled, compressed and sent to recyclers.

When multiple depots are present, the service areas must be defined to establish the accountability of the different depots at each collection site. As shown in Fig. 1, routes are defined within each service area to collect the three materials. Two types of transportation flows must be considered: the inbound flow from the collection sites to the depots and the outbound flow from the depots to the sorting station. In addition to the distance traveled to collect materials from the collection sites, one must also account for the round-trip distance from the sorting station to the depots.

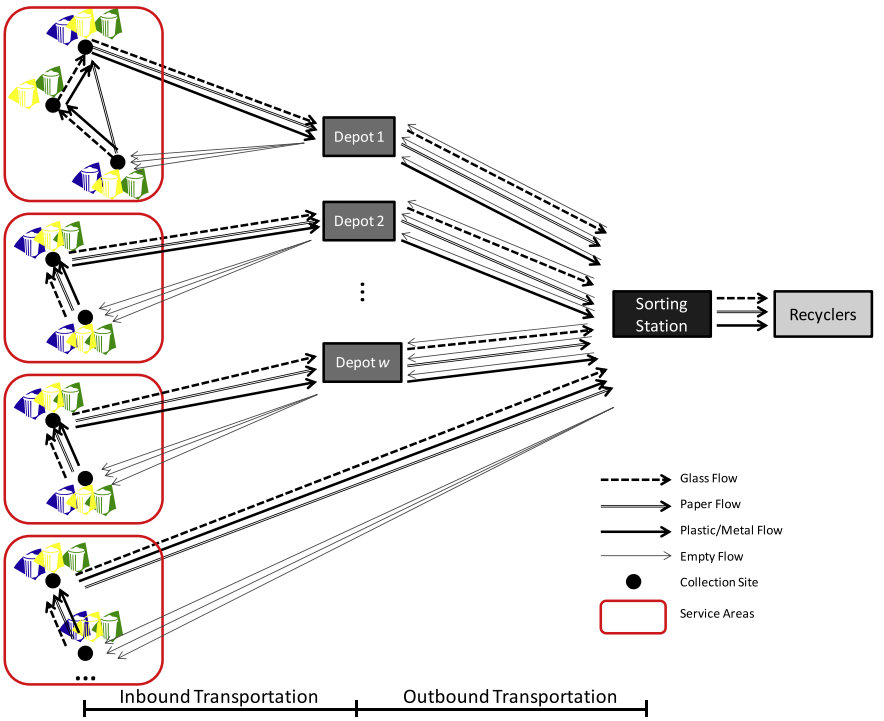

Fig. 1. Schematic representation of a recyclable waste collection network.