E-waste Reverse Logistic Optimization in Egypt

Rehaballah Elbadrawy
Associate lecturer, College of Management and Technology, BIS Dept.
Arab Academy For science and Technology, Alexandria, Egypt
Rehaballah2000@gmail.com

Ahmed Farouk Abdul Moneim
Professor of Industrial Engineering, College of Engineering and Technology,
Arab Academy For science and Technology, Alexandria, Egypt
mail@ahmedfarouk.org

M. Nashat Fors
Professor of Industrial Engineering
Faculty of Engineering, Alexandria University,
nashaat.fors@alexu.edu.eg

***Abstract*—Recently, the level of electronic waste (e-waste) is increasing especially in Egypt due to rapid technology change, and the increase in the consumption of electronic products. This paper proposed a reverse logistics network model for e-waste products that is solved by Genetic algorithm (GA), which aims tominimize the total cost and considering the collection cost, installation cost of sorting, repairing and recycling facilities, processing capacity, as well as the transportation between different facilities. The proposed model could help determine the optimal facility location and the material flows in the network.**

Keywords—Electronic waste; facility location;genetic alogorithm; reverse logistics; Mathematical Model

I. INTRODUCTION

Due to the rapid growth of economy, the huge evolution of electronic industry and the shortening electronic product lifecycle produced a gigantic number of outdated products and electronic waste (e-waste) that cause environment pollution [1]. E-waste refers to obsolete electrical devices that couldno longer be used and that had reached its End-of-life (EOL)[2]. E-waste contains significant amounts of copper, plastic, chemicals, glass, lead, and precious metals such as silver, gold, platinum, and palladium and heavy metals, which are hazardous [3].

Nowadays, industries worldwide suffered from the scarcity of resources for manufacturing, lack of energy and environmental problems. Moreover, efficiency in production is important and vital [4]. It is measured in terms of how raw materials were consumed by industries and the amount of waste should be minimized with lowest cost.

Reverse logistics (RL) is defined as a process of moving goods from their place of use, back to their place of manufacturing for re-processing, re-filling, repairs or recycling / waste disposal [5]. Recently, many researchers have been paid a lot of attention of the area of reverse logistics management that include collection, disassembly, component inspection, recovery and redistribution of E-waste [6]. The implementation of Reverse logistics (RL) at many industries will have many benefits such as: 1) the reduction of the cost of returned goods and inventory 2) improvement of customer satisfaction, 3) decrease of Environment pollution [7].

Reverse logistic (RL) are more complex than forward logistic systems because of the high degree of uncertainty the quantity and quality of the products, the diversity of e-waste suppliers and operational difficulties for the recovery of e-waste because of the differentiation of products' characteristics, life cycles, resources required and capacity of facilities[8].

Huge population, increasing income levels, popularity of digital lifestyle products, falling cost of devices and development in telecommunications infrastructure made Egypt become one of the biggest electronic consuming market in the world (including digital TV, smartphones, portable computers, home video and latest gadgets) [9]. Egypt's consumer electronics was US$ 16.7 billion in 2012. This number is forecasted to rise from 10% now to above 20% by 2016 [10]. Additionally, Egyptian market has 96.89 million cell phone users in 2013, which means an approximate more than 115.76 percent mobile penetration rate [11].

Due to shortening of product life cycles, this huge consumption of electronics in Egypt may lead to enormous amount of e-waste to be generated. The rank of Egypt in the Environmental Sustainability Index 2013 is 50 [12]. Therefore, the recovery of value from these consumer goods is becoming a necessity. Egypt has not set up an effective reverse logistics system to collect, transport, disassemble, recycle and disposal E-waste.

This research aims to design a reverse logistics network that optimizes costs in Egypt. Total costs associated with the reverse logistics network are minimized along with a reduction in installation cost and total transportation cost. To obtain a feasible solution to the RL network model, Genetic Algorithm (GA) is used.

The paper is organized as follows: Related literature in section II is reviewed. In Section III, the mathematical model is formulated. An example to illustrate the efficiency of method is demonstrated in section IV. Finally, Section V summarizes and concludes the paper.

