ANALYSIS AND EVALUATION A WEEE MANAGEMENT SYSTEM IN ITALY: A SIMULATION STUDY

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ABSTRACT
This paper presents a simulation study to evaluate the current performance of a waste of electrical and electronic equipment (WEEE) management system in the north of Italy.
The model takes into account several actors of the real WEEE supply network and allows to analyze different alternative scenarios for the functioning of the same network. The behavior of a real treatment plant has been simulated considering the incoming flow of waste material and all the outflows of recycled goods. The analysis is focused on two specific WEEE categories treated in the plant, which have been chosen as the most dangerous categories for the human health and the environment.
Some key performance indicators (KPIs) have been defined and used to assess the performance of the current WEEE network and compare it with some alternative configurations.
As it grounds on a real scenario, the model is expected to provide interesting proposals for future actions about the WEEE management in Italy.

1. INTRODUCTION

In the last years, the European governments have increasingly focused on the theme of the end-of-life management and recovery because of the lack of resources and the problem of waste management (Directive 2002/96/EC). In such context, reverse logistic activities become crucial to manage the reverse flow of materials from the final costumer to the manufacturer (Achillas et al., 2010).
As a consequence, the topic of the performance of closed-loop supply chains is becoming more and more studied in the current literature (Nukala & Gupta, 2007, Georgiadis & Besiou, 2010, Phuc et al. 2013; Bottani et al., 2015).
The interest in recycling electronic goods has recently increased, with the purpose of obtaining raw and secondary materials that can be put again in the production system and consequently sold on the market. Consequently, several case studies on the return flow of waste of electric and electronic equipment (WEEE) were published in recent years (e.g., Krikke et al., 2003, Gomes et al., 2011, Alavi et al., 2015).
WEEE include big and small electrical equipment such as computers, TV-sets, fridges and cell phones that don't work anymore. WEEE are grouped into 5 different categories depending on the kind of equipment. To be more precise, the categories are:

- R1 - refrigerating equipment (e.g. refrigerators, freezers, for conditioning equipment);
- R2 – "Big white" equipment (e.g. washing machines, dishwashers, microwave ovens, cookers, etc.);
- R3 - TV and monitor (e.g. televisions or computer monitors);
- R4 – ICT equipment, lighting equipment and others (e.g. vacuum cleaners, sewing machines, irons, fryers, blenders, computers components, printers, fax machines, mobile phones, video recorders, radios…);
- R5 - Light sources (e.g. neon, energy saving lamps, mercury vapor, sodium, iodide).

The main problems of the WEEE disposal is the presence of hazardous substances and the constant growth of their production volumes (Sthiannopkao & Wong, 2013). Also, WEEE recycling should ensure economic profitability of recovering the related raw materials (such as steel, aluminum, plastic…) and making them reusable. To this end, it is self-evident that a good recycling system is needed to maximize the recovery of components, as well as to dispose the non-recyclable material.
In Italy, the WEEE management systems are defined by the Decreto Legislativo 151/2005. Such a decree describes the organization of the global WEEE management system in terms of actors, manufacturers, local authorities, distributors and treatment plants, as shown in Figure 1.
The logistic network plays a crucial role in managing the reverse flow of WEEE. In particular, the location and capacity of both the collection points and the treatment plants are among the main leverages that affect the performance of the whole system.
This study focuses on the performance evaluation of a real WEEE management system, i.e. that of the area of

Parma in the north of Italy. We investigate, in particular, the flow of materials from the collection points to the treatment plant. All the data on the material flows have been provided from the local group that manages the garbage collection in the area of Parma and of the neighbor districts.

The remainder of the paper is organized as follows: section 2 analyses the context, section 3 exposes the logic of the simulation model. Then, the main results are shown in section 4 and some general conclusions are presented in section 5.

