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REVERSE LOGISTICS NETWORK DESIGN FOR THE RECYCLING OF WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENTS AND AN APPLICATION FOR TURKEY

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ABSTRACT

In recent years, Reverse Logistics (RL) has gained much attention in supply chain and operations management area because of economic, social and governmental reasons. In literature, researchers addressed some problems associated with RL such as; network design, return forecasting, economic and environmental performance, lot sizing, vehicle routing, etc. However reverse logistics network design is the most important research topic in literature. In this study, we proposed Mixed Integer Linear Programming (MILP) model for reverse logistics network design (RLND) problem. Then the presented MILP model, which takes into consideration WEEE regulations published in 2011, is applied to real case study on electrical and electronic equipment recycling sector in Turkey. To the best of our knowledge, this study is the first to propose e-waste RLND for Turkey in electrical and electronic equipment sector.

Keywords: Reverse Logistics Network Design, MILP, WEEE

1 INTRODUCTION:

Reverse logistics in nowadays, is one of the recognized key in supply chain process. Reverse logistics activities is important for businesses because of these reasons; ecological and economic reasons, individual and corporate responsibilities, social obligations, legislation, sustainable development, conservation of natural resources, less consumption of resources and materials. In this sense, it becomes necessity with ecological, economic and legal. In this context businesses, are turning to establish and develop a logistics network which businesses can take back their products, processing of products, enhance their products and recycle the products.

Because of waste reduction has become a major problem product recycling is one way to get the location of economic perceptions. Several factors are active ın the perception of the importance of recycling. Consumers are waiting have less environmental impacts of products

from businesses. Products which taken measures in this regard ,these are preferred by consumers.Also, increases the responsibilities of business laws, has gained importance and increased state control in this regard.In many countries, mandatory environmental laws are applied that the manufacturers of the products they produce , which requires them to be responsible for the whole life cycle. Recycling and recovery obligations have been enacted. All these factors together with the manufacturer,the economic benefits of reducing the costs of implementing reverse logistics have noticed. Reverse logistics activities involves that process of returned products, process of end of lifetime or process of recollecting the products which dispose of consumer products because of new products that take.And it is a process that can generate significant cost item and it has strategic importance.

The important issues are; how to collect products from the customer, after the grouping of these products, separation of products, maintenance of products or disposal of these products with the least damage, resulting of grouping and separation semi-finished products, sources of raw materials or wastes should be forwarded to the destination point with which channels.

2 THE LITERATURE REVIEW ON REVERSE LOGISTICS NETWORK DESIGN

In the literature, many researchers showed deep interest the reverse Logistics network design problem. The studies in the literature can be classified into two main categories: deterministic models and stochastic models.

Realff and others [1] have discussed closed-loop reverse logistics program with approach of stochastic on recycling carpet with single product, unconstrained capacity, and multi-stage.Salema and others [2] have evaluated the multi-stage reverse logistics problems, stochastic models with limited capacity and they are targeted the structure of the network as a closed-loop design and cost-minimization. Min and Ko [3], have evaluated the e-commerce problem which aimed approach of deterministic cost minimization and with limited capacity. Lee and Dong [4], have worked problems of deterministic closed-loop model aimed at cost minimization with limited capacity, multi-product. Yongshang and others [5], have proposed a deterministic closed loop model for recycling of products and however they have studied without capacity constraint with cost-minimization for a product. Francas and others [6] performed a study with multi-product, targeted profit maximization, closed-loop, and limited capacity. Shi and others [7], have studied reverse logistics network design problems for medical waste. They have preferred a heuristic approach for the solution of the model. They have analysed problems of structure in deterministic models with open-loop design, cost minimization, and multi-product.