II. LITERATURE REVIEW

Many researchers used various deterministic mathematical programming models for reverse logistics network design in the past few years. The design and management of a reverse logistics network is more difficult than that of forward logistics networks with direct flows. The existence of numerous uncertainties about the return flows such as quantity and quality of collected products, transportation cost, reprocessing time, the demand for recycled materials or repaired and refurbished products and others [13] non-conventional optimization algorithm such as Genetic Algorithm (GA) is needed to derive solutions to E-waste reverse logistics network problem.

Genetic Algorithm (GA) has many advantages. Genetic Algorithm could handle any kind of objective function and any kind of constraint (e.g. linear vs. nonlinear) defined on discrete, continuous or mixed search space. With genetic algorithm, Scan thru solution sets quickly, and is not affected by bad proposals as the algorithm rejects them. It is self-inductive and works by its own internal rules. Thus, Genetic Algorithm is good for complex or loosely defined problems [14].

Many studies and publications applied Genetic Algorithm GA) to reverse logistic network design problem. Genetic Algorithm (GA) was applied to solve a dynamic facility location problem [15] and also used for implementing the forecasting activities required in supply chain management [16]. Fang Xie [17] proposed a mathematical model of remanufacturing system for minimizing the total of costs of reverse logistics shipping cost and fixed opening cost of the returning centers, disassembly centers and repair centers by using a genetic algorithm (GA). Min et al demonstrated a nonlinear mixed-integer programming model and a genetic algorithm that couldsolve the reverse logistics problem involving product returns [5]. While Qinghua et al. [18] constructed and validated a genetic algorithm model for the returning of household electric product in such locations as collection, storage, disassembly, burying, and sale. Lee et al. [19] solved multi-stage reverse logistics network problems, which consider the minimizing of total shipping cost, and fixed opening costs of the disassembly centers and the processing centers in reverse logistics by using new genetic algorithm. Li [20] used a genetic algorithm to solve the reverse logistics model to select the location of re-manufacturing plant based on lowest transportation cost.

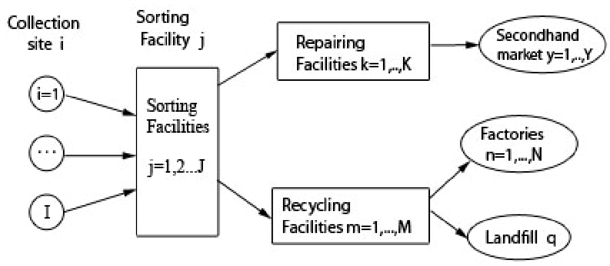
III. REVERSE LOGISTICS NETWORK MODEL

A. Components of the Reverse logistics network

Figure 1 shows a reverse logistics network for e-waste products. The model comprises of seven sets: collection sites, sorting facility, recycling facility, repairing facility, secondhand market, landfill and factory.

The first step begins at the collection sites e-waste will be firstly collected from companies, collectors or customers and transported to different collection sites. In the second step (sortingfacility), the collected products come into various conditions.

FIGURE 1: PROPOSED REVERSE LOGISTICS NETWORK FOR E-WASTE PRODUCTS



According to the characteristics of the various products and components, the possible treatment suggestions are decided, including repairing products or extracting recycled, hazardous and valuable materials from collected products. The repaired products need to be distributed to secondhand markets. The disassembly process in the recycling facility is occurred to extract valuable materials and metals such as copper, plastic, chemicals, glass, lead, silver, gold, platinum, palladium and heavy metals. Finally, the extracted materials are transported to factories and hazardous materials that are separated are recycled, incinerated, or disposed of in special landfills.

B. Mathematical formulation

1) Basic Assumptions:

a) Same products have the same price regardless its usage period.

b) The transportation cost is linearly related to distance and capacity (unit load is assumed to be per kilogram of products).

2) Parameters:

i: Set of collection sites $i=1,2,3\ldots,I$;
j: Set of sortingfacilities $j=1,2,3,\ldots J$;
k: Set of repairing facilities $k=1,2,3,\ldots,K$;
m: Set of recycling facilities $m=1,2,3,\ldots,M$;
n: Set of factories $n=1,2,3,\ldots,N$;
q: Set of landfillsq$= 1,2,3\ldots,Q$;
y: set of secondhand market $y=1,2,3,\ldots,Y$;
x: Set of recycled material $x=1,2,3,\ldots,X$;
h: Set of hazardous material $h= 1,2,\ldots,H$;
d: Set of repaired productsd$= 1,2,\ldots,D$;
g: incinerated material g;
ICS_j: *installation cost of setting up sortingfacilityj;*
ICR_m: *installation cost of setting up recyclingfacilitym;*
$ICRP_k$: *installation cost of setting up repairingfacilityk;*
PC: Unit cost of collected product;
WC_i: *Weight (ton) of collected product at collection site i;*

