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End-of-life vehicles allocation management under multiple uncertainties: An interval-parameter two-stage stochastic full-infinite programming approach

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ABSTRACT

One of the main negative consequences of uncontrolled export of used vehicles from the European Union to developing countries is resource shortage for major players of European vehicle recycling systems. The resource scarcity puts serious pressure on vehicle recycling managers. An effective end-of-life vehicles (ELVs) allocation management is considered vital for mitigating the effect of the growing export of used vehicles. This paper proposes an interval-parameter two-stage stochastic full-infinite programming model for end-of-life vehicles allocation management under multiple uncertainties. A case study is conducted in order to demonstrate the potentials and applicability of the proposed model. Influences of parameter uncertainty on model solutions are thoroughly investigated. The developed model can efficiently handle uncertainties expressed as functional intervals, probability distributions and conventional crisp intervals. It is able to reduce risk of ELV management system failure due to the possible constraints violation. The formulated model can take into account connections of modeling parameters and their impact factors, thus reflecting external uncertainties of ELV management systems. It can provide a flexible ELV allocation management schemes adjustable with the variations in prices of secondary metals and end-of-life vehicles. The proposed model is able to reflect trade-off between conflicting waste management system revenues and the associated penalties for violating ELV allocation targets, thus providing a valuable insight for decision makers.

1. Introduction

In the EU, there is currently no binding, legal framework that can prevent the export of used vehicles or at least limit it. Unfortunately, minimal economic gain often wins over environmental awareness of last vehicle owners. In fact, the number of used vehicles exported from the European Union (EU) keeps growing, as reflected by the decreasing number of end-of-life vehicles (ELVs) passing through the vehicle recycling systems across the EU every year. The latest data show that only 6.28 million ELVs were processed in 2012 (e.g., 9.0 million ELVs were processed in 2009) (Eurostat, 2015).

The main negative consequences of uncontrolled and increased export of used vehicles from the EU to developing countries (mainly to Eastern Europe countries, the former Soviet Union, Africa and the Middle East) are:

(1) Direct effect on the EU – resource shortage for major players of the European vehicle recycling systems. Vehicle recycling factories represent dominant participants of recycling systems world-wide. They are responsible for vehicle hulk shredding, separation of the various metallic fractions and partial recycling of generated automobile shredder residue. Many vehicle recycling factories located in some traditional EU member states (e.g., Germany, Belgium, France, Spain, Italy, UK, Netherlands, etc) are struggling to secure sufficient ELV feedstock because millions of used vehicles are exported every year;
(2) Indirect effect on importing countries – water, air and soil pollution intensification. In most developing countries, ELVs are not properly managed. As a result, used vehicles imported from the EU have caused serious environmental problems due to inadequately treated batteries and uncollected rare metals (Adie and Osibanjo, 2009; Nwachukwu et al., 2011). Excessive water, air and soil pollution are among the effects of improper management of ELVs, thus significantly endangering environment and social life in importing, developing countries; and

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(3) Indirect effect on the EU – outflow of base and rare metals. With intensive exporting, many base metals (e.g., iron, aluminium, copper, lead, and zinc) and rare metals (e.g., manganese, nickel, chromium and molybdenum from automotive engine, and platinum, palladium, tantalum, indium and rhodium from automotive catalysts and microcomputers) that can be utilized in the EU for new products are scattered and lost to human use due to non-effective recycling technologies in developing countries.

Growing export of used vehicles is expected to exert significant challenge toward ELV recycling systems in the years to come. Therefore, an effective ELV allocation management is considered vital for mitigating the direct effect of the above mentioned challenge. In fact, how to effectively allocate limited resources to satisfy vast processing demands of vehicle recycling factories becomes a major concern for recycling managers. This emphasizes the need of an effective vehicle recycling systems analysis approach for supporting the ELV allocation management. Intensive work on this subject is increasingly important for all authorities involved in management of ELVs, and especially for recycling managers.

Previously, a number of research works were undertaken for solving various issues of ELV management problem. Hedayati and Subic (2011) proposed a decision-making support framework for recovery of ELVs to provide the integrated sustainable treatment option. Pavlovic et al. (2011) proposed a fuzzy multi-criteria model based on Pareto analysis to determine the location of ELV dismantling centres. Vidovic et al. (2011) presented modeling approach that could be used to locate collection facilities for ELVs. Mahmoudzadeh et al. (2011) proposed a capacitated location-allocation model, formulated as mixed integer linear program, for determining the locations of ELV collection points from the perspective of a third party reverse logistics provider. Harraz and Galal (2011b) developed a mixed integer linear goal programming model for location-allocation of the ELV recovery facilities. Merkisz-Guranowska (2011) formulated a mixed integer linear programming models to determine the optimum locations of the key participants of ELV recycling network. Harraz and Galal (2011a) proposed a lexicographic mixed integer goal programming model for designing a sustainable recovery network for ELVs in developing countries.

