

# Reverse logistics systems for waste generated throughout vehicles life-cycle

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## Abstract

Waste produced during the service life of automobiles has received much less attention than end-of-life vehicles themselves. In this paper, we deal with the set up of a reverse logistics system for the collection and treatment of use-phase residues. First, the type of waste arising during vehicles' service life is characterized. Data were collected in collaboration with SIGRAUTO, the product stewardship organization in charge of vehicles' recovery in Spain. Next, three organizational models are proposed. The three alternatives are benchmarked and assessed from a double organizational and operational perspective for the particular case of the Madrid region in Spain.

**Keywords:** reverse logistics, end-of-life vehicles (ELV), automotive industry

## Introduction

Reverse logistics discipline has undergone an increasing development in the last 20 years. The main focus of the discipline has been centered on two aspects:

The organization of reverse material flows in supply chain networks (returnable packaging, commercial returns, remanufacturing) and the integration of the reverse flow and the forward flow in the so-called closed-loop supply chain (Guide, Harrison and van Wassenhove, 2003).

The management of products' end-of-life phase (waste management, recycling), mainly from an environmental perspective (Carter and Ellram, 1998).

Nevertheless, aspects related to the waste generated **during the use phase** of the product life-cycle have not been extensively dealt with neither by academics nor policy-makers. The legislation deriving from the principle of Extended Producer Responsibility (EPR) or product stewardship has focused on the waste generated at products' end-of-life phase. Waste generated throughout products' service life has been much less studied and regulated. For some particular parts or components, specific waste management systems have been developed, but those parts and components are considered like an end-product themselves rather than like waste generated during the use-phase in another product's lifecycle. Examples: toner cartridges, tyres, batteries, vehicles' oils.

In Europe, the automotive sector is subject to the End-of-Life Vehicles (ELV) Directive (2000/53/CE). The implementation of this norm has translated in the creation

of country-specific Producer Responsibility Organizations (PRO), such as SIGRAUTO in Spain (Delgado, 2002, Royal Decree 1383/2002), ARN in the Netherlands (Krikke et al., 1999) or KFZ Gewerbe in Germany (Schultmann et al., 2006). Nevertheless, to the best of our knowledge, legislation and research works to date consider the collection and treatment of end-of-life vehicles' waste (LeBlanc et al., 2006; Krikke et al., 2008; Cruz-Rivera and Ertel, 2009), while the waste generated during vehicles' service life is not considered with a holistic perspective.

In this research work, carried out in close contact with SIGRAUTO, the **objective** is to propose and to assess several alternatives for organizing the joint collection and treatment of different types of waste generated during vehicles' use-phase. More specifically, three organizational models for managing those residues are proposed. In this multi-level logistic system four actors are included: "repair shops"; "specific waste managers"; "managers for waste managers"; and "control entity".

The **methodology** used to address the main objective consists of the following four phases. First, empirical data on the waste generated during vehicles use-phase are collected through a field study carried out within the 1,100 official repair shops located in the Region of Madrid, Spain. By "official repair shops" we understand the service departments of car dealerships, typically linked to one particular Original Equipment Manufacturer (OEM). Second, the raw empirical data are statistically processed in order to get insights about the waste types and volumes generated in the repair shops. Next, three possible alternative logistic models to set out the collection and treatment of the waste generated during vehicles use-phase within those garages are elaborated. Finally, the three logistic models are assessed from a qualitative and quantitative point of view.

The rest of the paper is structured as follows. In section 2, we present an overview of reverse logistics systems in the automotive industry and justify the importance of waste generated during the vehicle use-phase. In Section 3, we characterize the data obtained during the field study. In Sections 4 and 5, we describe and assess the three alternative logistic models put forward in our study. Finally, in Section 6, the conclusions of this research work are presented.

