Cost models for Increased Value Recovery from End-of-Life Vehicles

Gareth Coates, Shahin Rahimifard
The centre for Sustainable Manufacturing And Reuse/recycling Technologies
Loughborough University, Wolfson School of Engineering, United Kingdom

Abstract

A sustainable approach to a products End-of-life processing needs to be a balance between the environmental impacts of a particular course of action, and it's economic viability. The research reported in this paper has investigated a structured costing framework to be used in conjunction with improved environmental practises, to provide an economic understanding of varying End-of-Life Vehicle processing routes. The paper presents an holistic end-of-life cost model for the vehicle recovery sector and focuses on the potential applications of this model to support both high and low level decisions, in terms of a processes economic merits and its influence on the ELV Directives recycling and recovery targets.

Keywords
End-of-life Vehicles, Cost modelling, Legislation, Value recovery

1 INTRODUCTION

Environmental legislation, the physical interpretation of the "polluter-pays" principal, has meant that manufacturers and businesses are becoming ever more accountable for their product's environmental effects beyond the traditional boundaries of the product development process. End-of-life disposal and product takeback legislation has taken a proactive stance and has formulated a number of prescriptive European directives encompassing the design, production and end-of-life treatment of a range of products. The automobile, through the End-of-Life Vehicles (ELV) directive [1] has become one of the first products to be actively legislated against, and will undoubtedly act as a reference model to other Original Equipment Manufacturers (OEMs). In its simplest sense the legislation requires vehicle manufacturers to provide free take-back and treatment for all its own vehicles post 2007, and meet recycling and recovery targets of 85% and 95% in 2006 and 2015 respectively. Many vehicle manufacturers have opted to conform to the directive by moving away from actively fulfilling the requirements themselves, in favour of utilising traditional waste reclamation routes. The vehicle recovery chain comprises of stakeholders that hold their core competency in a particular facet of vehicle salvage, whether it be a type of component reuse or material recovery. Unlike the vehicle supply chain the vehicle recovery chain is a somewhat archaic and reactive industry, and the ideas of lean operation, value improvement and Environmentally Conscious Recovery (ECR) are not well established.

Decisions made throughout a vehicles life-cycle impinge on its level of sustainability, but perhaps one of the most influential factors is where the vehicle recovery chain finally places it within the waste (reuse) hierarchy. Legislative recycling and recovery targets have some influence over this final product routing, but the decision is often based on how well a product retains its economic value and the level of end-of-life (EOL) processing required. Within the recovery chain the investment required to maintain that value can not always be perceivably justified, with little understanding as to the exact economics of varying EOL processing decisions and even less transparency in terms of environmental performance. The research reported within this paper identifies an holistic EOL costing model, to be used in conjunction with environmental best practise, to provide an economic insight into sustainable vehicle recovery.

2 BACKGROUND

The influence of the ELV Directive is apparent throughout the vehicle value chain, from supplier reporting requirements and manufacturer type-approval testing, to the end-of-life operators that actually process the retired vehicles. Each European member state has opted to transpose the Directive into its own laws in a variety of different ways. A more detailed discussion of these difference can be found within the environmental regulations report [2]. The UK has opted for an "own marquee" approach which has seen each vehicle manufacturer establish its own contracted network of Authorised Treatment Facilities (ATFs), where owners can return their vehicles free of charge. At these facilities the vehicle is de-polluted and cannibalised for spare parts, before the hulk is passed to the shredder operator. The shredder then fragments the vehicle and recovers the ferrous content, in advance of passing the remaining residue to the dense media plants to recover any other non-ferrous and non-metallic content. Figure 1 highlights the main actors and material flows within the vehicle value chain.

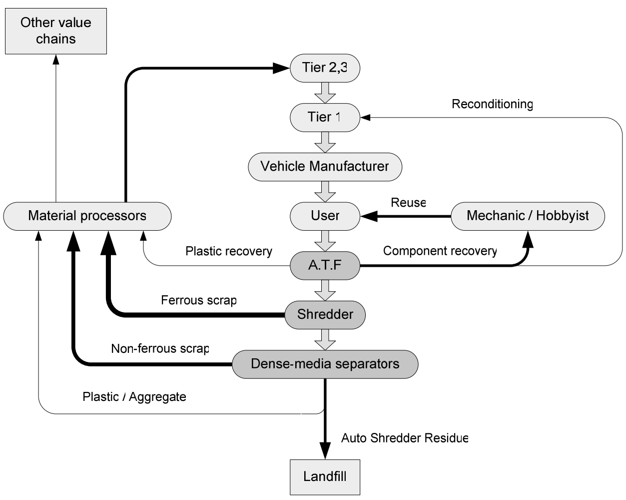

Figure 1: The recovery chain within the vehicle value chain.

Focusing on the End-of-life processing requirements of the ELV directive, the fulfilment of two key points are driving investment and reform within the recovery sector.

- The establishment of standards for storage, treatment and de-pollution of ELVs (this has been the catalyst for substantial improvements in the whole sectors environmental operating standards).
- Achievement of a recycling and recovery target of 85% (80% recycling) of a vehicles weight by 2006, and 95% (85% recycling) by 2015.