Denizel and others [8] have evaluated problems with approach of stochastic, open loop design, multi-stage, limited capacity and profit maximization. Foncesa and others [9] have evaluated reverse logistics network design problems for the recycling of solid waste, with targeted cost minimization, multi-product, multi-stage, open-loop network structure. Pishvaee and others [10] especially have focused on the design of an integrated network with forward logistics and reverse logistics networks. They have developed a mixed-integer nonlinear programming model that minimizes the total cost and aims to maximize the ability to respond of logistics network with limited capacity and multi-stage. Achilas and others [11] have discussed reverse logistics network design problem for electronic waste recycling deterministic model of multi-product, targeted cost minimization, with multi-stage, open-loop network structure, and limited capacity. Salema and others [12], have studied reverse logistics network design problem with limited capacity, multi-stage, multi-product and closed loop. Paksoy and others [13], have discussed deterministic models of minimizing the cost with approach of full solution, multi-stage for recycling single product, limited capacity and closed-loop. Demirel and others [14], have aimed in deterministic models with intuitive solution approach, closed-loop, multi-stage and multi-product design, limited capacity and

cost minimization. Alumur and others [15], have discussed the study on e -waste recycling which using deterministic methods with complete solution, open-loop design, limited capacity, multi-stage, multi-product and targeted profit maximization. Another study is in the literature regarding e-waste recycling was evaluated by Assavapokee and others [16]. They have evaluated deterministic models in the closed-loop design with limited capacity, targeted profit maximization, multi-stage, and multi-product. Das and Chowdhury [17] have evaluated reverse logistics network design problems for returns of products with targeted profit maximization, limited capacity, and multi-stage. Zhenquiang and others [18], have studied in the deterministic approach with cost minimization and unconstrained capacity for one product. With regard to e-waste Dat and others [19], have evaluated reverse logistics network with limited capacity, multi-stage, multi-product, cost minimization, and open-loop.

Table 1. Literature Review of Reverse Logistics

REFERENCES	MODEL	SOLUTION METHOD	NETWORK STRUCTURE	OBJECTIVES	CAPACITY CONSTRAINT	DECISION VARIABLE	FIELD OF APPLICATION	STEP NUMBER	NUMBER OF PRODUCT
SALEMA,POOVA,NOVAIS,2006	stochastic	complete solution	CLOSE LOOP	COST MIN.	YES	L,A		2	SINGLE
DENIZEL,FERGUSON,SOUZA,2010	stochastic	complete solution	OPEN LOOP	PROFIT MAX.	YES	A		2	SINGLE
FONSECA,SANCHEZ,MIER,2010	stochastic	complete solution	OPEN LOOP	COST MIN.	YES	L,A	solid waste	many	MULTI
PISHVAVEE,JOLAI,RAZMI,2010	stochastic	complete solution	CLOSE LOOP	COST MIN.	YES	L,A		many	SINGLE
FRANCAS,MINNER,2009	stochastic	complete solution	CLOSE LOOP	PROFIT MAX.	YES	L,A		2	MULTI
REALFF,AMMONS,NEWTON,2000	stochastic	complete solution	CLOSE LOOP		NO	L,A	carpet	many	SINGLE
ACHILAS,ET AL., 2010	deterministic	complete solution	OPEN LOOP	COST MIN.	YES	L,A	WEEE	many	MULTI
LEE,DONG,2009	deterministic	heuristic solution	CLOSE LOOP	COST MIN.	YES	L,A		2	MULTI
MIN,KO, 2006	deterministic	heuristic solution	CLOSE LOOP	COST MIN.	YES	L,A	e-commerce	2	SINGLE
DEMIREL, GÖKÇEN,AKÇAYOL,2011	deterministic	heuristic solution	CLOSE LOOP	COST MIN.	YES	L,A		many	MULTI
ALUMUR ET AL.2012	deterministic	complete solution	OPEN LOOP	PROFIT MAX.	YES	L,A	WEEE	many	MULTI
ASSAVAPOKEE AND WONGTHATSANEKORN 2012	deterministic	complete solution	CLOSE LOOP	PROFIT MAX.	YES	L,A	WEEE	many	MULTI
DAS AND CHOWDHURY, 2012	deterministic	complete solution	CLOSE LOOP	PROFIT MAX.	YES	L,A		many	MULTI
ZHENQIANG ET AL.,2012	deterministic	complete solution	CLOSE LOOP	COST MIN.	NO	L,A	-	many	SINGLE
DAT,ET AL., 2012	deterministic	complete solution	OPEN LOOP	COST MIN.	YES	L,A	WEEE	many	MULTI
YONGSHENG,SSOUYANG 2008	deterministic	complete solution	CLOSE LOOP	COST MIN.	NO	L,A	-	many	SINGLE
SALEMA,ET AL., 2010	deterministic	complete solution	CLOSE LOOP	COST MIN.	YES	L,A	-	many	MULTI
SHI ,ET AL.,.2009	deterministic	heuristic solution	OPEN LOOP	COST MIN.	YES	L,A	medical waste	2	MULTI
PAKSOY,ET AL.,2011	deterministic	complete solution	CLOSE LOOP	COST MIN.	YES	A	-	ÇOK	SINGLE