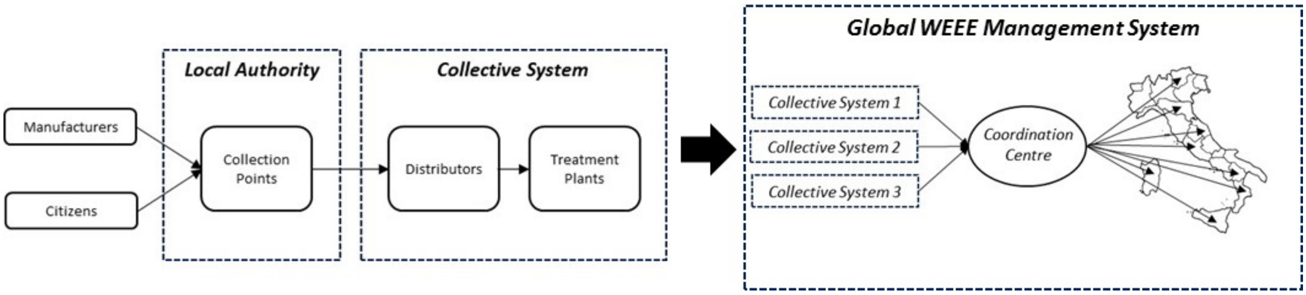

Figure 1: Italian WEEE management system

2. THE WEEE MANAGEMENT SYSTEM

In Italy, the total amount of WEEE recovered in 2014 accounts for about 230,000,000 kg/year in the whole country, with 136,386 pickups in a year.

In this study, we analyze the situation of a specific region, i.e. Emilia Romagna, which in 2014 achieved the second place in terms of WEEE total collection, with the 10% of the total amount of WEEE of Italy collected in that region. In such region, 11 different institution operate with the aim of managing the collection of the urban waste. Iren, the company that was involved in this study, manages the WEEE collection in the municipality area of Parma and controls 153 collection points. The total amount of material recovered in such area is about 1,650,000 kg/year, of which 19% R1, 30% R2, 27% R3, 23% R4 and 1% R5.

A detailed analysis of the WEEE collection system shows that Iren manages only the first part of the supply chain, i.e. from the end-users to the collection points, while the collective system handles the flow of WEEE from the collection points to the treatment plants. The collection system also makes decisions about the number and location of the plants involved in the recovery system, as well as on the amount of WEEE material that will be shipped to each of them. Finally, a coordination center should supervise the work of the collective systems, in order to guarantee a good service in each area of the country.

3. THE MODEL

A simulation model has been created using MS Excel^{TM} with the purpose of reproducing the flow of WEEE in the targeted area, as well as to simulate the treatment process of WEEE at the processing plant.

A specific plant, belonging to the consortium, has been visited with, with the purpose of collecting the necessary data to simulate its daily work. Example of these data are the production capacity and the possible constraints (e.g. the warehouse capacity). The targeted processing plant treats only 2 WEEE categories, i.e. R1 (refrigerators) and R3 (TVs and monitors). Indeed, each treatment plant is usually specialized in (and authorized for) the processing of a limited number of WEEE categories, because of the complexity of the processes required for the different WEEE. The categories treated by the targeted plant are considered as the most dangerous ones for the human health and the environment. The plant works 5 days/week for 8 hours/day in a one-shift situation, although the capacity of the plant could be doubled working on two shifts per day.

Overall, the network considered in the model consists of the treatment plant that receives the materials from (1) some collection points managed by Iren by means of external distributors, (2) other collection points located out of the Parma area but sufficiently close to the plant. Finally, the plant delivers the recovered materials to different markets and it disposes the waste in specific disposal plants. The supply chain examined is shown in Figure 2.

The simulation model developed is able to reproduce the behavior of the whole system by the treatment plant perspective. To this end, it is composed of 4 spreadsheets, one for each main process of the plant: the first one organizes the input data collected for the two categories, the second and the third ones reproduce the two treatment processes and the last one manages the stock of the output and provides the results of the whole simulation.

