Improving logistic efficiency of WEEE collection through dynamic scheduling using simulation modeling

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Abstract

The complexity of collection systems for Waste from Electric and Electronic Equipment (WEEE) in the EU is increasing, due to the latest directive that sets new collection targets and modes. The high variability and the uncertainty of reverse flows require innovative logistic approaches. One recent option for increasing efficiency and responsiveness in waste collection services, boosted by new technological solutions for waste level monitoring, is to adopt a dynamic collection scheme, where the collection frequency is not established a priori (based on a fixed plan), but it is based on the actual filling levels of waste bins. This option can allow the service provider to plan the collection service following the actual demand, resulting in a more responsive service, while improving the logistic efficiency. This paper evaluates the implementation of dynamic scheduling schemes for the collection of WEEE. A hybrid simulation model has been developed in order to support researchers and practitioners in assessing quantitative impacts of adopting dynamic scheduling in WEEE collection. Three logistic alternatives (a fixed collection schedule scheme, a pure dynamic scheme and a mixed one) have been compared in a test case based on data of an Italian municipality; collection services for different types of WEEE (i.e. large appliances and small items) have been analyzed. Results show a promising performance of dynamic schedules compared to the fixed one, revealing, for the specific test case, how a mixed solution can combine the advantages of dynamic and fixed scheduling, gaining flexibility towards customer demand while improving truck resource utilization.

1. Introduction

Waste from Electric and Electronic Equipment (WEEE) is one of the most critical waste flows worldwide. On one side, it is one of the fastest growing flows, since the volume of WEEE generated increases by a rate of 3–5% per year (Cucchiella et al., 2015). On the other side, products in the end-of-life stage contain precious materials that could be recovered, as well as hazardous substances that need to be treated and disposed properly (Mihai and Gnoni, 2016; Oliveira et al., 2012; Ongondo et al., 2011). Despite the Basel Convention treaty, the US and many European countries are exporting part of their WEEE to developing countries (mainly in Southeastern Asia and Africa), contributing to resource depletion and material loss for the exporter countries, while causing uncontrolled pollution and health issues related to a lack of waste valorization (Ongondo et al., 2011; Tansel, 2017). Despite the Basel Convention treaty, the US and many European countries are exporting part of their WEEE to developing countries (mainly in Southeastern Asia and Africa), contributing to resource depletion and material loss for the exporter countries, while causing uncontrolled pollution and health issues related to a lack of waste valorization (Ongondo et al., 2011; Tansel, 2017). Recently, the European Union established new collection targets for the member States, passing from a fixed target (i.e. 4 kg per inhabitant) (Directive 2002/96/EC) to a floating one proportional to the average quantity of EEE sold in the (three) previous years (Directive 2012/19/EU). This legislative change is forcing a strong increase in WEEE collection rate, which mainly depends on service efficiency. The adoption of new logistics models is essential to overcome some of the main criticalities related to WEEE collection. One recent solution, studied in some prototypal cases, is to transform the traditional (static) service approach into a Product-Service-System (PSS), where the service component (waste collection) is improved by a product component, i.e. technological solutions for waste monitoring and data transmission. This new approach could enable more dynamic collection schemes, in order to face the emerging complexity related to the management of highly variable waste flows. Specifically, a dynamic scheduling of the service, based on the actual level of waste produced monitored through sensors collecting real-time data, could be a valid alternative to the currently adopted fixed scheduling schemes, where the service is planned based on average demand forecast (Johansson, 2006).

This work analyzes the implementation of dynamic collection schemes for WEEE, comparing them with traditional fixed ones.
through simulation modeling. A dynamic collection scheme organizes collection frequency based on the actual level of bins; on the contrary, current collection services are often based on a fixed collection frequency set by an a priori service plan. The aim is to evaluate the technical efficiency of these new logistic models in collecting waste compared to traditional ones. A hybrid simulation model has been developed with this purpose.

The paper is structured as follows: a theoretical background is presented in Section 2. Section 3 describes the peculiarities of WEEE collection, with particular focus in the Italian system. Materials and methods are presented in Section 4, while results are discussed in Section 5. Section 6 summarizes the conclusions.