3 PROBLEM DEFINITION AND MATHEMATICAL MODELING

In this study; the problem which is a reverse logistics problem with open-loop, multi-stage, multi-product and limited capacity. Mixed İnteger Linear Programming models have been proposed for this problem. Intended for the e-waste recycling problems network structure is as follows: consumers, manufacturers, distributors, composed of local government customers i.e.; The first collection centers (ITM), central collection centers (MTM), recovery

centers (GKM), disposal centers (BM), and the second-hand markets (IEP). The aim of the presented model is to minimize total cost.

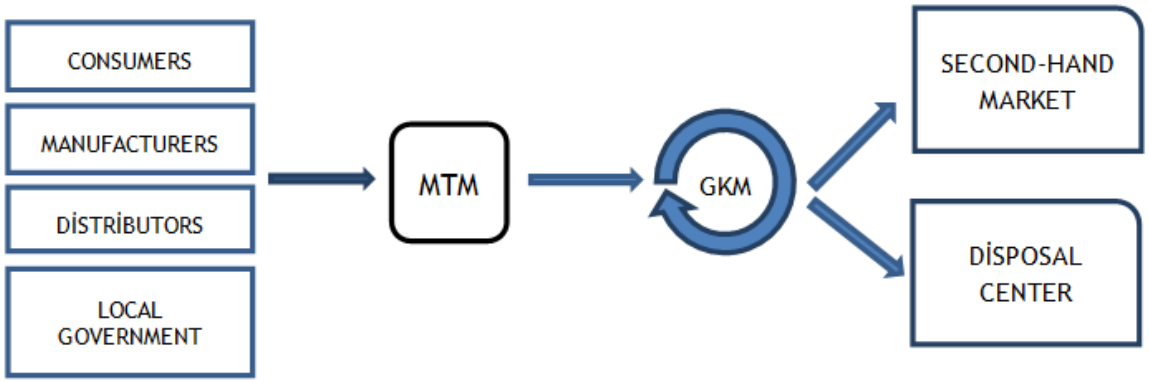


Figure 1: The Proposed Reverse Logistics Network Design For E-Waste

Consumers use of the expiry of life, returned, defective products...etc are collected in where manufacturers, distributors and local governments are determined. MTM are collecting centres and there is not any process of products in there. The collected products are taken at regular intervals with vehicles which belonging to the recycling firm and waste is brought to the GKM are subjected to the recovery process in GKM. In these centres; recyclable wastes are sent to the second-hand market for sale. If wastes cannot be recovered, are sent to disposal centre. Wastes which are sent to disposal centre have a specific cost. The formulation of the problem is as follows:

3.1.1 Formulation

Index

i: Potential First Collection Centre Index i
j: Potential Material Acquisition Centre (MTM) Index j
k: Potential Recovery Centre (GKM) Index k
b: Potential Disposal Centre (BM) Index b
p: Second Hand (EP) Markets Index p

Parameters

İTM: First Acquisition Centre
MTM: Central Collection Centre
GKM: Recycling Centre
BM: Disposal Centre
İEP: Second Hand Market

Facility Opening Costs

İTMC: ITM Opening Cost
MTMC: MTM Opening Cost
GKMC: GKM Opening Cost

Capacity Parameters

KMTM: Capacity of MTM

KGKM: Capacity of GKM

Processing Costs

cc: unit cost of collection in İTM
dc: unit processing costs in MTM
gdc: unit processing costs in GKM
bc: unit cost of disposal in BM
tc: unit transportation cost

Other Parameters

Q: The amount of waste material collected from i. customer

w: MTM according to opening costs to be opened or not opened
g: GKM according to opening costs to be opened or not opened
Y_j: MTM according to capacity constraints to be opened or not opened
Z_k: GKM according to capacity constraints to be opened or not opened
α: The percentage from GKM to second-hand markets
1- α:The percentage from GKM to BM
M: Large number