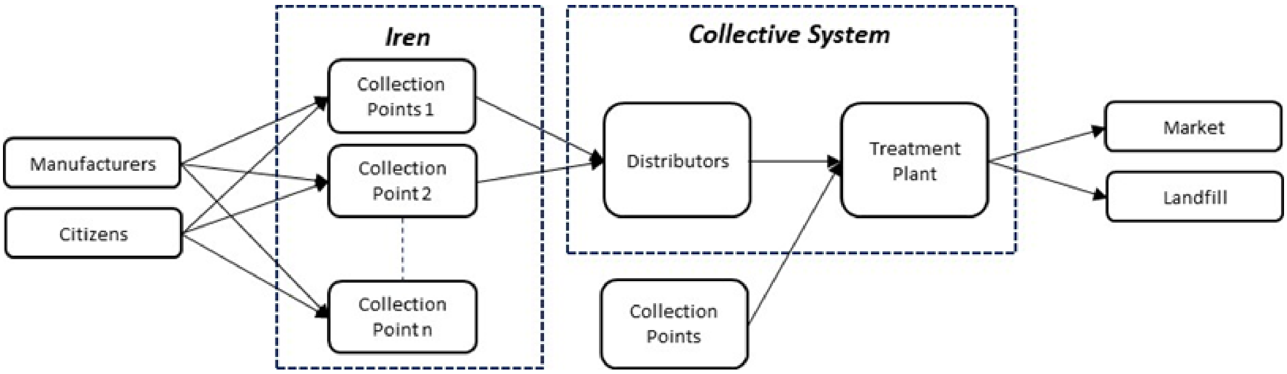

Figure 2: the supply chain modeled

In order to evaluate the performance of the collection and treatment system, as well as its response to the increasing needs of the WEEE management system, two different scenarios have been reproduced. We launched 10 replicates of each scenario simulated, to provide suitable results from the statistical point of view.

The first scenario aims to reproducing the current system (AS IS analysis), to evaluate its current performance and to identify its critical points. To this extent, the amount of the WEEE material processed by the plant (and set as input in the simulation model) reflects the real quantity treated by the plant in 2014. In the simulation, after a statistical analysis of the available data carried out with SPSS software package, the daily amount of WEEE treated was modelled with a uniform distribution. Some key performance indicators (KPIs) have been defined to compare the current situation and the future proposals; in particular, the plant aims at stocking the input material not more than one day.

For each replicate $r = 1,..10$, the average time in stock G_r is calculated as follows:

$$G_r = \frac{T}{I_r} \text{ [day]} \qquad (1)$$

where $T = 260$ days/year represents the number of working days per year of and I_r is the inventory turnover rate, calculated as:

$$I_r = \frac{Kg\ treated_r}{Kg\ not\ treated_r} \qquad (2)$$

Thus, the average time in stock G_r has to respect that constraint:

$$G_r \text{ (R1)} \leq 1 \text{ day}; G_r \text{ (R3)} \leq 1 \text{ day} \qquad (3)$$

Moreover, a cost/benefit evaluation has been included in the study to compare the different scenarios.

In particular, the total cost of each scenario has been calculated as the sum of different cost elements:

- cost of transport from the collection point to the plant;
- cost of stock, considering both the incoming WEEE and the final products at the treatment plant;
- cost of labor at the treatment plant;
- cost of disposal of the non-recycled materials.

As saving, the economic income is due to the sale of the recovered material and to a gate fee levied upon a given quantity of waste received.

The second scenario (TO BE evaluation) takes into account the possible situation where the treatment plant receives the materials from all the collection points of Parma, with the purpose of minimizing the total distance covered for collection.

The same simulation model has been used to reproduce the TO BE situation. The only main modification refers to the input data related to the incoming quantities. In this scenario, the quantity of R1 and R3 collected by Iren in 2014 have been added to the quantity treated by the plant in the same period; then, again after a statistical analysis carried out with SPSS software package, a uniform distribution has been hypothesized to reproduce the input data of the model.