2. Theoretical background

2.1. Towards dynamic scheduling for waste collection

Collection and transportation are critical steps in a solid waste management system, both from an economic and environmental perspective, as they account for a consistent part of the total management costs and imply an intensive use of vehicles (Boskovic et al., 2016; Król et al., 2016; Zsigraiova et al., 2013). Therefore, new solutions that aim at increasing the efficiency and the environmental performance of the collection process, like PSS, could affect positively the overall sustainability of the waste management system. PSS has been defined as “a system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models”. The adoption of PSS models in the public services sector is quite a recent approach: several benefits could be outlined starting from an increase in service efficiency to economic savings (Mont, 2002). Waste management represents an interesting public service where the adoption of PSS could make a relevant contribution, in particular in the collection phase. The implementation of PSS models in waste collection is mainly based on the diffusion of Internet of Things (IoT) in this sector. One example is the possibility provided by IoT devices to track the waste bin level, but also to identify the users of the waste collection service (Elia et al., 2015; Hannan et al., 2015). According to the type of waste flow and to local constraints and conditions, different technological solutions can be chosen: several prototypes for measuring the filling level of a bin and transmitting data to the service provider have been presented in literature, along with different solutions for the user identification (Anagnostopoulos et al., 2017). The massive diffusion of IoT technologies in the waste collection process will support more effective and efficient economic models, like the Pay-As-You-Throw (PAYT) approach, as well as innovative logistics models, like dynamic scheduling, which are implicitly connected. The basic idea derives from the PSS paradigm: the process has to be designed based on the actual demand of the user. Therefore, PAYT aims at charging the user proportionally to the service received, depending on the type and the quantity of the waste provided to the waste service (Biliweski, 2008). According to scientific literature, this approach results in several advantages for the user, the service provider and the society. On one side, it would improve the equity of the system, since the user would pay a fee proportional to the effective use of the service. This could also promote virtuous behavior, with environmental and economic benefits related to the increase of recycling rate; however, this outcome can change from case to case, since it is strictly dependent on the public perception of the PAYT system implemented (Dahlien and Lagerkvist, 2010). Dunne et al. (2008) analyze this issue and suggest some guidelines to improve acceptability. On the other side, an effective design of the system would allow the service provider to benefit from the economic advantages related (Reichenbach, 2008).

Dynamic scheduling aims at organizing the collection frequency based on the actual filling level of the waste bin rather than on fixed dates, and it has recently become a topic of increasing interest for researchers and practitioners (Elia et al., 2015). Dynamic scheduling can extend the “Pay-As-You-Throw” logic to a “Pay-As-You-Use” one by performing the collection only when required (Elia et al., 2016). Waste measurement in the different collection points, required in a PAYT system, can be combined with real time data collection and update, allowing the service provider to know the actual state of the system, including data about which collection point is getting full and needs to be served first. This could heavily improve the overall collection efficiency, since the service adapts to the current demand, as opposed to traditional schemes with fixed scheduling based on forecasts usually estimated on average generation rates (Fig. 1).

The focus of this study is to evaluate the technical convenience of adopting dynamic scheduling in waste collection from a logistics point of view.

2.2. Dynamic waste collection: a literature analysis

A literature analysis was performed to outline the state of the art about dynamic collection services in waste management. Recent studies deal with the technological and organizational perspectives, analyzing design issues or describing case studies. Thürer et al. (2016) analyzed the adoption of an IoT system for waste collection as a Kanban-based system, thus based on actual demand (the so called pull system) rather than on forecasts (as in traditional push systems). The Kanban method is a card-based inventory-control system usually applied in just-in-time manufacturing to manage pull production (Sugimori et al., 1977). The authors describe analogies and differences between Kanban for manufacturing processes and for reverse logistics, with a focus on the waste services. Anagnostopoulos et al. (2017) proposed a taxonomy for classifying intelligent waste management systems and their components, and used it to perform a literature analysis on IoT-based applications for waste management. Hannan et al. (2011) proposed a system based on different IoT technologies (RFID, GPS, GPRS and GIS) that helps monitoring the status of each bin, allowing to collect updated historical data for optimizing collection services. Similarly, Sharmin and Al-Amin (2016) described a cloud-based system for waste collection able to gather data about the bin weight and optimize the routing based on actual filling level; no comparisons with other approaches was proposed. Finally, Lindström et al. (2017) analyzed a collection model based on IoT technologies for dynamic scheduling, focusing on the description of the main organizational impacts for the provider, as well as advantages for the customers.

Other studies in the literature analyzed the implementation of dynamic scheduling focusing on the economic advantages and efficiency of these models, often compared to fixed ones. Johansson (2006) used analytical modeling and discrete events simulation (DES) to compare different scheduling and routing policies, based on real data from a Swedish solid waste management system with smart containers. Results showed the positive impact of adopting dynamic scheduling and routing for reducing operational cost in waste collection services in large areas; the benefit decreased for smaller contexts. Faccio et al. (2011) proposed an effective multi objective model integrated with traceability data, tested on an Italian municipality. Their analysis also included investment costs, demonstrating the economic feasibility of the system. Similarly, Anghinolfi et al. (2013) proposed a decision model for the dynamic optimization of materials collection in a waste management system, integrated with a GIS-based decision support tool; the model allowed an economic comparison between the fixed and dynamic services. Asimakopoulos et al. (2016) proposed a dynamic routing
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