17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

Design of recovery supply chains: a Portuguese recovery network for WEEE

Maria Isabel Gomes Salema,[a] Ana Paula Barbosa-Póvoa,[b] Augusto Q. Novais[c], Mónica Luizio[d]

[a]*CMA, FCT-UNL, Monte da Caparica, 2829-516 Caparica, Portugl mirg@fct.unl.pt*
[b]*CEG-IST,Av. Rovisco Pais, 1049-001Lisboa, Portugal apovoa@ist.utl.pt*
[c]*DMS-INETI, Az. dos Lameiros, 1649-038 Lisboa, Portugal augusto.novais@ineti.pt*
[d]*Amb3e, Av. do Forte, nº. 3, 2794-038 Carnaxide, Portugal mluizio@amb3e.pt*

Abstract

All European countries are building structures to support collection and recovery of electric and electronic waste (WEEE). In this work, the study of a Portuguese recovery network is presented. A MILP model is developed in order to determine the best WEEE network structure as well as the associated optimal plan. Several different analyses are performed.

Keywords: Supply chain design, Optimization, Electric and electronic waste.

1. Introduction

The European Union (EU) estimates a growth of 3 to 5% per year for the electrical and electronic equipment waste (WEEE). These figures are three times greater than for general waste. The EU also estimates that 90% of WEEE is going to landfills. The Directive 2002/96/EC on electrical and electronic waste aims at the reduction of the environmental impact of WEEE, encouraging end-of-life management, eco-design, life cycle analysis and extended producer responsibility [1]. Under this directive, producers are responsible not only for the new products placed on the market, but also for those equipments that were sold before 2002. This represents a new driving force that is enforcing producers to support the collecting and the recycling costs of their products.

All European countries are building structures to support this waste stream in order to meet the legal targets. Recovery networks have to be established, which may integrate various kinds of entities: collection centres, municipal sites, store retailers and/or producers, take-back centres and recyclers, among others.
In the last few years, several studies have been published for the design of recovery networks, in particular for electric and electronic equipments [2, 3]. The motivation for these studies is either new business opportunities perceived by companies or the need to adjust to the new legal framework.
In this work, the case study of the Portuguese recovery network for WEEE is presented. The primary objective is to design and plan the national recovery network. Several questions are to be answered. Where to place sorting centres? How many to open in each location? How many products have to be collected in order to meet the legal targets? What kind of transportation should be used? How should customers, sorting centres and recycling facilities be connected? Together with the previous strategic decisions, some tactical ones are to be taken. In a one year horizon and for each trimester, the distribution, sorting and recycling plans are designed. Also some answers concerning transportation are addressed: type of truck and number of freights, among others.
Following a previous work of the authors [4], a model is presented that will support the decision-making process required. The model is a Mixed Integer Linear formulation where the above decisions are modelled using binary and continuous variables. The objective function is the cost minimization.

2. Model description

A model, previously developed by the authors, is adapted in order to fit the problem. One major difference in the present version is that it is only concerned with the reverse network. Due to lack of space, only a general description of the model is next given. The model can be stated as:
<u>Given:</u> WEEE volume to be collected at each source; unit cost of not collected WEEE; recovery target set by legislation; sorting criteria to be performed at centres; initial stock levels at facilities; maximum storage capacity; maximum and minimum processing capacities; upper and lower bounds for flows; maximum capacity of each transportation mode; unit compensation fee given to recyclers and sorting centres; unit transportation costs; unit processing and storage costs. <u>Determine</u>, locations of sorting centres; flows amounts between sources of WEEE and sorting centres and between these and the recycling facilities; storage volumes at sorting centres and recycling facilities; number of flows of each type of transportation mode; processed and disposed volumes by recycling facilities. <u>So as to</u> minimize the total network cost.
In terms of constraints, the model is characterised by nine types of constraints related to: material balances; return satisfaction; target legal levels assuring that the legal target are met; disposal since it is estimated that 10% of the collected products are not proper to recycle; maximum stock levels; maximum and

minimum values for flows; sorting centres capacities limitations; and finally, transportation, which splits the flow between sorting centres and recycling facilities in three distinct transportation modes.

In terms of variables, three types of continuous variables (flow amounts, stock levels and non-satisfied return), one binary (choice of entities to integrate the network) and one integer (number of transport done by each transportation mode) are considered.

3. Case study

A group of 57 equipment producers created a non-profit organization (Amb3e) that is in charge of designing and manage the integrated system for the recovery of WEEE.With this organization, economies of scale are created, allowing for a more efficient management of WEEE and a reduction on the usual uncertainty associated to the quantity and quality of end-of-life equipments. For the year of 2006, Amb3e wants to recovery 75% of disposed WEEE. Figure 1 shows a schematic representation of the recovery network. It has three echelons: WEEE sources, sorting centres and recycling facilities. Sources of electronic waste can be of different nature: individual consumers, offices, companies and municipalities that collect waste; manufacturers or representatives of manufacturers that have to collect the old equipment when a new one is sold to the consumer. Due to the strategic nature of the problem, sources of WEEE are grouped by geographical locations according to municipalities. So, 278 locations are considered as sources of WEEE. The Portuguese household waste organizations group these 278 locations into 30 larger intervention areas (AI).

