Reverse Logistics for Electrical and Electronic Equipment: a modular simulation model

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Abstract: In recent years there has been a significant growth in WEEE production, which actually is the most worldwide rapidly growing category of waste. The synergic action of different actors involved in environmental protection, is pushing more and more EEE manufacturers to adapt their strategies, plans and business goals in an environmentally conscious way. As time goes by, the role of the Reverse Logistics is becoming more and more critical in this field: from the mere waste management to the actual managing, planning and control of the returns flow concerning raw materials, packaging, stocks, finished products from retailers to suitable collecting, reuse, recycling or remanufacturing centers. In this paper a logical model will be described reproducing the WEEE distribution flows, considering several functional aspects. The model is then implemented by means of specific simulation software to identify critical operational aspects. Considering actual data and opportunely tuning the model some important issues will be assessed.

Key-Words: Modeling, Logistic chain Integration, DES simulation, Reverse Logistics Theory

1 Introduction

WEEE means waste resulting from the use of electrical and electronic equipment (EEE) which operate by means of electric currents and electromagnetic fields. In recent years there has been a significant growth in WEEE production, which actually is the most worldwide rapidly growing category of waste with a growth rate of 3-5% annually (three times higher the growth rate of the common trash) even if it will unfortunately rise by 16-20% over the next ten years [20]. Handling this type of waste is becoming more and more difficult even in Italy: more than 850.000 tons of electrical and electronic equipment were discharged in 2008 from private households and businesses and only 14% were properly collected. As a matter of fact, these goods are sent for the most part (more then 80%) in landfills or incinerators at the end of their life cycle, with any pre-treatment or safety measure for dangerous substances. That being so and considering the increasing societal awareness about environmental matters, European Directives 2002/96/EC and 2003/108/EC, as concerns WEEE management, and European Directive 2002/95/EC, on reduction of hazardous substances contained within them (ROHS, Restriction of Hazardous Substances), were issued. These Directives were jointly implemented in Italy with the Legislative Decree 151/2005 which came into force on 31 December 2008. Even if the Directive was to engage the collection, by 2008, of 4 kg/person per year, just 2 kg/person are actually collected in Italy against a European average of 6 kg/person. In this paper a logical model will be described reproducing the WEEE distribution flows, considering several functional aspects. The model is then implemented by means of specific simulation software to identify critical operational aspects. Considering actual data and opportunely tuning the model some important issues will be assessed:

- the optimal location of collection centers;
- the optimal location of treatment facilities;
- optimization of routes.

This paper is further organized as follows. In Section 2 an insight into Italian legislative body and the actual organization of the Italian WEEE recovery system are presented. In Section 3 the above mentioned model is discussed. Simulation results are presented in Section 4. Some conclusions are drawn in Section 7.

2 WEEE recovery strategies and treatments

The Legislative Decree 151/2005, as enforced by the mentioned European Directives, specifies ten WEEE categories:
• Large household appliances;
• Small household appliances;
• IT and telecommunications equipment;
• Consumer equipment;
• Lighting equipment;
• Electrical and electronic tools (with the exception of large-scale stationary industrial tools);
• Toys, leisure and sports equipment;
• Medical devices (with the exception of all implanted and infected products);
• Monitoring and control instruments;
• Automatic dispensers.

These categories are further grouped into five homogeneous clusters: WEEE in the same cluster must be handled in the same way so to easier manage them in the collection centers as concerns their collection, transportation and safety measures to be adopted:

• Group 1 - Large cooling appliances, refrigerators, freezers, other large appliances for refrigeration and air conditioning;
• Group 2 - Other large white goods: washing machines, dryers, dishwashers, cooking appliances, heaters, microwave ovens, electrical appliances for heating and other large electrical equipment;
• Group 3 - TV and monitor (with and without CRT);
• Group 4 - Other: IT equipment, consumer equipment, small appliances, lighting, everything not explicitly present in the other groups;
• Group 5 - light sources (fluorescent tubes, discharge lamps and energy saving lamps).

The Decree furthermore introduces some regulatory reliefs for those affected by the legislation:

• distributors have to recover electrical and electronic equipment when a new one is sold without any additional charge on the customer;
• municipalities must manage collection centers and have close relationship to citizens.

