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An automotive bulk recycling planning model

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Abstract

The automotive recycling infrastructure successfully recovers 75% of the material weight in end-of-life vehicles primarily through ferrous metal separation. However, this industry faces significant challenges as automotive manufacturers increase the use of nonferrous and nonmetallic materials. As the nonferrous content in end-of-life vehicles rises, automotive shredders need to evaluate to what extent to separate nonferrous metals. We propose a recycling planning model for automotive shredders to make short-term tactical decisions regarding to what extent to process and to reprocess materials through multiple passes. In addition, the mixed integer programming model determines whether to combine materials for shipment. In a case study for automotive shredding decisions for the current composition and more polymer-intensive end-of-life vehicles, we use our model to show the sensitivity of the decision to reprocess light nonferrous metal to low and high metal prices. Contrary to observations in practice to mix light and heavy nonferrous metals for shipment, we show multiple scenarios where the model chooses to reprocess and ship separated light and heavy nonferrous metals.

Keywords: Environment; Production

1. Introduction

Of the approximately 150,000 cars per year reaching end-of-life in Sweden (Sverige, 1997), 70–75% of each end-of-life vehicle (ELV) was recycled (Borjeson et al., 2000). Likewise, of the 15,000,000 vehicles retired per year in the United States, 15–25% of their total weight is landfilled (Duranceau and Lindell, 1999). A significant fraction of the landfilled portion of ELVs, commonly called automotive shredder residue (ASR), is polymeric (Orr, 2000). The recycling of ELVs begins with parts recovery and proceeds to shredding and then material separation by magnetic and density properties (Phillips, 1996; Dalmijn, 1990). Automotive recycling outputs consist of ferrous metal, nonferrous metals, and ASR (Orr, 2000).

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Investigations to improve recovered material grades focus on processing parameters. For instance, Abous-souan et al. (1999) analyze the effectiveness of shredding different size, morphology, and metallographic distributions of shredded car fragments, using different sizes of square sieving mesh screens. Reprocessing mixed materials repeatedly through separators to generate purer output streams is investigated in (Nijhof and Rem, 1999; Stuart and Lu, 2000). Another approach to upgrade scrap is selective disassembly and material sorting prior to shredding (Boom and Steffen, 2001). Design for recycling, separation guidelines and processing to improve material output purity are important factors (Coulter et al., 1998; Rios et al., 2003).

Spengler et al. (2003) present a mixed integer linear programming (MILP) model for short-term recovery planning for electronic scrap acquisition, disassembly and bulk recycling. The sensitivity of the solution to the acceptance fees and the prices for copper and aluminum are investigated. The results show that the marginal revenue will decrease with decreasing acceptance fees as well as with decreasing metal prices, and that the decision for internal or external recycling of scrap types is strongly influenced by the acceptance fees and the market prices of materials. Process configurations are assumed fixed; reprocessing and shipment decisions are not included (Spengler et al., 2003). Sodhi and Reimer (2001) decompose the electronics recycling network into three independent mathematical programming models for the collection source, the recycler, and the smelter. The recycler model maximizes profit by choosing what materials to collect for a processing fee and to which smelters to send mixed materials for the highest returns. Lu et al. (2004) present an MILP model to make processing, reprocessing, set-up and storage decisions for electronics recycling planning. Their model does not consider shipment decisions.

Similar to the automotive shredder, the electronics recycler seeks to earn profit from separated materials. While the electronics recycler is paid to receive products and faces higher variability of incoming shipments, the automotive recycler uses purchase price to control incoming shipment quantities. Then they process hulks and sell the nonferrous metals to aluminum, copper, or brass specialized shops for further separation and resale to a secondary market (Isaacs and Gupta, 1998). However, the steel-intensive automotive design has been changing to lighter weight materials, such as aluminum, magnesium, plastics and composites (McAuley, 2003). According to Bhakta (1994), the rise of aluminum usage in automotive production has steadily increased from 43.9 kg to 80.3 kg in the six years following 1977. This triggers further research whether to separate aluminum residue from the nonferrous metals for separate sales. By using eddy current separation, the aluminum may be separated from the mixed nonferrous flow and sold separately for aluminum-to-aluminum recycling (Zhang et al., 1998). Research is needed to determine to what extent the shredder should process the light nonferrous metal to optimize profit.

The nonferrous flow may also be affected by the plastic content in vehicles. Isaacs and Gupta (1998) consider disassembly operations to remove 25% of the high value plastics prior to the shredding operations. Given a fixed shredding process, they analyzed the sensitivity of the profitability of the disassembler and the shredder to the polymer content in the vehicle design, quantity of polymer materials removed, and polymer disposal costs. Because their strategic model is based on a fixed shredding process, the impact of increasing plastic content on the shredder's processing decisions over shorter periods of time are not addressed. For example, as the plastic content in hulks increases, the shredder's ASR disposal costs increase, especially in areas where ASR is defined as hazardous waste (Straudinger and Keoleian, 2001). While polymers separated by a dismantler are not hazardous, those processed through a shredder may become mixed with hazardous materials.

Straudinger and Keoleian (2001) discuss the business economics of dismantlers and shredders. They stress that transportation costs play a large role in dismantler-to-shredding pricing relations. Further, they explain that key factors influencing shredder profitability include scrap metal prices, ELV metal content, and shredder proximity to metal smelters.

In summary, a model that considers processing, reprocessing, storage, and shipment composition decisions is needed for the specific planning requirements of automotive shredders. This recycling planning gap for automotive shredders is addressed in this paper.

2. Automotive recycling

This research studies short-term planning for automotive recycling by focusing on shredding and separating metallic and nonmetallic materials from car hulks through magnetic separation and eddy current separation. The hulks are purchased from scrap metal dealers or dismantlers who buy end-of-life vehicles (ELV) from con-