MCS_j: Maximum capacity of sorting facility j;

MCR_m: Maximum capacity of recycling facility m;

$MCRP_{jn}$: Maximum capacity of repairing facility k;

CCS_{ij}: Unit transportation cost / ton.km from collection site i to sorting facility j; regardless the units transported.

CSR_{jm}: Unit transportation cost / ton.km from sorting facility j to recycling site m; regardless the units transported

$CSRP_{jk}$: Unit transportation cost / ton.km from sorting facility j to repairing facility k; regardless the units transported.

$CRPSH_{ky}$: Unit transportation cost / ton.km from repairing facility k to secondhand market y; regardless the units transported.

CRF_{mn}: Unit transportation cost / ton.km from recycling facility m to factory n; regardless the units transported.

CRL_{mq}: Unit transportation cost / ton.km from recycling facility m landfill q; regardless the units transported.

DCS_{ij}: Distance (km) from collection site i to sorting facility j;

DSR_{jm}: Distance (km) from sorting facility j to recycling site m;

$DSRP_{jk}$: Distance (km) from sorting facility j to repairing facility k;

$DRPSH_{Ky}$: Distance (km) from repairing facility k to secondhand market y;

DRF_{mn}: Distance (km) from recycling site m to factory n;

DRL_{mq}: Distance (km) from to recycling site m to landfill q;

NS: number of candidate locations of sorting facilities

NRC: number of candidate locations of recycling facilities

NRP: number of candidate locations of repairing facilities.

3) Decision Variables:

VS_j=1if sorting facility j will be locate at site j

=0, otherwise;

VR_m=1if recycling facility m will be locate at site m

=0,otherwise;

VRP_k=1if repairing facility k will be locate at site k

=0, otherwise;

WCS_{ij}: Weight (ton) of collected product transported from collection site i to sorting facility j;

WSR_{jm}: Weight (ton) of collected product transported from sorting facility j to recycling facility m;

$WSRP_{jk}$: Weight (ton) of collected product transported from sorting facility j to repairing facility k;

$WRPSH_{dky}$: Weight (ton) of repaired products d transported from repairing facility k to secondhand market y;

$WXRF_{xmn}$: Weight (ton) of recycled materials x shipped from recycling facility m to factory n;

$WHRF_{hmn}$: Weight (ton) of hazardous materials h shipped from recycling facility m to factory n;

$WHRL_{hmq}$: Weight (ton) of hazardous materials h shipped from recycling facility m to landfill q;

$WGRL_{gmq}$: Weight (ton) of incinerated materials g shippedfrom recycling facility m landfill q;

b_{ij}= 1 if collected product will be shipped from collection site i to sorting facility j;

=0, otherwise;

o_{jk} = 1 if collected product will be shipped from sorting facility j to repairing facility k;

= 0, otherwise;

e_{jm} = 1 if collected product will be shipped from sorting facility j to recycling facility m;

= 0, otherwise;

f_{mn} = 1 if product will be shipped from recycling facility m to factory n;

= 0, otherwise;

r_{mq} = 1 if product will be shipped from recycling facility m to landfill q;

= 0, otherwise;

p_{ky} = 1 if repaired product will be shipped from repairing facility k to secondhand market y;

= 0, otherwise;

4) Model Formulation:

Minimize z=

$$\sum_{i=1}^{I}\sum_{j=1}^{J} WCS_{ij}DCS_{ij}b_{ij}CCS_{ij} + \sum_{j=1}^{J}\sum_{m=1}^{M} WSR_{jm}DSR_{jm}e_{jm}CSR_{jm}$$
$$+ \sum_{j=1}^{J}\sum_{k=1}^{K} WSRP_{jk}DSRP_{jk}o_{jK}\ CSRP_{jk}$$
$$+ \sum_{m=1}^{M}\sum_{q=1}^{Q} r_{mq}\ WGRL_{gmq}DRL_{mq}CRL_{mq}$$
$$+ \sum_{k=1}^{K}\sum_{y=1}^{Y} p_{ky}\ CRPSH_{ky}\sum_{d=1}^{D} WRPSH_{dky}DRRPSH_{dky}$$
$$+ \sum_{m=1}^{M}\sum_{n=1}^{N} f_{mn}\ CRF_{mn}\sum_{x=1}^{X} WXRF_{xmn}DRF_{xmn}$$

$$+\sum_{m=1}^{M}\sum_{n=1}^{N} f_{mn}\, CRF_{mn} \sum_{h=1}^{H} WHRF_{hmn} DRF_{hmn}$$

$$+\sum_{m=1}^{M}\sum_{q=1}^{Q} r_{mq}\, CRL_{mq} \sum_{h=1}^{H} WHRL_{hmq} DRL_{hmq}$$

$$+\sum_{m=1}^{M}\sum_{q=1}^{Q} r_{mq}\, WGRL_{gmq} DRL_{mq} CRL_{mq} + \sum_{i=1}^{I} PC\, WC_i +$$
$$\sum_{j=1}^{J} ICS_j VS_j + \sum_{m=1}^{M} ICR_m\, VR_m + \sum_{k=1}^{K} ICRP_k\, VRP_k \quad (1)$$

Subjected to:

$$WC_i = \sum_{i=1}^{I} WCS_{ij} \quad (i = 1,2,\dots I) \quad (2)$$

$$WCS_j = \sum_{m=1}^{M} WSR_{jm} + \sum_{k=1}^{K} WSRP_{jk} \quad (j = 1,2,\dots J) \quad (3)$$

$$WSR_m = \sum_{x=1}^{X} WXRF_{xmn} + \sum_{h=1}^{H} WHRF_{hmn} + \sum_{h=1}^{H} WHRL_{hmq} + WGRL_{gmq} (m = 1,2,\dots M) \quad (4)$$

$$WSRP_k = \sum_{y=1}^{Y}\sum_{d=1}^{D} WRPSH_{yd} \quad (5)$$

$$VS_j \sum_{i=1}^{I} WCS_{ij} \le MCS_j \quad (6)$$

$$VR_m \sum_{j=1}^{J} WSR_{jm} \le MCR_m \quad (7)$$

$$\sum_{j=1}^{J} WSRP_{jk} \le MCRP_k VRP_k \quad (8)$$

$$\sum_{j=1}^{J} VS_j \le NS \quad (9)$$

$$\sum_{M=1}^{M} VR_m \le NRC \quad (10)$$

$$\sum_{k=1}^{K} VRP_k \le NRP \quad (11)$$

Equation (1) represents the objective function: the minimization of the total cost including:

- Transportation costs from collection site i to sorting facility j for all moved weights.
- Transportation costs from sorting facility j to recycling facilitym for all moved weights.
- Transportation costs from sorting facility j to repairingfacilityk for all moved weights.
- Transportation costs from repairing facility k to secondhand market y for all moved weights.
- Transportation costs of recycled materials x, and hazardous materials h from recycling facility m tofactory n
- Transportation costs of, hazardous materials h and incinerated material from recycling facility m to landfill q
- Installation cost for setting up each of sorting facility j, recyclingfacility m and repairing facility.
- Cost of collected products

Constraint (2) weight balance of collected product at collection site i.

Constraint (3) weight balance of collected product at sortingfacility j.

Constraint (4) weight balance of collected productsat recycling facility m that transformed to recycled material x and hazardous material h that transported to factories, as well as hazardous material hand incinerated material g that transported to landfill q.

Constraint (5) weight balance of repaired productsat repairing facility k that transformed to secondhand market y.

Constraint (6) limiting the amount of product received by sorting facility j from collection site i by its maximum capacity.

Constraint (7) limiting the amount of product received by recycling facility m from sorting facility j by its maximum capacity.

Constraint (8) limiting the amount of product received by repairing facility k from sorting facility j by its maximum capacity.

Constraint(9) the amount of to-be-built sorting facilities could not exceed the number of optional locations NS

Constraint(10) the amount of to-be-built recycling facilities could not exceed the number of optional locations NRC

Constraint(11) the amount of to-be-built repairing facilities could not exceed the number of optional locations NRP.

