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Product-Service Systems across Life Cycle

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

Valerio Elia, Maria Grazia Gnoni, Fabiana Tornese*

Department of Innovation Engineering, University of Salento, Campus Ecotekne, via per Monteroni, 73100 Lecce

* Corresponding author. Tel.: +39 3298471817. *E-mail address:* fabiana.tornese@unisalento.it

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).

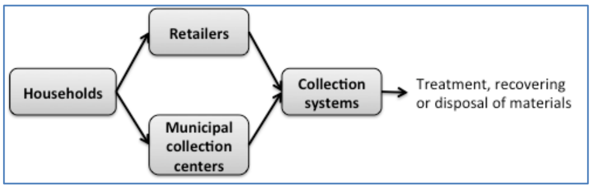

Fig. 1: Main stakeholders and flows in the Italian WEEE collection system

3.2. The analyzed WEEE collection scenarios

In this paper, we focus our attention on the e-waste flow managed by retailers, which need to respect binding constraints in the WEEE management, as already explained: whatever type of collection schedule the retailer chooses, the e-waste deposit can never exceed 3.5 tons in weight. Therefore, we consider two possible scenarios for the collection of e-waste from retailers that will be transported to collection centers, and later to treatment plants, under the responsibility of some collection system. In detail the two scenarios are:

- Scenario (S1): it is based on a fixed collection frequency, and it is currently the most applied model. The retailer stipulates a contract with the logistic company that has the license to transport WEEE, defining a fixed schedule based on historical data and forecasts. Whenever the weight of the e-waste stocked at the retailer reaches a critical level, an emergency call to the logistic provider for an extra service is done. In this scenario, each retailer needs to monitor the weight of its WEEE deposit, in order to fulfill law requirements (Fig. 2). In this case, the service cost is made up of a fixed and a variable part. The first one is related to the basic service scheduled by contract, the second one is the extra fee that the retailer has to pay every time an extra call is made.

- Scenario (S2): this is a PSS-based model as it is based on an “adaptive” collection frequency as an IoT-based system enables weight monitoring and data transmission. In this case, the logistic provider company is directly informed about the state of each retailer served and can organize its service according to their actual needs. Thus, the scheduling is dynamic and flexible and no emergency calls are needed (Fig. 3). Consequently, in this case the cost of the service bore by the retailer is proportional to the actual number of collections performed by the service provider.

Therefore, we consider the number of emergency calls (in S1) and of services performed (in S2) as drivers for the total cost of the service payed by the retailer.

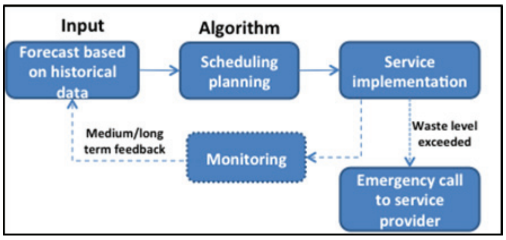

Fig. 2: The WEEE collection service proposed in the Scenario 1.

Some conceptual advantages of scenario S2 compared to scenario 1 can be easily outlined: the PSS gives the logistic provider the possibility to plan its activities with more precision, as there are not extra calls from customers and the level of e-waste is known in real time.

The service is performed only when needed, avoiding waste of time and resources and adapting to the variability of the demand. Moreover, the retailer does not need to use its resources or time to monitor the waste level anymore: this task is carried out by the PSS. Nevertheless, a deeper analysis is still needed to determine the actual economic convenience of a dynamic solution for e-waste management. We do not specify here which technologies are used to implement the PSS, as the focus of this work is not the design of the system. In this first phase of the study, we are only interested in estimating the efficiency of the PSS, considering the costs for the retailers.

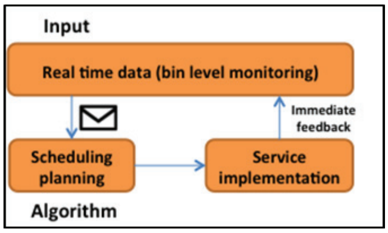

Fig. 3: The WEEE collection service proposed in Scenario 2.