## **Reverse logistics in the automotive industry:**

### **End-of-Life vehicles vs. Waste generated throughout vehicles use-phase**

Reverse logistics issues in the automotive industry have been focused until now in the so-called End-of-Life Vehicles (ELV). This is a consequence of the introduction in year 2000 of the ELV Directive, which made ELV recycling mandatory in the European Union (EU) countries, and the further extension of the spirit of this directive to other national legislations, such as the ones of Japan, South Korea, Taiwan or almost half of the states in the US.

Automobiles are complex products made up of different materials. Though most of a car's weight is made up of metals (ferrous and non-ferrous), a vehicle also includes a wide variety of other materials, such as plastics (whose share in a vehicle's weight has been increasingly growing), glass, rubber, fluids, textiles, etc. When a car service life comes to its end in an EU member state, such as Spain (Fig. 1), the vehicle is taken to an ELV collection point, a certified ELV dismantler, where the vehicle passes through a process of depollution (draining of the vehicle's fluids) and series of operations in order to promote reuse and recycling (removal of valuable parts, components and materials: battery, spare parts that can be reused or remanufactured, ...). After that, the remainder of the ELV is taken to a shredder in order to regain the metal fractions. First, the ferrous metals are recovered, and next, a series of methods have been developed in the last decade for regaining the non-ferrous metals remaining (copper, aluminum, etc.). After

metal separation, the remainder is a mixture of glass, plastics, textiles and other components, the so-called shredder fluff. The fluff is first treated for energy recovery and then landfilled.

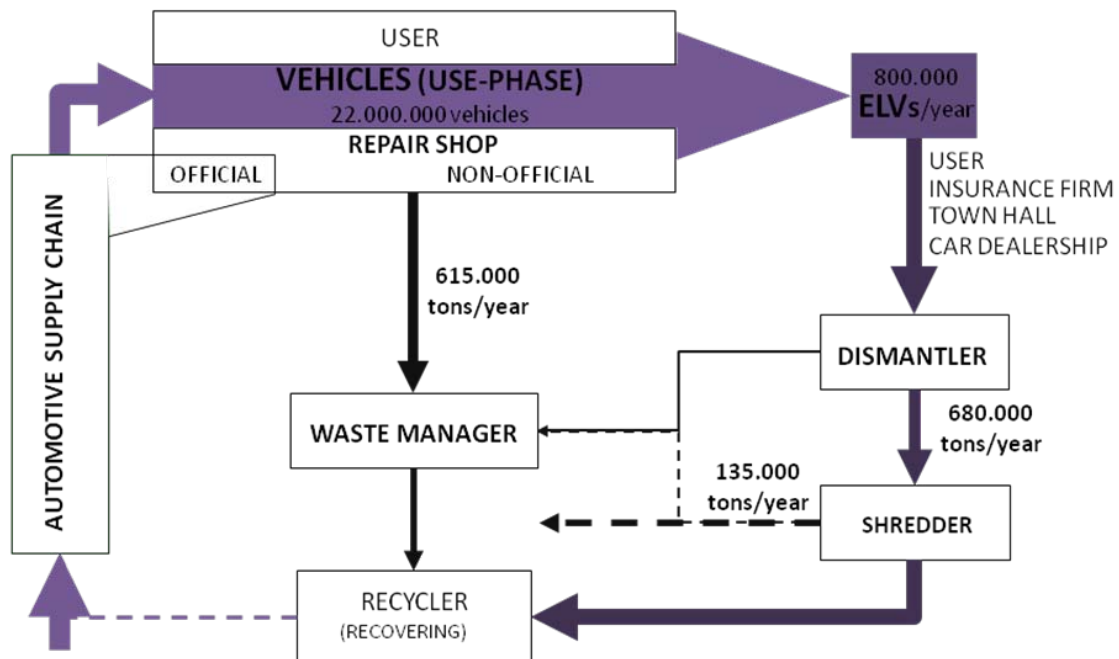


Figure 1 – Reverse logistics in the automotive industry in Spain. Own development.