Decision Variables

X_{ij}: The amount of waste taken from ITM sent to MTM
X_{jk}: The amount of waste from MTM to GKM
X_{kp}: The amount of second-hand products are sent to IEP from GKM
X_{kb}: The amount of waste are sent to BM from GKM

Distances (km)

u_{ij}: The distance between ITM to MTM
u_{jk}: The distance between MTM to GKM
u_{kp}: The distance between GKM to IEP
u_{kb}: The distance between GKM to BM

Objective Function = Cost Minimization

$$\sum_i tmc(i) + \sum_j w(j) * mtmc(j) + \sum_k gkmc(k)*g(k) + \sum_i \sum_j x_{ij} * tc * u_{ij} + \sum_j \sum_k x_{jk} * tc * u_{jk} + \sum_k \sum_p x_{kp} * tc * u_{kp} + \sum_k \sum_b x_{kb} * tc * u_{kb} + \sum_i \sum_j cc_i * x_{ij} + \sum_i \sum_j dc_j * x_{ij} + \sum_j \sum_k gdc_k * x_{jk} + \sum_k \sum_b bc_b * x_{kb} \quad (1)$$

Equilibrium Constraints

$$Q = X_{ij} \quad (2)$$
$$\sum_i x_{ij} = \sum_k x_{jk} \quad (3)$$
$$\sum_j x_{jk}(\alpha) = \sum_p x_{kp} \quad (4)$$
$$\sum_j x_{jk}(1-\alpha) = \sum_b x_{kb} \quad (5)$$

Capacity Constraint

$$\sum_i x_{ij} \le KMTM \cdot Y_J \quad \sum_j x_{jk} \le KMTM \cdot z_k \quad (6)$$

Logic Constraint

$$\sum_i x_{ij} = M.Y_J \quad \sum_j x_{jk} = M.Z_k \quad x > 0 \quad Y,Z = (0,1) \qquad (7)$$

4 APPLICATION

In this section; the model is applied on collection of e-waste in Turkey. The first collection centre in reverse logistics network design problem consists of domestic users, manufacturers, distributors and local government in twenty six provinces (Tekirdağ, Balıkesir, Bursa, İzmir, Manisa, Aydın, Antalya, Konya, Adana, Kocaeli, İstanbul, Zonguldak, Ankara, Kastamonu, Samsun, Aksaray, Kayseri, Trabzon, Erzurum, Ağrı, Mardin, Muş, Diyarbakır, Malatya, Gaziantep, Hatay). fifteen potential centres (Tekirdağ, Bursa, İzmir, İstanbul, Ankara, Zonguldak, Trabzon, Erzurum, Adana, Denizli, Antalya, Diyarbakır, Sivas, Gaziantep ve Sakarya) are determined as a MTM and GKM potential six centres (İzmir, Kocaeli, Ankara, Antalya, Erzurum and Adana) are determined. Two centres (Bursa and Gebze) were determined for recovered from wastes which are sent to the second-hand market. Wastes which cannot be recycled are sent to Kocaeli (İzaydaş) where the sole disposal centres of Turkey.