Really, the most important point is the transition of the exclusive competence and responsibility in managing this type of waste from municipalities to EEE producers. The latter must:

• design and implement the WEEE collection systems throughout the country;
• collect and ship WEEE to the suitable treatment facilities;
• inform consumers, recycling and disposal centers about the proper WEEE disposal;
• send regular communication to the Registry of Producers;
• financing and manage the WEEE (deriving from professional and consumer markets) collection and recycling system.

In the course of time EEE producers joined in voluntary non-profit consortium (Collective Systems). Each partnership had to take charge of a WEEE share equal to the market share of the producers who joined the partnership itself. To improve their performance, and to guarantee the same coverage throughout the country, a National Coordination Center was established, financed and managed by producers. Each consortium must adhere to the Coordination Center. Moreover, each Collective System:

• provides at its own expenses the best suited containers to each grouping of WEEE, considering the size of the specific collecting center;
• provides high service level to collection centers when withdrawing the WEEE;
• provides a common interface to collection centers (the staff will contact the hotline of the Coordination Center).

Looking through the different definitions of Reverse Logistics which can be found in the literature [8, 10, 22], one can understand how its role changed in the supply chain: from the mere waste management to the actual managing, planning and control of the returns flow concerning raw materials, packaging, stocks, finished products from retailers to suitable collecting, reuse, recycling or remanufacturing centers [6].

### 3 Theoretical foundations and methodological approach

A huge literature can be found which assess Reverse Logistics impact on companies profits growth, on the environmental protection, on waste and pollution reduction and, finally, on resources optimization [7].

In Fig. 1 a flowchart is presented which identifies all the activities within the field of the Reverse Logistics.

Several recovery options are considered as product recovery can take place at different levels:
- product level - *cleaning and repair*;
- single module level – *refurbishing*;
- component level – *remanufacturing*;
- part level – *parts recovery*;
- materials level – *recycling*;
- energy level - *incineration*.

Implementing an advanced WEEE recovery systems allows a company to choose from time to time among the above mentioned options in relation to products characteristics and investments rationale. Indeed, simply repairing old equipment, when it is technically possible and a specific demand volume there exist, can save a company the cost of processing and recycling and ensures economic benefits through the resale of used products at a lower price. Remanufacturing allows higher economic benefits: products are obtained by assembling new with recovered parts and components, the latter being properly treated and having the same quality of the new ones [13]. Recycling, finally, can be considered as a "final chance" for at least raw materials recovery from used products [15]. Once both economic and ecological impact of the proper product recovery strategy have been recognized, for practical purposes WEEE management and distribution systems have to be designed and properly represented, considering all the remarkable flows (consumers → collection centers collection centers → treatment facilities, treatment facilities → consumers) [11].

The logical model described in this section carefully reproduces the WEEE distribution flows, taking into account all the above mentioned functional aspects. Particularly, a single *Collective System* has been considered that operates throughout the Italy, but:

- the attention was focused on the activities in the Southern Italy;
- only WAEE belonging to the first two groups mentioned in Section 1 were considered.

Among the various partners of the *Collective System*, just one company was considered whose range spreads to Basilicata, Calabria and Campania (more than nine provinces were considered: Matera, Potenza, Cosenza, Crotone, Avellino, Benevento, Caserta, Naples and Salerno) and whose activities encompass used products collection, transportation, storage, treatment and disposal/recovery [14]. In the area 131 collection centers were found. Products flows stem from (end in) the treatment facility and end in (stem from) one of the collection centers. In order to better describe these flows, a zoning was carried out considering the provincial boundaries in the area (Fig. 2).

![Fig. 1 – Reverse Logistics Activities](image)

![Fig. 2 – Considered area and zones](image)
• each collection center, consists of a single 30 m³ unit load;
• transportation system up-time is 225 days per year (= 5400 hours/year);
• the request for withdrawal is on the whole equal to 60 withdrawal/day.

This model allows managing WEEE flows from two channels:
• direct users;
• telephone users.

Direct users are the citizens who carry on their own WEEE at collection centers. If the unit load is full or it is not in the collection center, WEEE are temporarily stored until the next unit arrives, otherwise they are loaded on the transportation unit. Telephone users, instead, represent those citizens who call the collection center to ask for the withdrawal service of their own WEEE. The user could be charged for this kind of service according to withdrawal features. The service is performed by operators of the collection center and is available 5 days a week, Monday through Friday, except holidays, and 24/7.