Every year in Spain about 800,000 vehicles are declared ELV. Each ELV is considered to weight 1 metric ton (t). After depollution, parts reuse and metallic scrap recycling, approximately 135,000 t of residues are generated and sent to be used as fuel (energy recovery) or directly landfilled.

Those figures from waste generated by end-of life vehicles can be compared with the waste generated by a vehicle during its service life. In a survey carried out in 2001 (Delgado, 2002), more than 600 repair shops located in Spain provided information about the waste quantities generated in their premises by vehicles repair orders. The study was limited to residues that could be identified with those coming from ELV. From that survey, it was stated that every year in Spain 615,000 t of waste are generated by vehicles in the use-phase of their life-cycle. Given that the total number of cars in use registered in Spain is about 22 million cars, and that the average car lifetime is 15 years, we can assume that each vehicle in use generates about 28 kg of waste per year, and that at the end of its use phase (15 years), a car would have generated about 420 kg of waste throughout its life before it becomes an ELV.

Therefore, if the carcass effect is taken aside (most of a ELV weight is made up of metallic materials), the amount of waste generated in Spain every year by vehicles in their service life is almost 4 times the amount of non-metallic waste generated by ELV (615,000 t vs. 135,000 t). In that figures, the waste generated in the repair shops due to the regular activity of the facility has not even been taken into account.

**Field study on waste produced during vehicles' use-phase:  
Data collection and data characterization**

According to SIGRAUTO (2009 data), there are about 50,000 repair shops in Spain. Of those, almost 20% are official repair shops, certified by one particular OEM. The Region of Madrid, where about 15% of the Spanish populations resides, accounts for 1073 (~11%) of those official repair shops. Those repair shops were classified depending on their size (number of Repair Orders (OR) performed) and on the type of activities carried out in the repair shop (just mechanics, paint and body shops, light or heavy vehicles, etc.). As a result, based on those variables and on SIGRAUTO's staff knowledge, six categories of repair shops emerged (A to F) for the Madrid region. Next, through a stratified random sampling process (Forza, 2002), a sample of 26 official repair shops belonging to 8 different OEM (Hyundai, Peugeot-Citröen, Fiat, Mitsubishi, Renault Trucks, Seat, Renault, BMW) was selected. Table 1 reflects the representativeness of this sample.

*Table 1 – Sample representativeness. Own development.*

<b>Repair Shop Type</b>	<b>% of repair shops in the whole population</b>	<b>Nb. of repair shops in a sample of 26 elements</b>	<b>Nb. of repair shops visited</b>
<b>A</b>	1.95	0.51	1
<b>B</b>	7.06	1.84	1
<b>C</b>	12.58	3.27	3
<b>D</b>	21.34	5.54	6
<b>E</b>	5.72	1.49	2
<b>F</b>	51.35	13.35	13
<b>Total</b>	100	26	26

Data collection was carried out between November 2008 and January 2009 through a field study. Each selected repair shop was physically visited 4 times in order to register the amounts generated for 39 different types of waste throughout 3 periods of time.

The waste generated in a repair shop has been classified in this research work in the following three categories: product waste, process waste and common waste.

*Product waste* includes all types of materials disposed in the repair shops coming directly from the vehicle. It includes a wide variety of materials, such as oils, batteries, different types of vehicle fluids (coolant- antifreeze, brake fluid, air-conditioning system fluid, fuels (petrol/diesel)), oil filters, tyres, glass, plastics (bumpers, dashboard, fluid containers in the vehicle, ...), textiles and foams, airbags, catalysts, etc. Besides all those non-metallic materials, an important part of product waste is made up of a metallic fraction that includes mechanics waste (recoverable components or spare parts that can be reused or remanufactured), ferrous metallic scrap that can be easily recycled into steel, and non-ferrous metallic scrap (aluminium, magnesium, zinc, copper, lead, ...) such as the lead wheel counterweights used in tyres balancing (that are being substituted by zinc ones).