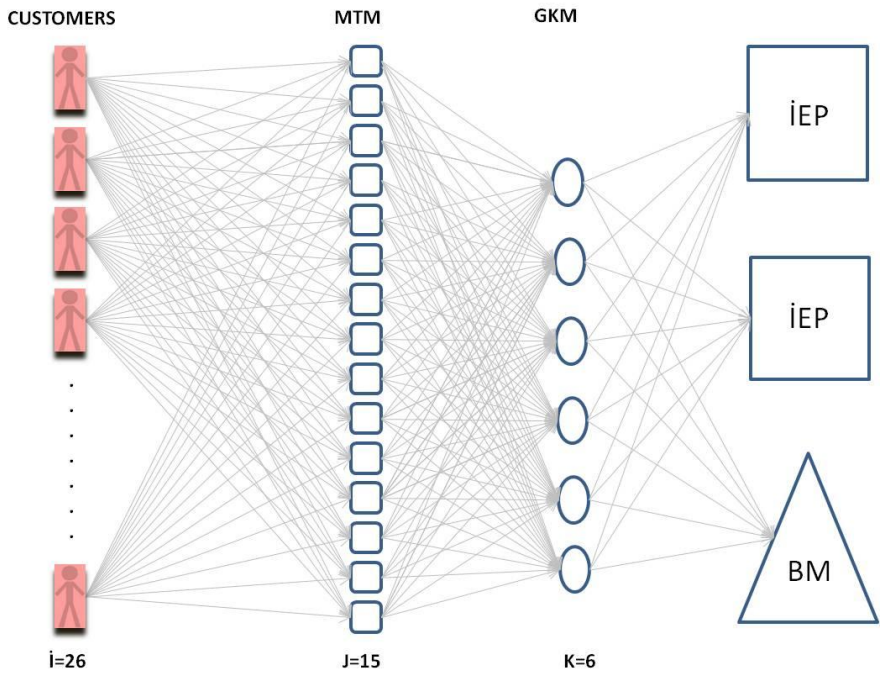


Figure 2: Proposed Reverse Logistic Network

Table 1. Reverse Logistics Network Structure and Number of Members

Members of Reverse Logistics Network Structure	Number
İTM	26
MTM	15
GKM	6
İEP	2
BM	1



Figure 3: Locations For GKM



Figure 4: Locations For MTM

5 CONCLUSION

Reverse logistics in nowadays, is one of the main key in supply chain process. Reverse logistics activities is important for businesses due to ecological, social, governmental and economic reasons. In this study; evaluating reverse logistics network design problem, deterministic multi-stage programming model is adopted. The proposed model is with single product, multi-stage, limited capacity deterministic programming model. The developed model has been applied to network design problem. In this study; a potential recycling system is designed for recycling of e-waste and evaluated within the scope of the mixed integer linear programming model, selection of the most appropriate location has been decided for potential MTM and GKM. Twenty six cities in Turkey are selected and First Collection Centres (ITM) has been established. When determining the capacity of İTM, calculated the amount of e-waste that may occur which result of official data of e-waste per person in 2011 multiplied by the number of official population of these cities in 2013. And considering these figures approximately ITM capacities were determined. When selecting Central Collection Centres (MTM) especially, easy access to many points of ITM were taken into consideration. However, recycling centres (GKM) are determined especially, where the quantities of waste are based on intensive. İTM the capacity limit has not been determined but, capacity of MTM and GKM are determined. In addition, opening cost of all facilities, per waste costs and transportation costs are determined. The collected wastes have moved to İTM where consist of consumers, producers, distributors and local administrations to MTM with roadway. Then, the wastes have moved to GKM to provide recycling. 95% of wastes recycling provided in GKMs and the wastes were sent to İzmit and Bursa defined as the second hand markets to meet with customers. The remaining 5%; has been sent to İzaydaş Kocaeli which is e-waste disposal centre in Turkey. The proposed model is solved with GAMS optimization program 23.5.1/CPLEX 2.12. All data are loaded into the program with specific constraints for the minimum cost model is calculated. Tekirdağ, Bursa, İzmir, Ankara, Trabzon, Erzurum, Adana, Ankara, Antalya, Diyarbakir, Sivas, Gaziantep, has been selected as MTM. İzmir, İstanbul, Ankara, Antalya and Adana are defined as GKM.

There are many uncertainties in the RL networks. The amount of waste which come from ITM, how much waste can be recycled and the variability of transport costs constitute the greatest uncertainty. Without exception, all of the waste which coming from MTM sent to GKM with appropriately be extracted and grouped. Also, maximum recovery is provided from examined waste by professional workers in GKM. In this way, the efficiency of reverse logistics system and earnings have increased, while the cost has dropped. Specifically; profit maximization and cost minimization in terms of business owners are required to draw attention to this point. It should be noted also environmental benefits will increase.

Studies on reverse logistics can be done in the future; when quantity, time, transportation costs, processing costs, acquisition price, plant capacity... etc are uncertain. In this case; the model could be complicated, heuristic methods must be used in the solution process. In the same way; taking into consideration environmental impact, recycling performance, both the profit maximization and cost minimization as purposes, a multi-purpose model can be considered in mind.

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