Even if the withdrawal is in any case made within two working days after the request, unless otherwise specified by the user, acceptance is made depending on the time at which the call is received: requests before 12 a.m. (the day denoted by the variable G), will be accomplished by the following day (G +1); requests after 12 a.m. (G) will be accomplished within 2 days (G +2).

In this way, an internal routing model is determined, that is, the path “centroid-citizen”/“citizen-centroid” is established for each area in which there’s at least one withdrawal request [3, 9, 12, 16].

The volume will be withdrawn that will be then deposited in unit load at the collection center, if it is present and not full, or will be temporarily stored.

When the unit load at the collection center is full a withdrawal request is sent to the Coordination Center and unit load will be waiting for the arrival of one vehicle. The Coordination Center in turn collects all requests from the provinces and forwards them to the treatment center that will send the vehicle to the collection centers.

3.1 Model description

The distribution network is represented by a weighted graph which describes the road system. The network does not provide for the inclusion of existing roads, but it is a linear representation of the considered paths (Fig. 3).

For each edge was therefore defined the initial node and the terminal node, the length (km), the cost of fuel (€/l) and the travel time. Data were used both for internal and external routing. As it concerns the latter route, travel time between every province and the treatment center were evaluated [5].

The model was implemented in Rockwell Arena by means of several sub-models, allowing the inherent advantages of a modular representation of the system [2, 21].

![Fig. 3 – Considered distribution network](image)

Adopted sub-models refer to phone requests management, direct requests management and waste creation, which is in turn split into four parts: internal routing, provinces management, external routing, vehicles creation (Fig. 4) [4, 17, 18, 19].

![Fig. 4 – Rockwell Arena model](image)

Simulating WEEE flows within the virtual network could help detecting the critical points in real flows managing, taking into account some important factors such as: number of vehicles, type of request, requests and withdrawals managing policy, number of centers to serve, provinces relative importance, vehicles availability.

Analyzing the dimension of the queues made of “waste entities” that are waiting to be accepted in the unit loads at the collection center, the suitable number of unit loads or vehicle which optimize waste management can be found. This is a critical issue because partners in the Collective System...
should jointly agree upon the spaces to be available within each collection center, supplied catchment area, number of unit loads to ensure WEEE flow. However, in the start-up phase, vague information and small data are available so that simulation can help in making some decisions. Particularly, the number of vehicles will be determined which allows to meet the whole demand, if just one unit load is available at the collection. This is because it is easier and cheaper to operate vehicles rather than increasing unit loads number, especially in small municipalities where small space is available and maintenance cost quickly increases.

4 Results and discussion

Four simulations were performed as the number of vehicles varies from 1 to 9. The mean dimension of the queues, and the resulting mean time spent by the entities waiting to be processed at the collection centers, allows for decisions about vehicles number to employ. Fig. 5 provides a meaningful picture of the situation. The first one shows the trend of the average values of the code, grouped by type of simulation.

With 5 vehicles a significant reduction in the mean queues dimension occurs; particularly, when the smaller collection centers are considered there are no entities waiting for processing. The mean values considering each province are showed in Fig. 6. This result is strengthen if the intervention time is considered. The maximum intervention time (MIT) is the time that elapses from the withdrawal request is set until the full load unit is replaced with an empty one at the collection center. This variable mainly depends on the catchment area supplied by the collection center and is enforced by the Legislative Decree 151/2005. Fig. 7 shows the estimated intervention time when just one or five vehicles are considered.

5 Conclusions

The synergic action of different actors involved in environmental protection, is pushing more and more EEE manufacturers to adapt their strategies, plans and business goals in an environmentally conscious way. Handling WEEE is becoming more and more difficult, especially in Italy where these goods, at the end of their life cycle, are sent for the most part in landfills or incinerators, with any pre-treatment or safety measure. To this end, the role of the Reverse Logistics is becoming more and more critical: from the mere waste management to the actual managing, planning and control of the returns flow concerning raw materials, packaging, stocks, finished products from retailers to suitable collecting, reuse, recycling or remanufacturing centers. Using simulation software it is possible to explore different network configurations and scenarios without incurring high costs. In this paper a logical
model has been described reproducing the WEEE distribution flows in the Southern Italy, considering several functional aspects. The model was implemented in Rockwell Arena by means of several sub-models, allowing the inherent advantages of a modular representation of the system. Results provided important information about the number of vehicles to be adopted in the network to minimize the intervention time at the collection centers.

References: