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# Assessing the economics of processing end-of-life vehicles through manual dismantling

Jin Tian, Ming Chen *

School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China

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ABSTRACT

Most dismantling enterprises in a number of developing countries, such as China, usually adopt the "manual + mechanical" dismantling approach to process end-of-life vehicles. However, the automobile industry does not have a clear indicator to reasonably and effectively determine the manual dismantling degree for end-of-life vehicles. In this study, five different dismantling scenarios and an economic system for end-of-life vehicles were developed based on the actual situation of end-of-life vehicles. The fuzzy analytic hierarchy process was applied to set the weights of direct costs, indirect costs, and sales and to obtain an optimal manual dismantling scenario. Results showed that although the traditional method of "dismantling to the end" can guarantee the highest recycling rate, this method is not the best among all the scenarios. The profit gained in the optimal scenario is 100.6% higher than that in the traditional scenario. The optimal manual dismantling scenario showed that enterprises are required to select suitable parts to process through manual dismantling. Selecting suitable parts maximizes economic profit and improves dismantling speed.



## 1. Introduction

The number of automobile owners worldwide has reached 1 billion, and the number of end-of-life vehicles (ELVs) is estimated to be approximately 60 million. Such a large number elicits people's attention because global resources are decreasing (Chen and Zhang, 2009; Go et al., 2011). Many countries face the challenge of rationally and efficiently utilizing these resources (Coates and Rahimifard, 2008). Various countries have developed appropriate policies and regulations to handle ELVs. Directive 2000/53/EC of the European Parliament and the European Council (September 18, 2000) is considered the first global policy for ELVs. This directive clearly regulates the responsibility of car manufacturers for recycling ELVs (Gerrard and Kandlikar, 2007). Directive 2000/53/EC required that no later than 1 January 2015, for all end-of life vehicles, the reuse and recovery rate shall be increased to a minimum of 95% by an average weight per vehicle and year. Within the same time limit, the re-use and recycling rate shall be increased to a minimum of 85% by an average weight per vehicle and year. Unlike the EU countries, Japan, and Korea, the end-of-life vehicle recovery in United States is driven by the market rather than by government regulation. The ELV management activities have been mainly impacted from national legislations (like Clean Air Act) addressing solid and hazardous waste disposals such as banning the disposal of free liquids in landfills and banning the disposal of lead acid batteries in landfills rather than a specific ELVs directive (Amelia et al., 2009).

Japan began to implement ELV recycling laws in 2005 (Che et al., 2011). Prior to this law, Japan had an ELV recovery rate of 85% in 2002; its target is to reach 95% by 2015 (Simic and Dimitrijevic, 2013). Implementing ELV recovery laws does not only reinforce the responsibility of car manufacturers but also regulates government management (Wang and Chen, 2013a,b). On April 26, 2007, the Korean Ministry of Environment issued the "Resource Recycling Law" for vehicles with nine seats or fewer and weights equal to or less than 3.5 t. Recycling and recovery rates have been decided as well. According to Directive 2000/53/EC, the definitions of recycling and recovery are different. Recycling means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. Energy recovery means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat. This law states that from January 1, 2009 to December 31, 2014, the recycling and recovery rates should be 80% and 85%, respectively. After January 1, 2010, the recycling and recovery rates should be 85% and 95%,

* Corresponding author at: School of Mechanical Engineering, Shanghai Jiao Tong University No. 800, Dongchuan Rd., 200240 Shanghai, PR China.

E-mail address: mingchen@sjtu.edu.cn (M. Chen).

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respectively (Park and Choi, 2005; Park et al., 2014). The State Council of China issued Decree No. 307, "Management Measures on Take-back of Scrapped Automobiles" (hereinafter referred to as the 307 Directive), in June 2001 to standardize ELV recycling activities, strengthen the management of ELV recycling, and restrain pieced vehicle activities to ensure safety (Chen, 2005; Che et al., 2011). The 307 Directive defined the threshold for ELV dismantling and recycling enterprises and the procedures for ELV disposal (Wang and Chen, 2013a,b).

Given common reasons (e.g., high labor costs and high technological maturity), shredding ELVs is widely adopted in Europe and other developed countries. Shredding is done in the US because it is the most economically viable. In the US, recycling rates are based on scrap industries making a profit to be sustainable. Although this method can be applied to process ELVs rapidly and efficiently, the goal of attaining a 95% recycling rate is difficult to achieve through this method. This year is 2016 and it seems like the recycling rate have not be achieved in many countries. As for Europe, there are large deviations in ELV recycling rates reported in a few European countries (Yi and Park, 2015). Also the real recycling rates are expected to be much lower than the depicted values since they are mostly based on recyclers' reports. Tasala Gradin et al. (2013) indicated that the current shredding scenario does not fulfill the current or future requirements of the 53 Directive. Table 1 shows the composition of passenger cars from several companies in 2014. Ferrous metals are the main component, followed by non-ferrous metals and plastics. Ferrous metals are removed through magnetic separation, and eddy current or dense media separation is utilized to separate non-ferrous metals (Kim et al., 2004). However, some non-ferrous materials, particularly lightweight materials, are difficult to separate and recover through eddy current or dense media separation (Mat Saman and Blount, 2006; Vermeulen et al., 2011). These materials and the residues from shredding form automotive shredder residue (ASR) (De Marco et al., 2007; Schmid et al., 2013). ASR is composed of plastic, rubber, foam, residual metal pieces, paper, fabric, glass, sand, and dirt (Ferrao et al., 2006). It is traditionally sent to landfills (Vermeulen et al., 2011). ASR is usually defined as the 15–25% of ELV's mass remaining after de-pollution, dismantling, shredding of the hulk, and removal of ferrous metals from the shredded fraction (Simic and Dimitrijevic, 2013). This is the key factor that makes the recycling rate of 95% hard to be achieved. Attempts have been made to recover energy from the process through incineration or pyrolysis (Santini et al., 2011) or by employing energy to build materials (Froelich et al., 2007). However, this process entails high costs because of the energy consumption, and several parts of land spaces are sacrificed and require treatment. With the requirements for lightweight automotive while still providing security, polymers are increasingly utilized in automotive interior/exterior parts, which undoubtedly increases the difficulty of sorting and recycling.