*Process waste* refers to the waste generated during the repair process that does not directly come from the vehicle. This includes for instance: industrial wastewater (floor and car washes), solvents used in the mechanic area (non-halogenated solvents, mineral spirits), waste paints, paint strippers, paint thinners, waste paint-contaminated materials (such as paint booth filters, masking paper, overspray paper), paint chips from sanding, absorbent sepiolite.

*Common waste* refers to the waste that can be generated in any type of repair shop, regardless of the type of repair activities carried out in the shop. This category includes

for instance: print cartridges, paper and cardboard, packaging materials (wood, metallic, plastic), strip light bulbs, electronic waste and so on.

Data collected during the field study were statistically treated with Statgraphics. In this statistical work, the average amount of waste generated by repair order (OR) was calculated. When possible, the confidence intervals of the average amount were also calculated. The data characterization process results are summarized in Table 2.

Table 2 – Average waste quantities per order of repair (OR). Own development.

	Average quantity per OR	Confidence Interval	Unit
<b>Product Waste</b>			
Oils	1,73	± 0,41	kg/OR
Batteries	0,05	± 0,013	kg/OR
Coolant	0,073	± 0,047	l/OR
Brake Fluid	0,02	± 0,01	l/OR
Fuels	0,059	± 0,026	l/OR
Oil filters	0,26	± 0,06	kg/OR
Tyres	0,13	± 0,03	units/OR
Glass	0,13	± 0,05	kg/OR
Bumpers	0,2	± 0,03	kg/OR
Metallic scrap	0,57	± 0,11	kg/OR
<b>Process Waste</b>			
NH Solvents	0,091	± 0,019	kg/OR
Masking paper	0,048	± 0,016	kg/OR
Paint booth filters	0,040	± 0,011	kg/OR
Waste paints	0,047	± 0,052	kg/OR
Paint chips from sanding	0,074	± 0,021	kg/OR
Sepiolite	0,015	± 0,029	kg/OR
<b>Common waste</b>			
Cardboard and paper	0,21	± 0,27	kg/OR
Wooden packaging materials	0,48	± 0,23	kg/OR
Plastic packaging materials	0,087	± 0,017	kg/OR
Metallic packaging materials	0,51	± 0,22	kg/OR

Besides, in the field study was analysed how many waste managers or producers responsibility organizations were used by each of the repair shops visited. The results show that, on average, each repair shop deals with 6 different waste managers.

## Organisational models proposal

In this research work, we have proposed three alternative multilevel organizational models for setting out the reverse logistics of the waste generated in repair shops throughout vehicles' use-phase. In this reverse logistics systems could take part up to four types of agents: repair shops; specialized waste managers (GRE); multi-purpose waste managers (GGR); and control entity (EC).

**Repair shop** (*taller*): is one of the official repair shops certified by one particular OEM.

**Specialized waste managers (GRE)**: this agent corresponds to the current waste managers or producers responsibility organizations (PRO), which are in charge of recovering just one particular type of waste. For instance, currently one specialized PRO has been set up in Spain for tyres recovery (SIGNUS) and another one is in charge of industrial oils recovery (SIGAUS). Those two PRO are the result of recent introduction of new national legislation regarding the extended producer responsibility of those two products (Royal Decrees 1619/2005 and 679/2006). Besides those PROs, there are other specialized waste managers for batteries, hazardous materials, etc. that support repair shops and other industries in their environmental management.

**Multi-purpose waste managers (GGR)**: this agent would act as the single contact a repair shop would handle for managing all the different waste types generated by the repair shop activity. The role of this figure is to act as a manager of waste managers. If the GGR role was introduced in the system, that would enable that a single entity takes care of all the waste generated in the repair shops within the geographic scope under its responsibility, either directly or through GRE.

**Control entity (EC)**: it is the organization that collects and centralizes all the information coming from GRE or GGR (if created), in order to evaluate the performance of the system and to control the effective application of environmentally-sound practices.