4. The proposed hybrid model and its main assumptions

The two scenarios have been built using Anylogic® software (release 7.2) that allows hybrid modeling thanks to a multi-method environment. This test case considers five big retailers (bounded to the one-to-zero policy) in a southern Italy municipality (Lecce). The position of the retailers and of the collection center, as well as the truck’s movements, have been modeled through the GIS component of the software. Both retailers and trucks have been modeled as agents. For retailers, a system dynamics diagram simulates the stock and flows of e-waste. In particular, two components influence the incoming flow: one is proportional to EEE sells (one-to-one collection) according to a generation rate, while the other represents the effect of one-to-zero policy, influenced by a zone coefficient that considers the popularity of the retailer considered (Fig.4). The generation rate has been set to 0.45, which is the objective indicated by the current law for 2015: we assume that this target is reached in each of the retailers considered. A state-chart regulates the behavior of trucks, which are called to service every time it is scheduled or an emergency call is done in S1, or every time the monitoring system of a retailer indicates a critical level in S2 (Fig. 5). Therefore, a critical level of e-waste has been set, calculated considering a forecasted time range before reaching 3.5 tons of 3 days (in S1) or 1 day (in S2). This difference reflects the higher flexibility given by real time data availability for the service provider in S2, while in S1 it needs a longer period to reorganize its activities when an emergency calls happens. Finally, discrete events simulation models the collection process, once the truck arrives at the retailer's location.

The total number of scheduled and emergency calls (in S1) and of services performed (in S2) has been monitored, as it has been considered as a driver for the estimation of the total cost of the service born by the retailers. Next to this, the hybrid model measures the total quantity of e-waste collected from each retailer, in both scenarios. Data about EEE sales were estimated starting from the last Italian WEEE reports [15], [16], [17], considering them proportional to the population of the municipal area studied, and assuming that the five retailers modeled realize the 50% of EEE sales in the area. However, as the enforcement of the new directive will take place in the next months, these data are subject to high variability. For this reason, several tests with different quantities of WEEE collected have been performed. The simulation time is 6 months.

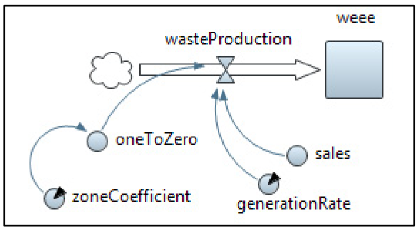

Fig. 4: System dynamics diagram for WEEE production

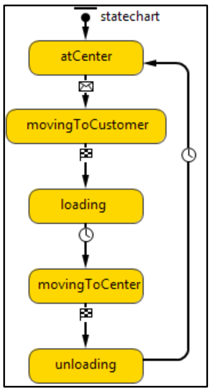

Fig. 5: State-chart of the truck

Table 1: Data about EEE sales (source [16], [17])

Year	EEE sold in Italy (tons)	EEE sold in Lecce (estimated tons)
2013	736625.5	1142.8
2014	804452.9	1248.0

5. Results and discussion

Four tests have been run in this preliminary stage of the study, according to the following conditions:

- The baseline (test 1) includes only the "one-to-one" component of the WEEE collection, which is the model currently applied in Italy and other EU countries.
- Test 2 includes both the "one-to-one" and the "one-to-zero" components. The critical levels of e-waste are calculated based on the *maximum* estimated value of daily WEEE collection (worst-case) for both scenarios.
- Test 3 includes both the "one-to-one" and the "one-to-zero" components. The critical levels of e-waste are calculated based on the *average* estimated value of daily WEEE collection for both scenarios.
- Test 4 follows the same assumptions of Test 3, but the quantity of e-waste is more variable.

Table 2: Input data for the three tests (Scenario 1 and 2)

Test	Critical level (S1) [kg]	Collection period (S1) [days]	Critical level (S2) [kg]
1 (baseline)	3014	18	3338
2	2870	13	3290
3	3074	21	3358
4	2993	17	3331

A uniform distribution models daily EEE sales in tests 1, 2 and 3, while a pert distribution is used in test 4. The one-to-zero component is modeled through a pert in all tests. Table 2 reports the input data for the four tests performed so far. The different conditions of the four tests performed try to simulate an increasing uncertainty of demand forecasts, which is one of the critical factors in the design of waste management services.

Table 3 shows the results of the simulation runs: the value reported for each indicator is the average of the five retailers considered. This allows us to make some observations.

