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A multi-stage interval-stochastic programming model for planning end-of-life vehicles allocation

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ABSTRACT

The amount of material entering end-of-life vehicles (ELVs) management systems all over the EU has been reduced due to increased export of used vehicles to non-EU countries. According to the latest data, only 6.23 million ELVs were processed in 2012 (e.g., 8.37 million ELVs were processed in 2009). Considering that currently 342 active vehicle recycling factories exist in the EU, as well as that in the last ten years the total processing capacity has been increased several times, it is clear that there is a serious conflict. This paper proposes a multi-stage interval-stochastic programming model for planning end-of-life vehicles allocation. The developed model is able to reflect dynamics in terms of decisions for ELV allocation from a multi-region waste management system to multiple vehicle recycling factories within a multi-period context. It is capable of incorporating multiple policies within the optimization framework. Uncertainties expressed as probability distributions and discrete intervals are effectively handled, based on a multi-layered scenario tree with a finite set of scenarios. A semi-hypothetical 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 examined. Comprehensive analyses of various policy situations, associated with different levels of economic penalties and system failure risks, are presented. The proposed model is effective for solving difficult ELV allocation problems with uncertainties included as part of the formulation. It can help quantify the relationships between ELV management system profit and disruption risk of the vehicle recycling factories, and thus provide optimal ELV allocation schemes.

1. Introduction

End-of-life vehicle (ELV) is a specified vehicle which is discarded or is to be discarded by its registered owner as waste (Go et al., 2011). Waste from ELVs is the issue of a world-wide concern, because of its rapidly increasing quantity and special composition of hazardous substances. ELV waste is considered as a huge environmental problem, because it is composed of many different materials that have harmful impact on the environment (such as mercury, cadmium, hexavalent chromium, anti-freeze, brake fluid and oils) (Tasala Gradin et al., 2013). As a result, the ELV problem has become very serious, especially in the last decade (Olugu and Wong, 2012; Smink, 2007), and more and more efforts are made in order to reduce its impact on the environment (Simic, 2013).

ELVs are a major stream of waste in the EU (ECDGE, 2012; Giannouli et al., 2007). They are estimated to reach a volume of 14 million tonnes by 2015 just in the EU alone (Cherrington et al., 2012; Passarini et al., 2012). However, the amount of material entering ELV management systems all over the EU has been reduced due to increased export of used vehicles from EU member states to non-EU countries for reuse as second-hand vehicles or as sources of used parts and materials. The latest data show that only 6.23 million ELVs were processed in 2012 (Eurostat, 2015a). Considering that 8.37 million ELVs were processed in 2009 (Eurostat, 2015a), when vehicle ownership was 7.77 million lower (Eurostat, 2015b), it is evident that the used vehicles export is increasingly growing and threatening to put at risk the (economic) continuity of the European ELV management systems.

Many of ELVs generated in the EU are exported globally, mainly to Eastern Europe countries, the former Soviet Union, Africa and the Middle East (BAE, 2014; Blume and Walther, 2013; Buchert et al., 2007; Mazzanti and Zoboli, 2006; Mehlhart et al., 2011). In addition, both the export of ELVs from the EU and the generation of ELVs

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in developing countries are anticipated to increase with future economic growth and the accompanying motorization of developing countries. On the other hand, with intensive exporting, many base and rare metals that can be utilized in the EU are scattered and lost. Unlike the EU, developing countries cannot be expected to recover resources from ELVs as most do not yet have effective recycling technologies in place (Wilts et al., 2011). Therefore, there is an apparent resource scattering risk that these metals will be lost to human use due to their outflow from the EU.

Finally, export of used vehicles represents the most significant barrier to the more efficient vehicle recycling in the EU, because millions of vehicles, which are supposed to go to domestic vehicle recycling factories, are exported. Today, European vehicle recycling factories, the dominant participants of vehicle recycling systems, are struggling to secure sufficient ELV feedstock. The latest data show that there are 342 active vehicle recycling factories in the EU (McKenna, 2014). The largest number of them is located in Italy (62), France (50), UK (47) and Germany (43). Thus, even 59% of the total number of vehicle recycling factories is in the EU member states which are the largest exporters of used vehicles (i.e., the countries which risk the danger of having lack of ELV feedstock). At the beginning of this century, 202 vehicle recycling factories existed at the territory of 28 countries that are now part of the EU (McKenna, 2014). Considering that in the last ten years many larger shredders (with at least 6000-hp) and two 10,000-hp mega shredders have been installed in the EU (EFR, 2010; McKenna, 2014), it is clear that total processing capacity has been increased several times.