In several developing countries, especially China, dismantling enterprises commonly adopt the "manual + mechanical" dismantling approach (Chen, 2005). China currently has more than 600 ELV dismantling enterprises. This approach is based on the abundant labor resources. It also satisfies the requirement of a high recycling rate (Kazmierczak et al., 2005). However, most companies are still small-scale and have low technological level. Their environmental protection may also not meet the green industry requirement. Meanwhile, the labor cost is increasing, but the dismantling speed is not improving. These issues exert a heavy financial burden on companies. Nevertheless, this manual dismantling model is extensively discussed in EU (Ferrao and Amaral, 2006). Coates and Rahimifard (2007) stated in their study that despite the commonly held perception that manual material removal is not economically viable, the targeted removal of certain components for recycling is.

**Table 1**
Composition of passenger cars from several companies (Daimler, 2014; Volkswagen, 2014; Ford, 2014; Fiat-Chryler, 2014; Nissan, 2014).

| Material | Daimler (%) | Volkswagen (%) | Ford (%) | Fiat-Chrysler (%) | Nissan (%) |
|---|---|---|---|---|---|
| Ferrous metals | 46.9 | 58.99 | 76 | 63 | 59.4 |
| Non-ferrous metals | 24.3 | 11.96 | | 10 | 14.1 |
| Plastics | 21.1 | 19.78 | 18 | 13 | 13 |
| Fluids | / | 4.69 | 0.8 | 5 | / |
| Electronics | 0.2 | 0.17 | 0.2 | / | / |
| Others | 7.5 | 4.41 | 5 | 9 | 13.5 |

The present study focuses on the manual dismantling of ELVs and disregards the process of shredding or crushing because nearly all dismantling companies in China do not crush ELVs and sort the materials. For example, in Shanghai, the ELVs recycling management system is called "1 + 4 + 1" pattern. The first "1" means a Shanghai ELV Recycling Service Center is built for the unified recovery of all ELVs in administrative areas (not including the army). "4" means four ELV dismantling enterprises. These four enterprises separately dismantle large lorries, small trucks, large passenger cars, and small cars (including motorcycles). The last "1" means one ELV crush facility in a metallurgical enterprise which crush all five assemblies that are forbidden for use after ELV dismantling. A data collection study was performed at a Chinese ELV dismantling facility. An economic model of ELV dismantling was constructed, and fuzzy analytic hierarchy process (FAHP) was applied to determine the weights of all factors. The model aims to assess the economic implications of manual dismantling and highlight the dismantling scenario, in which parts are recycled as much as possible.

A common concern among individuals is that implementing manual dismantling is costly because of the manual labor required (Tasala Gradin et al., 2013). Coates and Rahimifard (2007) provided a specific costing approach for vehicles to assess the economics of manual dismantling (specifically glass, rubbers, and plastics) according to value recovery and target attainment. They emphasized pre-fragmentation material recovery. However, the present study considered the overall dismantling process and proved that enterprises still acquire a large profit regardless of the relatively high cost of manual dismantling.

## 2. Background of ELV dismantling

Dismantling can be categorized into destructive or non-destructive according to whether the disassembly process causes injury or damage to the assemblies or products (Hatcher et al., 2011). Destructive dismantling means the parts may be broken after the dismantling process; non-destructive dismantling means the parts are separated from the ELVs while retaining its completeness at most after the dismantling process. Chinese companies generally adopt destructive dismantling for vehicles that are more than 10 years old (Chen, 2006). Given that the parts of such vehicles are seriously worn and with the promotion of new vehicles, the parts and components of these old vehicles can hardly meet the requirements for a new car. After environmental pretreatment, an ELV is easily cut through oxygen cutting and the cutting parts could be sold as materials. For vehicles that are 10 years old or less, enterprises usually adopt non-destructive dismantling, as shown in Fig. 1. This study focuses on non-destructive dismantling only.

Environmental pretreatment is the initial step once an ELV is registered in a dismantling enterprise. The environmental pretreatment employed in China handles combustible liquids, such as gasoline/engine and oil/battery. Next, the method handles exterior parts, such as doors, windscreens, and bumpers. These exterior parts are disassembled using common tools only, such as screw-