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Product-Service Systems across Life Cycle

Assessing the efficiency of a PSS solution for waste collection: a simulation based approach

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Abstract

Driven by both policy pressures and environmental concerns, new business models are becoming applied in waste management mainly based on introducing more equitable and sustainable pricing schemes (e.g. “pay-as-you-throw”): the aim is to support the transition from a tax based system to a pure service based approach, where the user pays for the actual use of the waste management service provided. This new trend requires the service provider’s activities to be planned with a schedule that reflects the actual users’ needs in order to reach a real efficiency in the collection phase: dynamic routing and scheduling schemes, which could be enabled through the application of smart technologies, can lead to a more rational use of the resources. In the last decade, technological progresses allowed a growing use of IoT (Internet-of-Things) applications in the service sector; recent pilot applications are being tested also in waste management; one example is the introduction of bin level detection and data transmission technologies for waste collection. This work aims to contribute to the assessment of IoT-based PSS solutions for waste collection. The main objective is to evaluate the cost efficiency of a PSS for waste collection enabling dynamic scheduling, comparing it to the performance of more common schemes (e.g. fixed routing and scheduling service and call-based service). Hybrid simulation modelling – based on system dynamics, discrete events and agent based modelling- has been applied to test the transition from a fixed to a “pay-as-you-throw” fee in WEEE (waste from electrical and electronic equipment). A test case regarding an Italian municipality has been proposed to assess quantitative results based on a simulation model.

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Keywords: PSS design; waste collection; WEEE; pay-as-you-throw; hybrid simulation modelling; system dynamics; agent based modeling

1. Introduction and problem statement

Waste of electrical and electronic equipment (WEEE) is one of the most critical waste stream worldwide, with a production of 41,8 Mt/yr in 2014, of which 6,5 Mt/yr collected and treated by formal national take-back systems, and a forecasted growth rate of 4-5% per year until 2018 [1], which is about three times the growth of municipal solid waste [2]. Due to these increasing flows of materials, legislations are being updated in several nations. One example is the new European directive on WEEE (2012/19/EU), establishing new collection objectives and redefining some rules in the framework of WEEE management [3]. One main innovation introduced by the Directive is about the way to measure the target level of waste to be collected: it proposed a modification from fixed values (4 kg per inhabitant per year) to floating targets based on a fixed percentage (i.e. 45%) of the average weight of EEE placed on the market in the three preceding years. This change will heavily increase quantities of waste to be collected from the reverse logistics system. Moreover, collection models have been also modified: besides the traditional “*one-to-one*” collection service available – i.e. the WEEE is collected for free when you buy a new EEE -, a “*zero to one*” collection service – i.e. it is not mandatory to buy a new EEE if you want to leave your WEEE - must be activated for free by retailers for small WEEE. This change will determine a higher variability of the quantities to be collected at the retailer. The future diffusion of “*one-to-zero*” option, together with new quantitative targets to be reached, will push retailers to create new reverse logistics models.

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Different models have been applied worldwide in the WEEE reverse logistics [3], [4]. The present study proposes the adoption of the PSS (Product-service system) approach for designing new WEEE collection services. PSSs are defined as "a system of product and services supporting network and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models" [5]. Adopting PSSs in WEEE reverse logistics can enable the implementation of new collection services: traditionally, collection services in waste management are based on a fixed collection period, estimated based on forecasted waste quantity. More dynamic models should be adopted for facing the increase of quantity and variability of WEEE flows. This paper proposes a hybrid simulation model to assess the feasibility of adopting an Internet of Things (IoT)-based system to enable a WEEE collection service based on PSS approach. The aim is to evaluate how hybrid modelling can be applied to verify the efficiency and capability of PSS-based models to follow the uncertainties and variability of the WEEE collection demand.

The remainder of the paper is structured as follows: firstly, a brief state of the art about dynamic scheduling in waste management implemented through IoT solutions is proposed in Section 2. The main features and burdens characterizing the problem in analysis are detailed in Section 3, and the hybrid simulation model is described in Section 4. Section 5 draws results and discussion, while conclusions are summarized in Section 6.

2. Waste monitoring and dynamic collection services: a brief analysis

Adopting PSS approach in waste management is a new issue. Tukker [6] defined as result-oriented those PSS in which "the client and provider in principle agree on a result, and there is no pre-determined product involved". IoT technologies could represent a value-added tool for supporting the adoption of PSS approach in waste management services. A review by Hannan et al. summarizes the technologies used in solid waste monitoring and management systems [7]. According to the type of waste flow and to local constraints and conditions, different IoT technologies sets can be chosen to enable smart collection through dynamic scheduling: several prototypes for bin level detection and data transmission have been presented in literature [8]. Despite the increasing diffusion of IoT technologies both in the industrial and service sector [9], they are still in an experimental stage in the waste management field. One reason is that the adoption of IoT technologies for monitoring waste quantities requires new reverse logistics models: from traditional ones based on fixed collection frequencies to more dynamic approaches based on variable collection frequencies. The use of IoT technologies for enabling smart waste collection through dynamic scheduling has recently become a topic of increasing interest for researchers and practitioners [8]; according to Tukker's definition, these solutions can be classified as PSS. Nevertheless, Lelah et al. [10] were the first to define waste collection service based on IoT technologies as a PSS. In their work, they discuss the use of a machine-to-machine PSS solution for waste glass collection, analyzing its main environmental impacts and benefits through LCA. Some other studies in literature analyze the effects of dynamic scheduling in waste collection, both from an economic and environmental side. Johansson [11] performed a study using analytical modeling and discrete events simulation to compare different scheduling and routing policies, based on real data from a Swedish solid waste management system with sensors-equipped containers. This revealed that dynamic scheduling and routing have significantly lower costs than a static policy in large systems, this advantage decreasing when switching to smaller contexts. Faccio et al. [12] proposed a multi objective model integrated with traceability data, tested on an Italian municipality, which demonstrates its economic feasibility. Similarly, Anghinolfi et al. [13] proposed a decision model for the dynamic optimization of materials collection in a waste management system, showing the benefits with respect to the traditional system, while Anagnostopoulos et al. [14] presented a dynamic waste collection model for high priority areas, based on IoT technologies.

3. The problem in analysis

3.1. The Italian WEEE collection service

Most European states organize WEEE collection through a double channel: in partnership with the existing municipal solid waste collection schemes and through additional take-back systems involving EEE retailers [4]. This happens also in Italy, where several Collection Systems are in charge of the WEEE management, coordinated by a Coordination Center (Fig.1). Five categories of WEEE are identified - R1, R2, R3, R4 and R5-, which define the type of WEEE: as an example refrigerators fall under R1 category or PC under R4. Each EEE producer has to adhere to a Collection System, if it does not wish to provide itself a separate collection scheme. As previously explained, EEE retailers guarantee free one-to-one collection for all types of WEEE, and free one-to-zero collection for small WEEE (compulsory only for big retailers), realizing a preliminary deposit of the collected e-waste. Retailers can choose to send WEEE to collection centers either every three months, or when the quantity reaches the weight of 3.5 tons, in both cases following the constraints defined by the legislative decree (D.Lgs 151/2005).

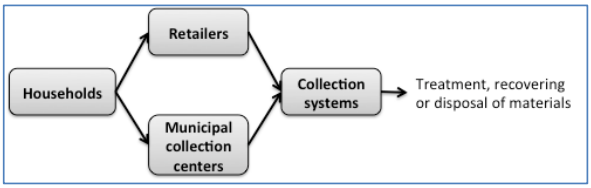

Fig. 1: Main stakeholders and flows in the Italian WEEE collection system