In Figure 2 the three proposed organizational models for the management of waste generated throughout vehicles use-phase are depicted schematically.

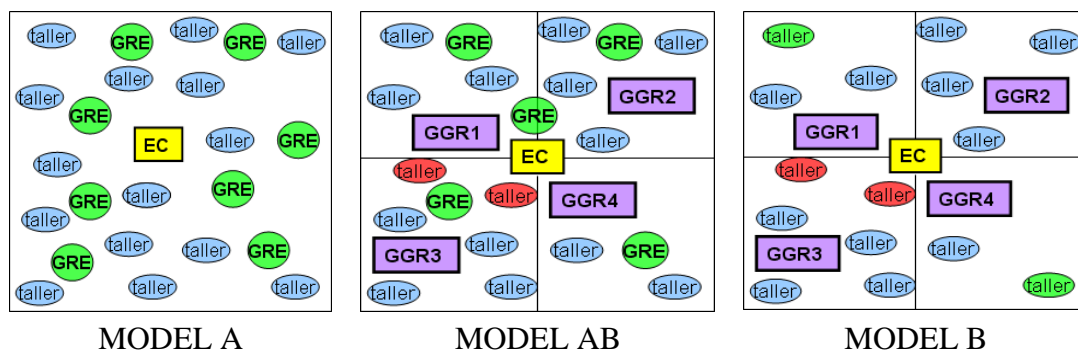


Figure 2 – Organizational models for waste generated throughout vehicles life-cycle. Own development.

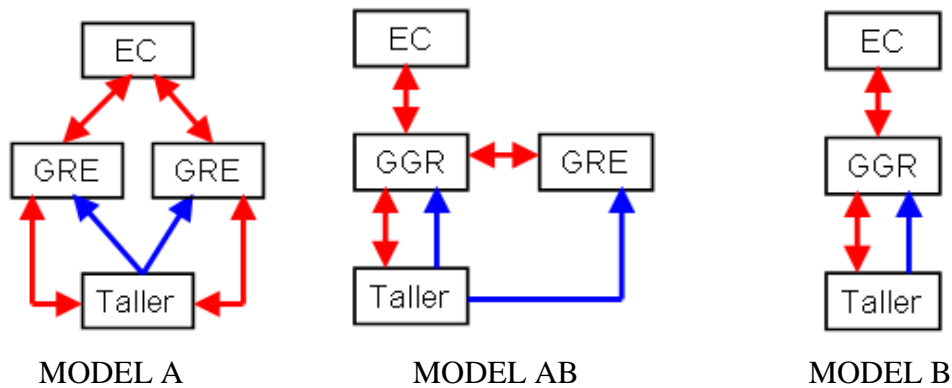
Model A corresponds to the current situation (waste managers are product-specific, PRO model), except for the introduction of a Control Organization (EC) that supervises the system. Each GRE is in charge of collecting all the quantities generated of their specific waste product (tyres, oils, batteries, waste paints,...) in all the repair shops of the geographical area considered.

Model B corresponds to a situation in which there are no specialized waste managers (GRE) but multi-purpose waste managers (GGR) that are in charge of collecting all the waste products generated in the repair shops in a given geographic area.

Finally, model AB is a hybrid between the above-mentioned models. The GGR acts as the single contact point for the repair shops allocated under its scope. For the collection of the most common and massively generated waste products, the GGR relies on specific waste managers (GRE) that provide support to all the GGR created in the geographical area considered.

The information and materials flows are different within each organizational model. The models proposed are depicted in Figure 3, ranged by the organizational complexity involved within each alternative (model A involves the highest organizational complexity, model B the lowest). The materials flows are represented by the blue arrows whereas the red arrows correspond to information flows.

Figure 3 – Organizational complexity of the three alternatives. Own development.