4. RESULTS AND DISCUSSION

The first analysis brings out that in the current situation the plant is able to respect the main constraint, as shown in Table 1.

Replicate	G_r (R1) [day]	G_r (R3) [day]
1	0.79	0.002
2	0.43	0.002
3	0.75	0.003
4	0.06	0.000
5	0.33	0.002
6	0.45	0.003
7	0.58	0.004
8	0.37	0.001
9	0.38	0.003
10	0.40	0.003

Table 1: AS IS average time in stock for the two categories.

In particular, the results show that the capacity of the plant to treat R3 is highly oversized; indeed, the plant is able to process the WEEE material with a very low time in stock.

A specific analysis of the input data underlines that the whole system does not operate by minimizing the distance between the collection points and treatment plants. The main reason concerns the fact that the consortium probably sorts the WEEE among all of the plants, regardless of distance considerations. Such results motivated us to verify the feasibility of having the targeted plant treating the whole amount of WEEE materials collected in the area of Parma. The results of the simulation are shown in Table 2.

Replicate	G_r (R1) [day]	G_r (R3) [day]
1	1.217	24.46
2	0.592	78.71
3	1.061	133.76
4	0.076	27.38
5	0.398	248.30
6	0.560	303.86
7	0.727	361.78
8	0.469	209.08
9	0.466	473.43
10	0.490	530.19

Table 2: TO BE #1 average time in stock for the two categories.

The analysis of the TO BE scenario shows that the treatment plant considered would be able to work all the R1 quantities accumulated in the area of Parma, but the average time in stock exceeds the limit defined by the company two out of ten times (replication 1 and 3). Such constraint is the most relevant one because of the lack of space to stock the incoming WEEE.

Moreover, Table 2 shows as the plant is not able to process the incoming amount of R3, with a resulting increase of G_r (R3) for all the replications.

As a solution, in order to manage the new R3 volume the plant should duplicate the working shift; this last situation would minimize the distance and the cost of the transport of the whole system but the R1 line would not need it.

After all the considerations above, a second TO BE scenario has been modeled (TO BE #2): in this case, the scenario considers the constrain of the average level of stock and hypothesizes a one-shift situation for the treatment of R1 (the same of the previous TO BE #1 scenario) and a two-shift situation for R3, with the purpose of optimizing the total cost of the whole system. In this latter case, the plant would be able to process all the incoming WEEE with G_r (R3)<1 day, but the total capacity of the plant would work under its production capacity. In fact, the incoming amount of R3 doesn't justify the second working shift.

Scenario	Average Incomes [€]	Average total cost [€]	Net Profit [€]
AS IS	19676	9868	9808
TO BE #1	28421	15156	13265
TO BE #2	28432	14216	14216

Table 3: Economic results of the simulation model.

Also, from an economic point of view, Table 3 shows that the new scenario TO BE #2 is better than the current situation. The total cost growths because of the increase of the amount of material treated, but for the same reason also the sale of the material recovered bring to a high income.

5. CONCLUSIONS

This study focuses on the performance evaluation of the WEEE management system in the area of Parma in the north of Italy. In particular, the waste flow of 2 specific categories, i.e. R1 and R3, have been analyzed. A detailed analysis, carried out exploiting a simulation model, has showed that the system could be improved by minimizing the distance covered to ship the WEEE from the collection points to the treatment plants. A particular solution has also been defined considering the capacity of a real plant and its constraints.

The simulation model has proved to be very useful from a practical point of view; in fact, it allows to compare different scenarios, with the purpose of optimizing the efficiency of the plant and minimizing the distance covered by the distributors. Moreover, the topic of the waste management is very relevant around the world, as it involves a lot of actors and public institutions; for this reason, more and more researchers are working on it.

Future research activities could include in the study all the treatment plants served by Iren in order to analyze the efficiency of the whole system in the area of Parma.

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