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Methodology to design a municipal solid waste pre-collection system. A case study

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ABSTRACT

The municipal solid waste (MSW) management is an important task that local governments as well as private companies must take into account to protect human health, the environment and to preserve natural resources. To design an adequate MSW management plan the first step consists in defining the waste generation and composition patterns of the town. As these patterns depend on several socio-economic factors it is advisable to organize them previously. Moreover, the waste generation and composition patterns may vary around the town and over the time. Generally, the data are not homogeneous around the city as the number of inhabitants is not constant nor it is the economic activity. Therefore, if all the information is showed in thematic maps, the final waste management decisions can be made more efficiently. The main aim of this paper is to present a structured methodology that allows local authorities or private companies who deal with MSW to design its own MSW management plan depending on the available data. According to these data, this paper proposes two ways of action: a direct way when detailed data are available and an indirect way when there is a lack of data and it is necessary to take into account bibliographic data. In any case, the amount of information needed is considerable. This paper combines the planning methodology with the Geographic Information Systems to present the final results in thematic maps that make easier to interpret them. The proposed methodology is a previous useful tool to organize the MSW collection routes including the selective collection. To verify the methodology it has been successfully applied to a Spanish town.

1. Introduction

In a municipal solid waste (MSW) management system, selective collection is divided into two stages: pre-collection and collection. Pre-collection includes the activities which involve the handling of the waste at origin (separation, storage and pre-processing) in order to gather it together to facilitate its collection. In some cases, this stage also involves modifying some of the physical characteristics of the waste material such as its density, moisture, etc. Collection is the activity that consists in transferring the MSW from the primary disposal site to a treatment plant. To define the selective collection system, it is necessary to take into account an important number of technical, economic, environmental and legal factors related to the place where the activity will be carried out (Rada, 2013; Baltes et al., 2009; Toso and Alem, 2014). Therefore, there is no single, universal model valid for all towns and cities.

The active role of citizens in the pre-collection stage, as waste generators and service users, means that the social factor is of great importance in designing it. Thus, Bolaane (2006) highlighted that the citizens' participation is one of the main factors to be considered when several selective collection alternatives are analyzed. There are a number of practical reasons why citizens might not participate in a selective collection system (Castagna et al., 2013; González-Torre and Adenso-Díaz, 2005). Some of these reasons include the distance to the collection point, overflowing bins, the lack of space at home, a distrust of correct management of the recovered materials, the presence of family members who are not willing to participate, the low number of recyclable products generated or poor knowledge of the selective collection system if they are new neighbors in the zone (Berné et al., 2000; Keramitsoglou and Tsagarakis, 2013; Martin et al., 2006; Wagner, 2013; González-Torre et al., 2003; McDonald and Oates, 2003). However, other studies show that a higher participation in the recycling system by citizens is related to their environmental awareness and to their considering that it is everybody's responsibility (Vicente and Reis, 2008; Rada et al., 2014a,b). In fact, Mueller (2013) found an increase in the separation ratios when the investment in recycling education

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programs increased. The methodology usually employed to assess the degree of acceptance in a new selective collection system or the implementation of certain measures to enhance the separation ratio is to conduct a citizens' survey (Bolaane, 2006; Karousakis and Birol, 2008; Keramitsoglou and Tsagarakis, 2013).

Another important point to be taken into account when designing a waste pre-collection system is the economic factor, which involves studying the investment and system management costs (Munizaga Plaza and Lobo García de Cortázar, 2013). Selective collection costs may represent 70% of the total cost of MSW management and can vary depending on the pre-collection system applied (Tavares et al., 2009; Rada et al., 2013). Several studies have analyzed the costs of the selective collection of MSW (Zsigraiova et al., 2013; McLeod and Cherrett, 2008). Some of them compare the economic costs of management systems that include selective collection with those without waste separation (Tonjes and Mallikarjun, 2013; Lavee, 2007), results varying from one study to another. Lavee (2007) established that selective collection is economically viable in medium-sized and large towns, whereas Tonjes and Mallikarjun (2013) pointed out that selective collection is not efficient if environmental factors are not taken into account.

One of the aims of selective collection is to improve the environmental conditions, as MSW reutilization and recycling reduces the extraction of resources required to obtain new materials (Margallo et al., 2010; Rada et al., 2014a,b; Raicu et al., 2011). Additionally, the recovery of nutrients and materials also reduces greenhouse gas emissions (Menikpura et al., 2013). Along similar lines, De Feo and Malvano (2009) showed that with the same MSW treatment, the scenario with a higher percentage of selective collection is environmentally better.