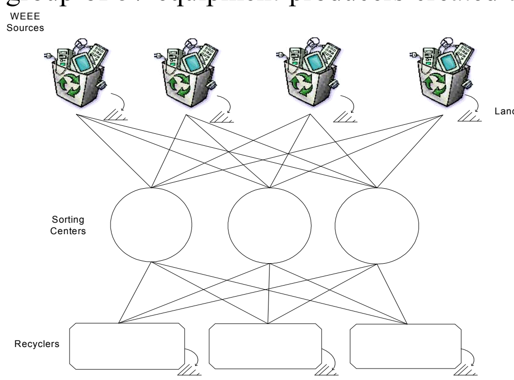

Figure 1: Schematic representation of the recovery

The location of the sorting centres is the major challenge of this problem. As the recovery network is still in its design phase, Amb3e has to certificate entities to operate as sorting centres. In order to do that, the organization needs to know what locations serve better its objectives. Considering that all Portuguese municipalities have possible sites to open sorting centres, Amb3e prime objective is to know what municipalities to chose and how many centres to certificate in each municipality. A maximum distance is imposed between each source of WEEE and at least one sorting centre.

In Portugal, there are two facilities operating as WEEE recyclers. One is dedicated to lamps-bulbs (located in Setubal) while the other recycles all the

other types of equipments (located in Tondela). At this stage, Amb3e is only considering these two facilities to process its equipments.
In terms of products, sorting centres should perform a basic sorting operation. Each collected equipment has to be classified into one out of five categories: large equipments, cooling and refrigeration equipments, small equipments, monitors and televisions, and lamps. Neither tests are performed in order to evaluate equipment quality, nor dismantling activities are carried out.
There is no fixed cost associated with the opening of a sorting center. For each ton of materials that centers send to recycle, Amb3e pays a pre-established amount (called 'sorting cost'). In terms of time, the network will be established for one year and the planning decisions will be taken on a trimester basis.

Results

The design network considers the opening of 149 (out of about 600) sorting centres located in 93 cities. These centres serve 259 sources. The remained 19 sources do not have any return collected. Figure 2 shows the location of the sorting centres (large dots) and the location of sources that are not served (squares). Note that non-served sources are located either in the northeast of Portugal or in the south (Alentejo), the two of the least populated regions in the country.

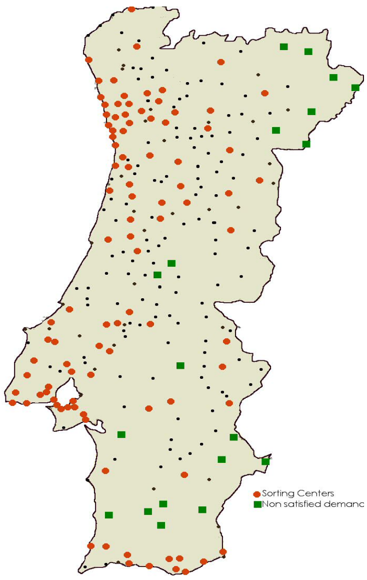

Figure 2: Recovery network.

Concerning sorting centres one sees that they are grouped into three regions: around Porto (North), around Lisboa and in the Algarve (South). These correspond to the three regions where the volume of return is higher. Figure 3 shows the relation between return volumes and the number of opened centres by AI. There are four AI with a very large number of opened centres: AI 23 (Lisboa), AI 5 (Porto area), AI 14 and AI 30 (Algarve). AI 14 is the largest region in terms of geographical area, which is the reason why the number of centres is also so large. Figure also shows that the number of opened centres is closely related with the existing volume of WEEE.
The model produces a very large amount of data. Due to lack of space, only a few illustrative examples will be mentioned.
Figure 4 shows all cost present in the objective function. Recycling and transportation costs represent 70% of the total cost. Costs coming from Lisboa & South are always higher than the ones from the North & Centre. The latter are explained by the higher collected volumes of WEEE in this region and also

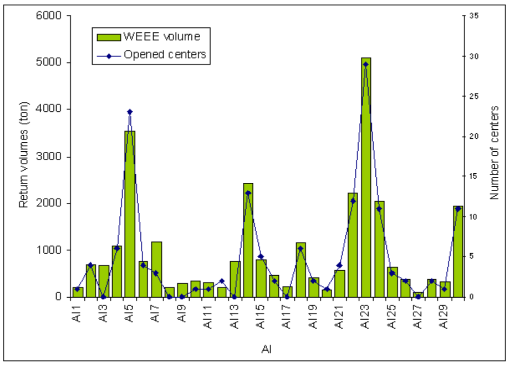

Figure 3: Relation between opened centers and the volume of WEEE to be collected.