- The average amount of waste collected per retailer for each test slightly diverges in the two scenarios. The difference of kg collected between S1 and S2 ranges between 190 kg (test 2) and 970 kg (test 4), representing respectively the 0.7% and 3% of the amount collected, and it is due to the different collection models.
- The average amount of waste collected per retailer increases from the baseline to test 4, because of the one-to-zero component (not included in the baseline) and the increasing variability of the sales. Consequently, the number of calls per retailer increases as well in both scenarios.
- In scenario 1, the increase of e-waste causes a higher number of scheduled calls in test 2, but no extra-calls are needed thanks to the forecasts that considered the worst-case scenario: the critical level is low enough that the

emergency condition is never reached. On the contrary, in test 3 a more optimistic estimation of the demand (based on average instead of maximum value of waste produced) causes the activation of several emergency calls (4.8 on average). Although the total number of calls is almost the same in both cases (14 in test 2 and 13.8 in test 3), it is likely that a higher cost would be bore by the retailer in test 3, as extra services have been required. The same considerations can be done for test 4, where the higher uncertainty of the demand causes a further increase of the extra calls (7.6), while the scheduled calls remain close to the baseline value.

- On the other hand, in scenario 2 we notice a more gradual growth of the calls: only 0.7 more in tests 2 and 3, 2 more in test 4 compared to the baseline. This is due to the different nature of the service designed, which seeks to respond to the customer's needs in a flexible way, avoiding waste of resources.
- Comparing the performances of the two scenarios, we can notice that in all tests S2 allows to have a lower number of calls than S1 (as shown in the graph in Fig.6). Even in conditions of lower uncertainty (baseline), the flexibility of the PSS allows to keep a higher critical e-waste level, therefore to delay the service request. When the uncertainties arise (test 2, 3 and 4), the fixed schedule of scenario 1 performs even worse, not being able to follow the fluctuations of the demand. The difference of number of services requested ranges between 3 (baseline) and 9.6 (Test 4).
- For S2 we find the same performance in tests 2 and 3, while this is not true for S1. This confirms that a fixed schedule is considerably more sensitive to the accuracy of data forecasts than a PSS. Therefore, the introduction of the one-to-zero component, increasing the uncertainty on the amount of e-waste collected, might heavily reduce the efficiency of a fixed schedule for retailers.

Table 3: Results for the four tests, Scenario 1 and 2 (average values per retailer)

	S1			S2	
Test	Kg collected	#base calls	#extra calls	Kg collected	#PSS calls
1 (baseline)	22905.5	10.2	0	23442.2	7.0
2	25283.1	14.0	0	25092.9	7.6
3	25138.5	9.0	4.8	25608.7	7.6
4	31070.0	11.0	7.6	30100.2	9.0

Some potential criticalities of this study have to be pointed out. In this preliminary analysis, we did not differentiate among the five WEEE categories, even though in the real case there can be a distinction in the collection phase. A following step in this study could include a more detailed simulation model to analyse the efficiency of a PSS solution in more complex environments, including the simulation of the seasonality for the two components of e-waste production.

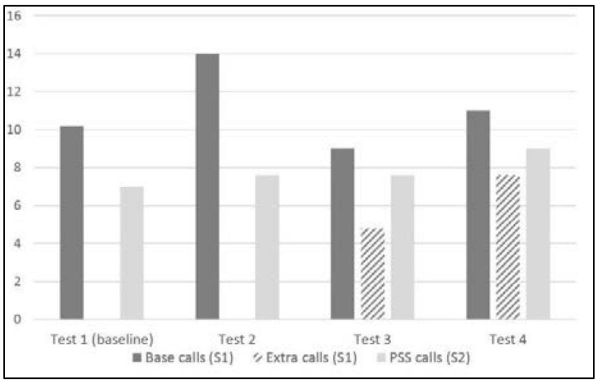

Fig. 6: Number of service calls for both scenarios in the four tests

Moreover, the analysis of the efficiency so far relied only on one main performance indicator (i.e. the number of services performed). This allows a qualitative evaluation of the two scenarios. For a deeper analysis, other points should be analysed in depth, such as the definition of the technologies used for the PSS and the cost structure of the service for the retailers. This would allow quantifying the advantages of a PSS solution versus a traditional one (e.g. through a cost-benefit analysis). Finally, an environmental comparison between the two collection scenarios could complete the economic evaluation, defining the sustainability profile of the two solutions. All these improvements can be considered for further research.

