Journal of Cleaner Production 112 (2016) 2101–2113

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A mixed integer linear programming model to optimize reverse logistics activities of end-of-life vehicles in Turkey

Eray Demirel [a], Neslihan Demirel [b], Hadi Gökçen [b,*]

[a] Gazi University, Graduate School of Natural and Applied Science, Department of Environmental and Technical Research of Accidents, Teknikokullar, 06500 Ankara, Turkey

[b] Gazi University, Faculty of Engineering, Department of Industrial Engineering, Maltepe, 06570 Ankara, Turkey

ARTICLE INFO

Article history:
Received 19 December 2013
Received in revised form
1 October 2014
Accepted 20 October 2014
Available online 1 November 2014

Keywords:
ELVs
Network design
Recycling
Projection
Turkey

ABSTRACT

There are legislations encumbering manufacturers to incorporate environmental factors into their decisions in several industries. Automotive is one of these sectors and in many countries, particularly in those who are a member of the European Union, there are regulations to guarantee the recycling of end-of-life vehicles (ELVs). In Turkey, recovery of ELVs is regulated with Regulation About Controlling of ELVs which was issued by the Turkish Republic Ministry of Environment and Forestry in Official Gazette in 2009. Manufacturers are responsible for free take-back of ELVs from end-users, depolluting, dismantling, shredding and recycling of ELVs. In this paper, in order to comply with related regulations and manage the recovery of ELVs efficiently, we presented a mixed integer linear programming (MILP) model for network design including the different actors taking part in ELV recovery system. The proposed framework is justified by a real case performed in Ankara, the capital and second largest city of Turkey. We also presented a modeling approach for the projection of car ownership and number of ELVs and generated scenario analyzes based on the long-term average developments in the number of ELVs. The case study and analyzes provided important insights on how logistics network behave over time. The results demonstrated that the number of facilities to be located and the system cost increase while the number of ELVs are getting higher in the future.

1. Introduction

Management of end-of-life products becomes vitally important not only because of environmental effects of increasing waste quantities due to worldwide increasing trend of consumption but also economical factors. The automotive industry is one of the industries where the responsibility of the manufacturers is regulated by governments. ELVs are classified as hazardous waste and have the potential for polluting the environment if they are not managed properly whereas they are potential sources of recyclable materials.

The volume of in-use vehicles in world, which is increasing dramatically, is expected to triple in the next years (Levizzari et al., 2002) which accounts for a large amount of ELVs. In 2009, it was estimated that 30 million vehicles reached the end of their service life throughout the world (Ahmed et al., 2009). This number is rising rapidly due to the increasing number of vehicles on the roads. Approximately 14 million ELVs of classes M1 (passenger vehicles with less than eight seats) and N1 (vans not exceeding 3.5 tons) retire each year in Europe (Johnson and Wang, 2002). In order to cope with the problems created by the generation of ELV waste arisings, the European Union adopted the ELVs Directive (2000/52/EC) in October 2000. This directive attempts to reduce the amount of hazardous waste and sets clear targets for reuse, recycling, and recovery (Moakley et al., 2010). The directive also called for developing an infrastructure for the manufacturers to establish ELV collection and recycling network (Kanari et al., 2003).

From the perspective of Turkey, according to data from Turkish Statistical Institute (TURKSTAT), the population increased 5.5% in the last decade, whereas the number of vehicles on the roads increased by 87%, reaching 17 million by the end of 2012. There was a vehicle for eight inhabitants and an automobile for fifteen inhabitants in 2003. These numbers became a vehicle for four inhabitants and an automobile for nine inhabitants in 2012 with the increase in the number of vehicles. Turkish ELV directive came into force on the 1st of January 2011 and currently states that 85% of an ELV must be reused and recovered similar to EU directive on ELVs, and the ratio must reach 95% by 2020. The European Union expects

* Corresponding author. Tel.: +90 312 582 38 59; fax: +90 312 230 84 34.
E-mail addresses: eraydemirel@hotmail.com (E. Demirel), neslihanozgun@gazi.edu.tr (N. Demirel), hgokcen@gazi.edu.tr (H. Gökçen).

http://dx.doi.org/10.1016/j.jclepro.2014.10.079
0959-6526/

a 95% ELV recovery and reuse rate, an increase from the current target of 85% by 2015. Since manufacturers are responsible for free take-back of ELVs from end-users as well as depolluting, dismantling, shredding and recycling of them, it is necessary to manage the ELV recycling process effectively to minimize the costs. We designed a network configuration for fulfilling the requirements of the relevant directive as well as effective management of recycling process of ELV of class M1 which contains vehicles for passenger transport with a maximum of eight seats. Proposed model aims to gain the economic value from the ELV wastes constituting an important source of recycled materials and to minimize the harmful effect of ELVs on the environment by reducing the landfilled quantities. The proposed general framework is justified by a case study focusing on reverse logistics network design for ELVs in Ankara, the capital and second largest city of Turkey. We also presented a model in order to quantify the long-term average developments in the number of ELVs and generated scenario analysis based on the projections of ELVs till 2022.