Iranpour et al. (2012) illustrated three China-tailored value analyzing models: model of ELV to raw materials, model of intermediate scrap to product and model of remanufacturing. Simic and Dimitrijevic (2012b) presented a tactical production planning problem for vehicle recycling factories in the EU legislative and global business environments. Simic and Dimitrijevic (2012a) expanded linear programming modeling framework proposed by Simic and Dimitrijevic (2012b) in order to incorporate vehicle hulk selection problem. Cheng et al. (2012) examined operational characteristics of ELV recycling and treatment industry in Taiwan, and its relationship to recycling performance by using production capacity, power efficiency and recycling rate as indicators. Stoyanov (2012) formulated a multi-source capacitated facility location model in order to design a network of dismantling centres for ELVs in Bulgaria.

Wang and Chen (2013) proposed the user-producer-fund-recycling developing model to support the dismantling and recycling enterprises financially, promote the ELV take-back and restrain the black market. Simic and Dimitrijevic (2013a) proposed a short-term recycling planning model for Japanese vehicle recycling industry, formulated as a linear program. Mahmoudzadeh et al. (2013) used a mixed integer linear programming formulation to solve a location-allocation problem of ELVs scrap yards in Iran. Merkisz-Guranowska (2013) proposed a bi-objective mixed integer linear programming models aiming at the reorganization and construction of the ELV recycling network in Poland. Gołębiewski et al. (2013) proposed a simulation approach that could be used to determine optimum locations for ELV dismantlers. Farel et al. (2013) modeled ELV glazing recycling network in France using system dynamics simulation approach. Simic and Dimitrijevic (2013b) developed a risk explicit interval linear programming model for optimal long-term planning in the EU vehicle recycling factories.

Mora et al. (2014) proposed a mixed integer linear programming model for ELV closed-loop network design. Ene and Öztürk (2015) formulated a mixed integer linear programming model for managing reverse flows of ELVs within the framework of a multi-period, multi-stage, capacity-constrained network design problem. Demirel et al. (2016) proposed a mixed integer linear programming model for reverse logistics network design including different actors taking part in ELV recycling system. Simic and Dimitrijevic (2015) formulated and comprehensively tested an interval linear programming model for long-term planning of vehicle recycling in the Republic of Serbia. Simic (2015a) developed a two-stage interval-stochastic programming model for supporting the management of ELV allocation under uncertainty. Simic (2015b) presented a fuzzy risk explicit interval linear programming model for ELV recycling planning in the EU. Chen et al. (2015) applied dynamic modeling and cost-benefit analysis to investigate how polices may affect recycling of ELVs in China and outlined that parameter uncertainty should be further explored. Ohno et al. (2015) used a waste input–output material flow analysis to investigate the content of alloying elements in ELVs.

Xia et al. (2016) applied cost-benefit analysis to perform the construction and investment analysis of ELV disassembly plant in China and highlighted that even though they work involved a large number of parameters clouded by uncertainty their values were considered as deterministic. Simic (2016a) formulated an interval-parameter multi-stage stochastic programming model for planning end-of-life vehicles allocation. Ahmed et al. (2016a,b) used DEMATEL and extent analysis method on the fuzzy AHP to rank ELV management alternatives with respect to several sustainable criteria. Zhou et al. (2016) developed a multi-criteria model based on the fuzzy VIKOR technique to evaluate ELV recycling service providers from the perspective of sustainability. Simic (2016b) proposed an interval-parameter chance-constrained programming model for uncertainty-based decision making in ELV recycling industry under rigorous environmental regulations.

From the review of previous literature, it is evident that a number of systems analysis methods were developed for solving various ELV management problems. However, they cannot address the uncertainty related to functional interval parameters in ELV management systems. Functional intervals represent a type of highly complex uncertainty in real-world systems (He and Huang, 2008), because they have characteristics of intervals and functions. Different from conventional crisp intervals, a functional interval can reflect both internal (by interval parameters themselves) and external (by functional relations to external impact factors) uncertainties of the system (He et al., 2009b). Technique that can tackle functional intervals in the objective function and constraints is full-infinite programming. Moreover, none of the previous studies on ELV management focused on simultaneously deal with problems with parameters expressed as functional intervals, crisp intervals and random variables. In order to comprehensively reflect multiple uncertainties which exist in the ELV management systems and in view of the limitations in previous works, this study aims to develop an interval-parameter two-stage stochastic full-infinite programming model for end-of-life vehicles allocation management. This research presents the first attempt to develop an interval-parameter two-stage stochastic full-infinite programming model for some end-of-life management system. The developed model has advantages in reflecting uncertainties expressed as crisp intervals, probability distributions and functional intervals. In addition, by allowing the modeling parameters in the objective function