IV. ILLUSTRATIVE EXAMPLE

The collection sites are known (i_1, i_2, and i_3) and landfill is located at q1. The locations of sorting facilities j_1, j_2 and j_3 existed at the same location of collection sites. The available locations of recycling facilities are m1, m2, and m3, and 2 locations should be selected. The proposed locations of repairing facilities are k_1, and k_2, and only one location should be selected.

After recycling the collected product, recycled material x_1, and hazardous materials h_1 and h_2 and incinerated material g are obtained. Recycled valuable material x_1 accounts for 70 %, hazardous material h_1 accounts for 18%, hazardous material h_2 accounts for 8% and 4% accounts for incinerated material of the total at each recycling facility Recycled valuable materials x_1 is shipped to factories n_1, n_2 and n_3, Hazardous materials h1 is shipped to factories n_2 and n_3, while h_2 and incinerated material g are disposed in a special landfill. Finally, repaired products d is transported to second-hand market y_1

The process of genetic algorithm is an iterative one, which comprises of numerous steps as follow:

Coding: Coding includes the design of an appropriate chromosome. There are three alterantives for sorting facility, three alternatives for recycling facility and two alternatives for repairing facility (figure 2). The solution (chromosome) has two recycling facility and one repairing facility. Each facility has two statuses: opening (1)/closing (0).

FIGURE 2: A GENETIC REPRESENTATION SCHEME OF CHROMOSOME

Recycling facility			*Repairing facility*		
1	….	*NRC*	*1*	….	*NRP*
1	*1*	*0*	*0*	*1*	*0*

Selection operator: Roulette wheel method has been selected in order to choose parents according to the probability distribution based on the fitness values of the chromosomes. The better chromosomes have a greater chance of being selected.

Cross-over: Single point crossover method is applied.

Mutation: mutation operator is randomly selecting one of the candidate facilities and then randomly changing the bit solution.

Fitness function: Objective function is calculated directly from a chromosome.

As output of this imperical example, best solution has been reached for recycling facility and repairing facility.

V. CONCLUSION

This paper proposed a model for the e-waste recycling network, which considers the minimizing of total cost including collection cost of e-waste, transportation cost, and installation costs of sorting, recycling and repairing facilities. This model could help decide the location of the optional locations of recycling and repairing facilities. Additionally, it determines the optimal weights transported from collection sites to recycling and repairing facilities. A genetic algorithm was employed to solve the model more efficiently for large-sized problems. Many Scenarios could be applied by slight changes in the constraints.

In future work, a mathematical model should consider uncertainty condition associated with the quantity of collected e-waste products. Additionally, the environmental impact and environemntal costs of the e-waste recycling system should be taken into consideration in the planning of the recycling network.

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BIOGRAPHY

Rehaballah ElBadrawy is a Teaching Associate at the College of Management and Techology, BIS department, Arab Academy for Science and Technology. She has published many papers and articles in international conferences and journals in the e-commerce fields and in Industrial engineering and engineering management fields. She has ten years of experience in teaching and academic research. She earned her Masters in Industrial Engineering from Production Engineering Department, Faculty of Engineering, and she is a PHD student at Faculty of Engineering, Industrial department, Alexandria University, Egypt.

Ahmed Farouk Abdul Moneim is Professor Emeritus of Industrial Engineering, Arab Academy for Science and Technology and Maritime Transport, Alexandria Egypt. Ph.D. in Hydrodynamics 1970 from Soviet Union. He is the Founding Chairman of Industrial and Management Engineering Department 1996-2000 in the Academy. He has written or co-authored number of research papers and articles on Hydrodynamics (Motion of multiple bodies in fluids), Operations Management (Facility Location problems), Project Management (Delay in projects), Operations Research (Fuzzy Genetic Prioritization), Reliability and Maintainability Engineering.

M. Nashat Fors, is Professor Emeritus of Industrial Engineering, Production Engineering Department, Alexandria University, Egypt. He earned his PhD in Industrial Engineering 1981 from Production Engineering Department, Faculty of Engineering, Alexandria University. He has written or co-authored research papers and articles on Industrial Applications of Mathematical Programming, Supply Chain Management, Maintenance planning, Water Management, Scheduling & Distribution. Dr. Fors has many joint projects, consultation, and training programs with industry in the area of Operations planning & scheduling, Maintenance planning, and Project management.