OPTIMIZATION OF A REVERSE LOGISTICS NETWORK WITHIN THE AMBIT OF MOBILE PHONES

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ABSTRACT

The present paper deals with the study of the design of a recycling chain for a certain type of WEEE, the mobile phones. The goal is to analyse the optimal design of the logistics network required to guarantee that the amount of wasted mobile phones obtained at the generation points is collected, managed and transported in an appropriate way to the destination points constituted by recycling companies. The problem falls into the category of the so named LRP (Location and Routing problems).

The solution is achieved by adopting a sequential approach which implies to divide up the problem into two interrelated problems: one double location problem (of recycling centrals and transfer stations) and a routing problem which is solved by means of a modified version of Clarke and Wright (1964) method with limited capacity (CVRP) and with multiple depots (MDVRP).

Keywords: Optimization, Reverse logistics network design, MDVRP

1. INTRODUCTION.

Nowadays concern on such aspects as sustainability and competition creates the need of providing adequate answers to the new approaches given rise by the new demands. This causes the enterprises to set new efficiency levels derived not only from reductions in the amount of consumed raw matters or generated waste, but also from a better management of reverse flows. Reverse flows are all those flows that due to different reasons are returned upstream through the supply chain.
One of the flows that has received most attention during the last years is the one derived from the electric and electronic equipment. The waste generated by this type of products (known by the acronym WEEE, Waste Electrical and Electronic Equipment) have been estimated in a 4% of municipal wastes and show a growth rate between a 3% and a 5% according to the European Commission.

The present paper deals with the study of the design of a recycling chain for a certain type of WEEE, the mobile phones. Its interest is justified by a series of reasons such as i) the increase in the

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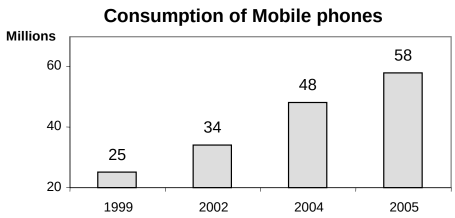
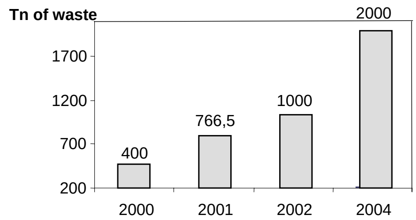
consumption experienced in the last years (see Picture 1a), ii) the generation of a great amount of waste, iii) the recent environmental pressure emerged from the coming into effect of Directive 2002/96/CE on January the 27 2003 and the promulgation of a new law which from December 2006 on, will made it compulsory to collect a minimum of 4 Kg of home generated WEEE per citizen and year and iv)the high degree of recyclability of mobile phones which reaches up to a 95% [2].



Picture 1a. Mobile Phone Consumption
Source: Vodafone y ASIMELEC



Picture 1b. Generated Waste

The goal is to analyse the optimal design of the logistics network required to guarantee that the amount of wasted mobile phones obtained at the generation points is collected, managed and transported in an appropriate way to the destination points constituted by recycling companies. This problem requires the determination of the number and the location of the recycling centrals, the determination of the number and the location of the feasible intermediate consolidation points (called from now on, transfer centrals), the configuration of the routes which are to be followed by the means of transport and the assignation of collection points to those routes. This is why it falls into the category of the LRP's.

In the same way, to achieve the final solution, the traditional quantitative variables have been taken into account as well as qualitative variables. With respect to these last variables, the 7 relevant factors in location problems, recently identified in [7], have been taken into account. The authors group up these factors around three targets: economic, environmental / social and those of infrastructure.

2. ADOPTED PROCEDURE

The resolution of a LRP consists in minimising a target function in which relevant cost elements are fundamentally considered. These costs are those of the collection, transport, management, storage and recycling of the mobile phones. The formulation regarding to our case of study is the next one:

$$Min\left\{a * \sum_{k=1}^{k}\sum_{g=1}^{z}\sum_{h=1}^{z} D_{gh} * CT_k * X_{ghk} + b * \sum_{j=1}^{N} CF_j * z_j + b * \sum_{z=1}^{M} CF_z * z_z + \right.$$

$$\left. + c * \sum_{z=1}^{M} CP_z * \left(\sum_{j=1}^{N} Q_j * y_{zj}\right) + b * \sum_{i=1}^{P}\sum_{z=1}^{M} T_{iz} * CC_{iz} - d * \sum_{z=1}^{M} S_z * W_z \right\}$$