### Organizational models evaluation

Each alternative has been assessed from two perspectives: organizational complexity and operative efficiency. On the one hand, **organizational complexity** is a qualitative indicator that depends on the number of agents involved in the model and the corresponding amount of information flows among them. On the other hand, **operative efficiency** is a quantitative indicator that measures the workload required for the collection of all the waste generated along the 1,100 official repair shops in the Region of Madrid. Operative efficiency is measured by the hours of truck per month required within each of the three models. This metric is determined by the time spent in transit by waste collection trucks and by the residence time of those trucks at the repair shops for waste collection operations. The first factor (transit time) depends on distances to be covered within each model. The second factor (residence time) depends on the number of repair shops visited by each waste collection truck. During the field visits, residence time was measured and its value ranged between 20 and 30 minutes, so for the purpose of this study, we used an average residence time of 25 minutes per visit.

Model A (current situation) resulted to perform worse than the two other alternatives (models AB and B) either from the organizational complexity perspective and from the operative efficiency perspective. Model B is simpler than model AB from the organizational point of view, but its operative efficiency is smaller: 222.000 against 185.000 hours-truck/month.

This results show that the current logistic model used for the collection of waste generated throughout vehicles use-phase in Madrid (model A) is overcome by the other two alternative models proposed in the study (models B and AB).

### Conclusions

In the last decade, the automotive industry has concentrated their environmental efforts in providing solutions to the end-of-life vehicles problem. However, vehicles also

generate a relevant amount of waste during their use-phase. Reverse logistics systems dealing with waste generated throughout vehicles use-phase manage a higher amount of materials and are more complex than reverse logistics systems for ELV. The number of points where waste is generated is much higher (capillarity of the repair shop system) and the characteristics of the different types of waste generated in those repair shops show a wide heterogeneity.

To the best of our knowledge, this is the first time that the problem of designing reverse logistics systems for waste generated throughout vehicles use-phase has been addressed in the operations management literature. In this study, the different types of waste that repair shops generate have been characterized, and the waste volumes generated per repair order in the repair shops of the region of Madrid have been estimated. In addition, we have made a first effort to design and quantitatively evaluate several alternatives for organizing the corresponding logistics system.

An integrated waste management system that considers waste generated throughout vehicles use phase with a holistic perspective has revealed to be the best choice (either from the organizational point of view and from operative efficiency point of view), as shown for the region of Madrid. Within this geographical scope, the integrated (holistic) model has led to better results than those obtained by the models that consider waste from just a product-specific perspective.

The expected benefits of such a holistic proposal in terms of environmentally-sound practices are twofold. On the one hand, more efficiency within waste management activities leads to reduce repair shops' reluctance to get involved in those activities. On the other hand, the integrated model provides better control and enables to detect and penalise those repair shops that do not carry out waste management activities. In addition, the system-wide perspective of the control entity facilitates the identification of the main challenges and barriers that the system has to deal with. Hence, special efforts can be proposed to address to those key issues, resulting in a continuous improvement of the system for proper treatment of the waste generated during vehicles service life.

Under this approach, the main further extensions of this research work will be directed towards the operational level of that waste management system. We will focus on aspects related to the materials and information flows. Within the materials flows, we intend to: (a) analyze the effects of introducing multiproduct transport equipment, and (b) to deepen our understanding on the collection frequencies required for different types of residues. Regarding the information flows, we will further research on (c) the monitoring, and (d) deviation analysis, to be carried out by the Control Entity.

This research work contributes to OM theory and practice, and more specifically to the Reverse Logistics area, by analyzing for the first time with a holistic perspective all the different types of waste generated during a product service life. For the particular case of vehicles, on the one hand, the paper characterizes the waste types and volumes generated during a vehicle use-phase. On the other hand, the paper proposes alternative logistic models to deal with that waste in an environmentally sound manner. The results presented here may be interesting for operations managers in PROs of other countries different to Spain and subject to specific legislation on end-of-life vehicles, for environmental policy-makers and for OM academics working in the sustainability and reverse logistics areas.

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