2. Overview of the literature

Due to the increasing environmental concern, resource reduction and depleting landfill capacities in many countries, reverse logistics has received growing attention in the last decades (Demirel and Gökçen, 2008). The design of product recovery networks is one of the important and challenging issues in reverse logistics environment. Enacted obligations by governments on waste minimization and end-of-life (EOL) products make reverse logistics processes more important in certain industries such as packaging, electrical and electronic equipment and battery. Automotive is also one of these industries since huge amount of vehicle quantities on roads means a huge amount of ELVs and high metal content in the vehicle makes it an attractive source of raw material recovery (Harraz and gallal, 2011). For example, in 2001, the 217 million vehicles on the U.S. roads contained 5.3% of all steel and 13.8% of all aluminum in use in the United States (Jody et al., 2010). Different end-of-life strategies, as well as their main features, are addressed in the literature. Reuse, repair, refurbishing, recycling, cannibalization and remanufacturing are among the most used (Saavedra et al., 2013).

This section gives a brief overview of relevant recent studies and advancements in the design of recovery networks for different EOL products and strategies. In addition to the studies provided by this section, readers are referred to Ilgin and Gupta (2010) for a comprehensive survey on reverse logistics network design models.

Caruso et al. (1993) developed a location-allocation model to determine the number and locations of the waste disposal plants in the region of Lombardy (Italy) while Bautista and Pereira (2006) focused on selecting the locations of municipal waste collection points in Barcelona. Wang et al. (1995) dealt with determining the optimal site locations of processing stations for paper and cardboard which formed the largest fraction of post-consumer and municipal solid waste in the state of Iowa. A model for optimizing the collection and recycling processes of EOL computers and home appliances was developed by Shih (2001). Spengler et al. (1997) focused on the development of MILP model for recycling byproducts in steel industry. Sand recycling was addressed by Barros et al. (1998). Flapper et al. (1998), Realff et al. (1999), Ammons et al. (1997) and Louwers et al. (1999) considered designing recycling network for carpet waste. Krikke et al. (1999) presented a MILP model to determine an optimal reverse logistics network for copiers. Krikke et al. (2003) developed a model to support product design and logistics network design together. In order to illustrate the applicability, the model was applied to a closed loop supply chain (CLSC) design problem for refrigerators. Schultmann et al. (2003) and Kannan et al. (2010) addressed recycling network design for spent batteries. Sasikumar et al. (2010) developed a mixed integer nonlinear programming (MINLP) model to maximize the profit of reverse logistics network and presented a case of truck tire remanufacturing. Gomes et al. (2011) developed a MILP model for network design for electric and electronic waste recovery including waste sources, sorting centres and recycling facilities in Portuquese. Mutha and Pokharel (2009) proposed a mathematical model for the design of a reverse logistics network that consists of retailers, warehouses, reprocessing centers, remanufacturing factories, distribution and recycling centers, spare markets, disposal sites and suppliers. They considered modular product structure with different disposal and recycling fractions for each module of each product in the model. Demirel and Gökçen (2008) proposed a MILP model for a remanufacturing system including both forward and reverse flows. Baenas et al. (2011) analyzed the reverse logistics chain adopted by car battery industries in the midwest of the state of São Paulo, Brazil. Santibanez-Gonzales and Diabat (2013) proposed a mathematical model for a three echelon reverse logistics network including sourcing facilities, collection sites and reclamation facilities. They used Bender's decomposition algorithm to solve the problem and computational experiments for randomly generated networks are presented. Özkır and Başlıgil (2013) proposed a mathematical model for CLSC regarding three recovery options; material recovery, component recovery and product recovery with the objectives of maximizing satisfaction level of trade, maximizing satisfaction degrees of customers, and maximizing total profit of the chain. Özceylan and Paksoy (2013a) proposed an integrated, multi-echelon, multi-period, and multi-part MILP model to optimise the production and distribution planning for a CLSC network. They presented computational results for a number of scenarios. In another study of authors, they extended their previous mathematical model by including fuzziness (Özceylan and Paksoy, 2013b). They used GAMS software to solve the proposed problems in both studies. Fahimnia et al. (2013) proposed a MILP model to evaluate the effects of carbon pricing on a CLSC. They implemented the model on a textile firm servicing in Australia.

Besides given studies, several authors proposed inventory models and policies for integrated production systems including manufacturing and recovery (Teunter, 2001). Teunter proposed an EOQ (Economic order quantity) model of an inventory system for recoverable products. He addressed repairing, refurbishing and remanufacturing options for product recovery in the model (Teunter, 2001). Jonrinaldi and Zhang proposed an integrated production and inventory control model for a CLSC including multiple products. They considered third party logistics (3PL) providers for collection of used products from end customers and disassembly of used products (Jonrinaldi and Zhang, 2013).

It has been recognized that although there are many papers in the published literature on the optimization of the reverse logistics networks for different EOL products recovery, only few of them concern ELV recycling (Guranowska, 2011). Zarei et al. (2010) proposed a mathematical model in which new vehicle distributors were responsible for ELV collection and they used joint potential facilities for distribution and collection. A number of test problem instances were generated in order to measure the effectiveness of the proposed model and solution methodology based on genetic algorithm. Mansour and Zarei (2008) proposed a network design and its mathematical formulation from the perspective of manufacturers in order to obtain maximum economic benefits from ELV recovery and fulfill the relevant legislations. The proposed model focused on establishing the optimized locations for collection centers and dismantlers and material flows between the facilities. For the collection of ELVs in Mexico, a strategic network design was studied by Cruz-Rivera and Ertel (2009). The authors aimed to