With the following constraints:

$\Sigma\, T_{ij} < CCR_{max}$	(1)	$\Sigma\, T_{kj} < Q_j$	(2)
$\Sigma\, T_{kj} > CE_{min}$	(3)	$\Sigma\, T_{iz} \leq CA_{max}$	(4)
$\Sigma\, T_i\, \Sigma\, x_{ihk} \leq C_k$	(5)	$\Sigma\,\Sigma\,\Sigma\, x_{ihk} \geq 1$	(6)
$\Sigma\,\Sigma\, x_{ghk} * D_{gh} \leq D_{maxk}$	(7)	$\Sigma\, T_{kz} < \Sigma\, T_{kj}$	(8)

$\Sigma x_{ghk} - \Sigma x_{hgk} = 0$	(9)	$\Sigma CT_i - \Sigma T_i * y_{ij} = 0$	(10)
$\Sigma T_{iz} < \Sigma T_{zj}$	(11)	$\Sigma \Sigma x_{ihk} = 1$	(12)
$A_z \in P$	(13)	$C_j \in P$	(14)

Where:

$$x_{ghk} = \begin{cases} 1 \text{ if node g precedes node h in vehicle k route} \\ 0 \text{ in the rest of the cases} \end{cases}$$

$$y_{iz} = \begin{cases} 1 \text{ if collection point i is assigned to the the transfer station z} \\ 0 \text{ in the rest of the cases} \end{cases}$$

$$y_{ij} = \begin{cases} 1 \text{ if collection point i is assigned to central j} \\ 0 \text{ in the rest of the cases} \end{cases}$$

$$z_j = \begin{cases} 1 \text{ if facility j is opened} \\ 0 \text{ in the rest of the cases} \end{cases}$$

$$z_z = \begin{cases} 1 \text{ if facility z is opened} \\ 0 \text{ in the rest of the cases} \end{cases}$$

$$w_z = \begin{cases} 1 \text{ if there is subsidy for transfer station z} \\ 0 \text{ in the rest of the cases} \end{cases}$$

D_{gh} : Distance between nodes.	CA: Store capacity.
CT_k: Vehicle k cost of transport per Km.	Q_j : Quantity demanded by central j.
CP: Cost of the personnel of the facility.	S: Subsidies.
CF: Fixed cost of the facility.	CE: Quantity of delivery.
C: Recycling centrals.	D_{maxk}: Maximun distance allowed for the route.
CC: Cost per each unit transported.	T : Tons collected.

i: Index of the town with waste collection i = 1, ..., P (P=47).
j: Index of the centrals j = 1, ..., N.
z: Index of the transfer stations z = 1, ..., M.
k : Index of the route k= 1, ... , K.
h, g : Index of the nodes.
a: Weight coefficient of infrastructure factor.
b: Weight coefficient of the terrain economic factor.
c: Weight coefficient of the personnel economic factor.
d: Weight coefficient of the environmental / social factors.

The aim of this paper is to adopt a sequential focus when it comes to solve the actual LRP, dividing it up into two sub-problems:

a) Location problem (of centrals and transfer stations).
b) Problem of routing calculation which is solved by means of a modified version of [3] method with limited capacity (CVRP) and with multiple depots (MDVRP).

To achieve the final solution it was developed a computing program combining different technologies, such as Visual Studio, Visual Basic and Visual C++, SQL (Structured Query Language (ANSI) ADODB), and the Microsoft Data Access Components (MADC) which in the end eases the results for the different possibilities taken into account. It run in 2 Compaq ML 570 4 Processors Servers with 8 GB RAM, 2,5 TB storage in RAID 0+1 HDD's, on Windows Server 2003 Enterprise Edition.

2.1. LOCATION OF THE RECYCLING CENTRALS.

The use of various methods of solution (Sweep method, Clarke & Wright Basic algorithm, etc.) unanimously pointed towards a solution consisting in setting the specific mobile phones recycling central in the city of Madrid. However the viability analysis (Return Period, VAN, TIR) this solution underwent to check its quality, proved it no to be profitable, since initial investment would not be recovered even after 20 years' time. Once its un-viability was proved, the study went on adopting as starting situation the one with the 3 WEEE recycling centrals existing in Vizcaya, Barcelona and Valencia.