Nevertheless, the environmental impact will vary depending on how the pre-collection is carried out (Ionescu et al., 2013; Giugliano et al., 2011; Ghiani et al., 2012). For example, drop-off sites will cause less environmental impact than door-to-door collection or pneumatic collection (Iriarte et al., 2009). Large-volume containers will also generate less environmental impact than door-to-door collection (Rives et al., 2010).

Legislation is another important factor to be considered when MSW pre-collection is being designed. MSW management is ruled by international, national, regional and local regulations. Moreover, regulations can condition the generation of certain kinds of waste, like the generation of plastic bags, especially in those countries where regulations are more developed (Mazzanti et al., 2008). In Europe, Directive 2008/98/EC addresses the aims of waste recovery and recycling. In Spain, this Directive has been entirely transposed by the law Ley 22/2011 (BOE, 2011). In Flanders, the aim of the "Implementation plan for household waste 2003–2007 and sustainable management 2010–2015" is to reduce and maintain waste generation at 150 kg inh^{-1} $year^{-1}$ (Gellynck et al., 2011). In Denmark, the Waste Strategy 2005–2008 was developed to reach the aims established in Directive 2004/12/EC about the selective collection of packaging (Larsen et al., 2010). Similar regulations can be found in other European countries.

In addition, there are political programs to boost the reduction of waste, a more adequate handling of waste or greater recycling of materials. These objectives have been developed as plans which involve instruments offering incentives to manage MSW properly, to encourage selective collection or to punish excess waste generation. André-García and Cerdá Tena (2006) sorted these instruments into three classes: A payment proportional to the rate of generation, a tax applied to the packaging of products, and incentives on recovering and recycling. Some industrial sectors have committed themselves to achieving recycling goals as set out in the European Declaration on Paper Recycling 2011–2015. Hence, in 2015, a recycling rate of 70% must be attained by the European Union member countries. To achieve this aim, waste pre-collection and collection require a process design. In fact, the pre-collection design must define all its main elements (like the waste fraction rate, the storage level, the type of bin, etc.) as well as the relations. For example, the model proposed by Coutinho-Rodrigues et al. (2012) determines the number of facilities to be opened, their respective capacities, their locations, their respective shares of the total demand, and the population that is assigned to each of the candidate sites to be opened. Furthermore, they must be adapted to the characteristics of the geographic zone where the pre-collection will be carried out (Gellynck et al., 2011). For all these reasons, several authors have developed different methodologies that allow selective waste collection to be designed accurately. Correct distribution and size of the disposal points are essential to achieve the desired level of source separation, to offer a good service (disposal points without spilling and with low visual impact), and to facilitate waste collection. These methodologies establish a wide range of goals: optimization of the collection routes (Zamorano et al., 2009); estimation of MSW generation over time, and the weekly and daily peak hours (Zafra, 2009), in order to minimize the distance the user must walk to the collection bin and to maximize the number of users covered (Gautam and Kumar, 2005; Bautista and Pereira, 2006), or to highlight the relevance of regular system monitoring as a service assessment tool (Teixeira et al., 2014).

In the literature there are also several specific studies about how to carry out pre-selective collection in small towns (less than 50,000 inhabitants), like Churriana de la Vega (Zamorano et al., 2009) and Aranjuez (López Alvarez et al., 2009), and in big towns, like Hsinchu (Kao and Lin, 2002). Other authors compare different pre-collection scenarios in a zone. Tanskanen and Kaila (2001) analyzed the efficiency of six pre-collection scenarios in Helsinki, while Larsen et al. (2010) compared the influence of the rate of at-source separation in five pre-collection schemes in Aarhaus (Denmark).

The main aim of the present paper is to present a general methodology for designing MSW pre-collection and its application in a case study. The methodology detailed here is flexible so as to allow waste pre-collection design in towns with different characteristics.

Geographic Information System (GIS) tools are also used as a support in the methodology because they are extremely useful in work that needs to analyze and treat spatial data (for example, to measure distances, to optimize collection routes, to analyze the collection points and to allocate them, etc.) and it is an interactive decision support system (Tralhão et al., 2010). The methodology proposed in this paper can be a suitable tool for enterprises and administrations that deal with MSW management.

2. Methodology

In order to manage the MSW in a specific geographical area correctly it is essential to have previously defined an adequate pre-collection system. The methodology proposed here takes into account technical, economic, environmental and legal factors, among others, that affect every stage of the pre-collection design. In fact, when the specific characteristics of an area are considered, the pre-collection must be perfectly adapted to the socio-demographic, economic, cultural and geographic characteristics of the environment where the collection is to be carried out. Fig. 1 shows a schematic representation of the stages of the methodology proposed and the factors that affect each of them.

The purpose of the methodology is to help waste managers to locate the minimum number of MSW collection points in a town and determine the number of bins needed, taking into account some variables like the storage level (SL), the frequency of collection, the bin volume, etc.