6. Conclusions

The new EU directive about WEEE management imposes new collection targets, as well as new collection models (i.e. one-to-zero). Aiming at increasing the amount of e-waste collected, this will be likely to have an impact on retailers, who will need effective e-waste management models to meet the new requirements. With these conditions, a collection scheme based on a fixed schedule and extra emergency services could be no more economically efficient: a pure service based approach with dynamic schedule might be more economically convenient for retailers. Researchers and practitioners have been exploring the use of PSS solutions in the waste management sector, mainly for the implementation of pay-as-you-throw schemes, even though it has not been applied for WEEE yet. In this preliminary study, two scenarios are analysed with the aim of assessing their efficiency for the retailers: a PSS for e-waste collection and a fixed schedule scheme have been compared through a hybrid simulation model. The analysis showed that a PSS could better follow the fluctuations of the demand, working on the base of the retailer's needs, while a fixed schedule revealed to be ineffective when the variability of the demand arises, causing an increase of extra calls, thus of the costs for the retailer. Moreover, the PSS allows the retailer to keep a higher e-waste critical level, as its response to the service demand is quicker than in a fixed schedule. For this reason, even with precise forecasts of the demand, the number of collections with a PSS results considerably lower than in a traditional scheme.

Future research can include in the simulation model more complexity by adding different e-waste flows and more variable demands. Moreover, a quantitative cost analysis and an environmental impact analysis can detail the sustainability profile of the two scenarios considered.

References

[1] Baldé C. P., Wang F., Kuehr R., and Huisman J. The global e-waste monitor – 2014. United Nations University, IAS - SCYCLE, Bonn, Germany, 2015.

[2] Duygan M., Meylan G. Strategic management of WEEE in Switzerland—combining material flow analysis with structural analysis. Resour. Conserv. Recycl., 2015; 103: 98–109.

[3] De Felice F., Elia V., Gnoni M.G., Petrillo A. Comparing environmental product footprint for electronic and electric equipment: a multi-criteria approach. Int. J. Sustain. Eng., 2014; 7(4): 360–373.

[4] Elia V., Gnoni M.G. How to design and manage WEEE systems: a multi-level analysis. Int. J. Environ. Waste Manag., 2015; 15(3): 271.

[5] Mont O. Clarifying the concept of product–service system. J. Clean. Prod., 2002; 10(3): 237–245.

[6] Tukker A. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strategy Environ., 2004; 13(4): 246–260.

[7] Hannan M. A., Abdulla Al Mamun M., Hussain A., Basri H., Begum R.A. A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges. Waste Manag., 2015; 43: 509–523.

[8] Elia V., Gnoni M. G., Tornese F. Designing Pay-As-You-Throw schemes in municipal waste management services: A holistic approach. Waste Manag., 2015; 44: 188–195.

[9] Atzori L., Iera A., Morabito G. The Internet of Things: A survey. Comput. Netw., 2010; 54(15): 2787–2805.

[10] Lelah A., Mathieux F., Brissaud D. Contributions to eco-design of machine-to-machine product service systems: the example of waste glass collection. J. Clean. Prod., 2011; 19(9–10): 1033–1044.

[11] Johansson O. M. The effect of dynamic scheduling and routing in a solid waste management system. Waste Manag., 2006; 26(8): 875–885.

[12] Faccio M., Persona A., Zanin G. Waste collection multi objective model with real time traceability data. Waste Manag., 2011; 31(12): 2391–2405.

[13] Anghinolfi D., Paolucci M., Robba M., Taramasso A.C. A dynamic optimization model for solid waste recycling. Waste Manag., 2013; 33(2): 287–296.

[14] Anagnostopoulos T., Kolomvatsos K., Anagnostopoulos C., Zaslavsky A., Hadjiefthymiades S. Assessing dynamic models for high priority waste collection in smart cities. J. Syst. Softw., 2015; 110: 178–192.

[15] Centro di Coordinamento RAEE. Rapporto annuale 2012 - Ritiro e trattamento dei rifiuti da apparecchiature elettriche ed elettroniche in Italia. 2013.

[16] Centro di Coordinamento RAEE. Rapporto annuale 2013 - Ritiro e trattamento dei rifiuti da apparecchiature elettriche ed elettroniche in Italia. 2014.

[17] Centro di Coordinamento RAEE. Rapporto annuale 2014 - Ritiro e trattamento dei rifiuti da apparecchiature elettriche ed elettroniche in Italia. 2015.