2.2. DESIGN OF THE ROUTES OF TRANSPORT.

The goal of the problem of routing design in our case consists in servicing every collection point, while minimising the number of required vehicles as well as the total distance to the recycling centrals. To get it solved, it was applied the "*cluster first, route second*" criterion. According to it, the collection points are assigned to the closest centrals in the first place, which affects the computational efficiency. This way subsequent calculations are simplified. Once each collection point is assigned, the routes were designed taking into account a series of considerations. So, every node has a fleet of limited capacity vehicles. Every vehicle's route starts and finishes at the central. It is also required the consideration of additional constraints as for instance, the time window imposed at the destination for the delivery to take place, the maximum distance or the minimum volume accepted by the central .Sub-indexes had to be adapted to make them show the change of view-point imposed by the analysed flows' backwards direction .

2.3. LOCATION OF THE TRANSFER NODES.

Once an initial solution for the routing design has been established (see Picture 2a), it was developed an algorithm to have the optimality of the solution checked by comparing it with the one obtained by adding new transfer stations that would serve to consolidate volumes; since deliveries towards the recycling central only take place when the waste saturate the capacity of the containers used for the transport (40 m^3). Reducing this way the costs stemming from transport. The algorithm supplies not only with the number of stations but also with its location.

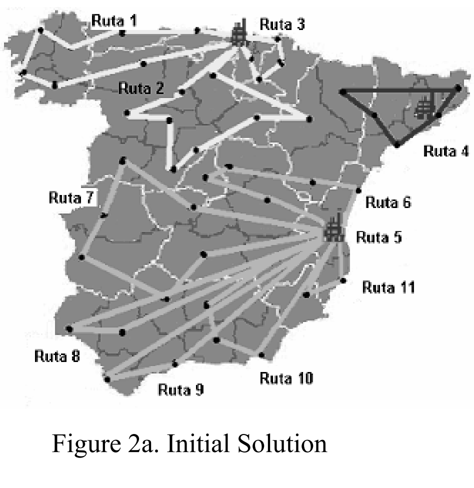


Figure 2a. Initial Solution

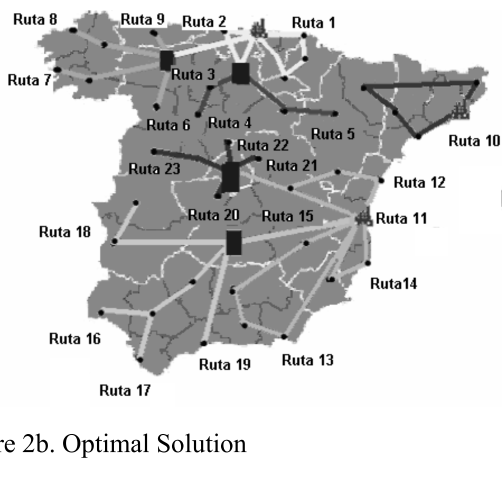


Figure 2b. Optimal Solution

The solution identified as the optimal one implies a network with three transfer stations. Picture 2b depicts the network design within a national frame.

3. CONCLUSIONS.

The present paper intention is to give an answer to an urgent need of today which will grow more serious shortly, according to the growing consumption patterns, waste generation and environmental pressure, all of which results in the need of efficiently managing out-of-use mobile phones waste.

That is why it has been proposed an ambitious model that simultaneously tries to solve two closely related problems: the node location in a network problem and the routing design problem. The interest of the study falls not only in its contribution to the solution of a present day problem which exists all over the world and demands quick results finding, but also in the labour of research, selection, adaptation and application of procedures traditionally linked to the solution of problems with different features (traditional logistics) to those stemmed from the returns management. (Reverse Logistics).

With that aim it has been developed a Visual Basic program capable of competing with other commercial programs, such as CPLEX. The fact of a WEEE recycling central being built in the community of Madrid, a node regarded as important in our solution's network, can be considered as an indicative of the quality of this solution.

In the same way the solution shows that the creation of a recycling central exclusively for mobile phones does not seem to be a profitable option. However this situation might appreciably vary in the short term.

To end with, let's point out that the used methodology is not only valid for telephones. It could be extrapolated to other different areas.

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