As a result, a sound ELV allocation strategy is considered vital for mitigating the effect of the abovementioned conflict and minimizing potential shortages in supplying vehicle recycling factories. Therefore, to whom, how much and when, are the most important questions to which every vehicle recycling manager must find optimal answers.

The relevant literature for our contribution originates from different streams of research, but from a domain-oriented point of view only the work on ELV management is significant. A detailed analysis of these papers is needed to identify the key directions for the further development of this important and dynamic research area. Hedayati and Subic (2011) propose a decision-making support framework for recovery of ELVs to provide the integrated sustainable treatment option. Pavlovic et al. (2011) proposes a fuzzy multi-criteria model based on Pareto analysis to determine the location of ELV dismantling centres. Vidovic et al. (2011) present modelling approach that could be used to locate collection facilities for ELVs. Mahmoudzadeh et al. (2011) propose a capacitated location-allocation model, formulated as mixed integer linear program, for determining the locations of ELV collection points from the perspective of the third party reverse logistics provider. Harraz and Galal (2011b) develop a mixed integer linear goal programming model for location-allocation of the ELV recovery facilities. Merkisz-Guranowska (2011) formulates a mixed integer linear programming models to determine the optimum locations of the key participants of the ELV recycling network. Harraz and Galal (2011a) propose a lexicographic mixed integer goal programming model for designing a sustainable recovery network for ELVs in developing countries.

Vermeulen et al. (2012) propose an overall sustainability assessment method suitable for assessing and comparing industrial waste treatment processes. Iranpour et al. (2012) illustrate 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) present a tactical production planning problem for vehicle recycling factories in the EU legislative and global business environments. Simic and Dimitrijevic (2012a) expand linear programming modelling framework proposed by Simic and Dimitrijevic (2012b) in order to incorporate vehicle hulk selection problem. Stoyanov (2012) formulates a multi-source capacitated facility location model in order to design a network of dismantling centres for ELVs in Bulgaria.

Wang and Chen (2013) propose 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) propose a short-term recycling planning model for Japanese vehicle recycling industry, formulated as a linear programme. Farel et al. (2013a) propose linear programming model to determine configuration and material flow sizing of the future ELV glazing recycling network in France. Mahmoudzadeh et al. (2013) use a mixed integer linear programming formulation to solve a location-allocation problem of ELVs scrap yards in Iran. Merkisz-Guranowska (2013) proposes 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) propose a simulation approach that could be used to determine optimum locations for ELV dismantlers. Farel et al. (2013b) model ELV glazing recycling network in France using system dynamics simulation approach. Simic and Dimitrijevic (2013b) develop risk explicit interval linear programming model for optimal long-term planning in the EU vehicle recycling factories.

Mora et al. (2014) propose a mixed integer linear programming model for ELV closed-loop network design. Ene and Öztürk (2015) propose 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 at al. (2015) formulate a mixed integer linear programming model for reverse logistics network design including the different actors taking part in ELV recycling system. Simic and Dimitrijevic (2015) formulate and comprehensively tested an interval linear programming model for long-term planning of vehicle recycling in the Republic of Serbia. Simic (2015) presents a fuzzy risk explicit interval linear programming model for ELV recycling planning in the EU. Chen et al. (2015) apply dynamic modelling and cost-benefit analysis to investigate how polices may affect recycling of ELVs in China and outline that parameter uncertainty should be further explored.

From the review of previous literature, it is evident that a number of systems analysis methods are proposed for solving various ELV management problems. However, the above methods cannot adequately reflect the dynamic variations of ELV management system conditions, where decisions need to be revised in each time stage on the basis of the sequentially realized uncertain events. Moreover, they can hardly deal with uncertainties in the right-hand sides (uncertain parameters located at the right-hand sides of the constraints) presented as random variables with known probability distributions. In fact, no previous study has reported on multi-stage stochastic programming for ELV management. On the other hand, only a few research papers try to tackle ELV management problems through interval-parameter programming (Simic, 2015; Simic and Dimitrijevic, 2013b, 2015). This approach is the alternative for dealing with uncertainties existing in the left- and right-hand sides of constraints and in the objective function that cannot be expressed as distribution functions. Nevertheless, no previous study has reported on the development of multi-stage stochastic programming associated with inexact optimization and its application in the ELV management research area. In view of the limitations in previous works, this study aims to develop a multi-stage interval-stochastic programming model for planning end-of-life vehicles allocation. The proposed model will improve upon the existing ELV management systems analysis