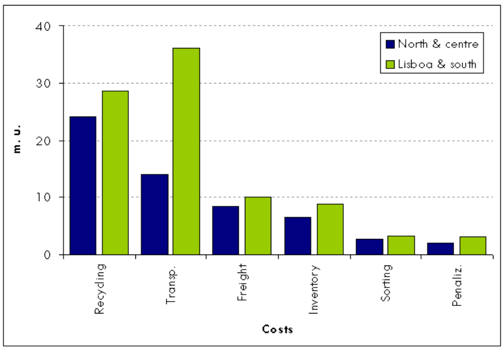

Figure 4: Costs computed at the objective function.

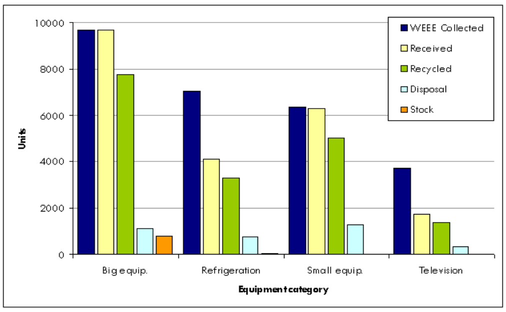

Figure 5: Flows at Tondela factory.

because the recycling factory is located in the centre region more precisely in the town of Tondela. This last factor also explains why Lisboa & South transportation costs are more that twice the value North & Centre costs. The cost of non-satisfying a customer (penalization cost) represents only 4% of total cost.

In each trimester, sorting centres can process between 30 to 65 tons of WEEE. Analysing all 149 centres, one sees that about 70% of them work between 65% and 70% of their capacity, 10% work below 65% but above 50%, and the remaining 20% work 75% to 80% of their capacity. So, the designed network is capable of absorbing some of the uncertainty related to return volumes that were estimated by Amb3e. In terms of factories, very different recycling scales exist. Setubal factory is dedicated to lamps-bulbs, which represents about 1.5% of all collected WEEE. This means that the significance that this stream of WEEE has on the design of the entire network is almost negligible. Note that most centres do not collect annually enough products to fill the smaller containers considered. In terms of the factory located in Tondela, the scenario is very different (Figure 5). It receives 80% of what is collected by sorting centres. Some refrigeration equipments and televisions collected are kept in stock at the sorting centres. These are the categories characterised by higher recycling costs. These 80% are split into three different flows: recycled (64%), stocked (3%) and sent to disposal (13%). Tondela factory has enough capacity to recycle all WEEE collected in order to meet Amb3e target. However, considering a natural growth of the WEEE volumes due to an increasing awareness of the population to this problem, the factory could be experiencing soon a lack of capacity. Two actions need then to be analyzed: create/contract a second recycling unit and/or expand the capacity of this factory. The computational results are shown in Table 1. Due to insufficient memory, the network could not be designed in a single run. Therefore, Portugal was split into two regions: North & Centre (NC), and Lisboa & South (LS). The two resulting models are of a high dimension. Nonetheless, it can be said that the model performed quite well given its size. The solution model was able to reach optimality gaps below 2% in less than half an hour. All models were solved by GAMS/CPLEX (built 22.2), in a Pentium 4, 3.40 GHz.

Table 1: Model computational results.

Region	Total variables	Binary variables	Total constraints	Number of LP's	CPU's (sec.)	Gap	Opt. value (10^3 m.u.)
NC	172 636	55 329	157 983	129 089	1 535	1.8%	5 661
LS	95 529	30 532	86 985	64 270	916	1.4%	8 880

4. Conclusions

In this work the study of the Portuguese recovery network for electric and electronic equipments is presented. The primary objective was to determine the location of the centres that are going to collect and sort WEEE. Some targets were to be met. With the described model all goals were achieved. Also, from the results, it can be concluded that the optimal network has enough capacity to face some uncertainty that exist in the estimated parameters that attempt to express the real situations. Although having some computational problems, these were overcome and the resulting runs revealed good performances.

As future work, the authors are going to analyse how the network performs in a longer time horizon, assuming the growth in WEEE estimated by the EU. Also, sensitivity analyses will be conducted in order to identify and study the most critical parameters.

Acknowledgements

The authors gratefully acknowledge the support of the Portuguese National Science Foundation through the project POCTI/AMB/57566/2004 and to Amb3E for all the data of the case-study.

References

1. Savage, M. (2006), Institute for Prospective Technological Studies.
2. Mayers, C.K. et al.(2005), Journal of Industrial Ecology, 9(3): 169-189.
3. Spengler, T. et al. (2003), Or Spectrum, 25(3): 413-442.
4. Salema, M.I. et al.(2006), in Processidings of ESCAPE 16, Germany.