Current ELVs hold a great wealth of intrinsic value given the current scrap steel prices that many EOL operators receive for their vehicle hulks. Vehicle manufacturers have used this to their advantage when negotiating ELV collection contracts with stakeholders within the recovery chain. This has resulted in the formulation of “zero-cost” contracts [3], allowing the manufacturers to achieve the 2006 recycling and recovery target using the existing infrastructure without the need for further direct investment.

Work that has focused on costing the attainment of the 2006 and 2015 targets has concluded that the economics of pre-shredder dismantling are unfavourable compared to that of automated post-shredder separation [4], despite the improvements in purity and secondary applications that can be achieved by utilising dismantled materials [5,6]. The general consensus is that the 2006 target will be achieved utilising the existing stakeholders, but a number of papers [4,7] have highlighted the inability of current post-shredder separation technologies to meet the 2015 target. This has prompted discussion in both the UK and EU as to whether the later target should be reviewed [8].

The economic ramifications of this conformance has left many EOL stakeholders in a uniquely different market to that of which they have been traditionally used to. Their only recent inclusion within the vehicle value chain has meant that the demands of being part of the manufacturers extended enterprise have never been present, and as such the ideas of waste reduction and value improvement have never been major industry concerns. With the introduction of the ELV legislation comes an increased need for the recovery chain to better understand the economics of its own operations. Once achieved the sector will more realistically consider environmentally beneficial alternatives.

3 RESEARCH METHODOLOGY

Given the drastic reform and investment that the recovery industry is currently undergoing, there will eventually be a need, either due to risk mitigation or business survival, to achieve higher levels of value recovery than that which has been traditionally accepted. This requires an understanding not only of the costs of processing a particular type of vehicle (pre and post-fragmentation), but also of the achievable revenues from the sale of materials and components. Each stakeholder within the recovery chain is different, from the level of investment in their facilities to the variation in their core competencies and value added operations. To establish an economic understand of their operations and make sustainable recommendations based on it, a method is required that allows the costing of this variation. This has resulted in the development of an EOL costing model, which establishes a base “as-is” model for a particular stakeholder within the vehicle recovery chain before analysing and optimising potential “to-be” scenarios. Figure 2 highlights the main modules used within the framework, and the following sections discuss some of the data collected and techniques used.

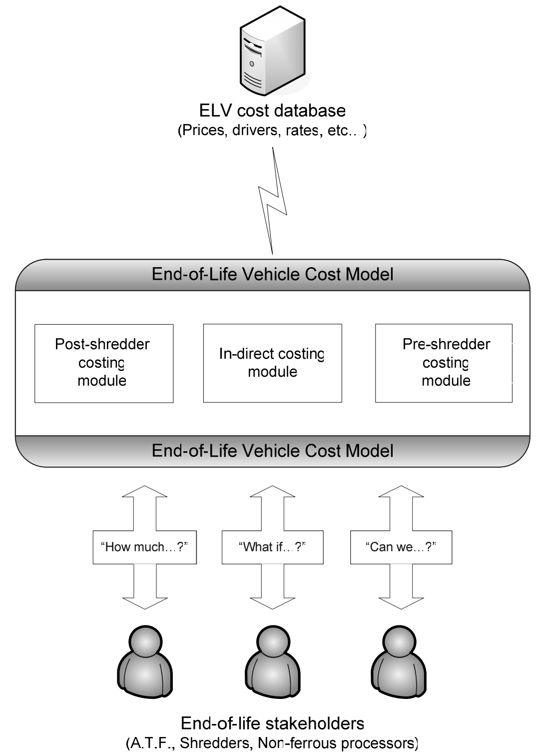

Figure 2: Generalised cost model structure

3.1 ELV costing database

The database acts as a central source of reference from which users of the model have access to typical data, this can be used to generate a base model of their operations. Table 1 outlines some of the typical information structures used within the database and the costing modules in which the information is used. The majority of the data has been catalogued from an extensive review of UK EOL operators.

Information structure	Model purpose
Capital equipment costs	Typical investment costs, depreciation, power requirements, etc…
Average material pricing index	Material prices, used to assess the feasibility of material removal at various stages of processing.
Material property data	Typical material property data (density, conductivity, etc…), used as part of the post-shredder costing module to determine the achievable waste stream separation.
Machine efficiency values	“Tromp curve” values, used within the post-shredder costing module that describe the ability of a particular machine to separate materials.
Vehicle information	Average vehicle composition and list of removable materials, used as part of the pre-shredder costing module to identify components to be removed.
Rates	Labour, exchange, fuel, power, business, etc…

Table 1: Typical information structures within the ELV database.

The database is designed to act not only as a knowledge based repository to assist the user in the generation of an "as-is" base model, but also as a live updatable information source if located on a web server. This would allow parameters within the database (such as the materials price index and waste management costs) that seriously affect the economics of the system to be regularly updated.

3.2 Indirect ELV processing costs

To assess the true cost of processing an ELV, both the direct and indirect costs must be considered. Direct costs are often more visible and easier to attribute, whereas in-direct costs are often shared by a number of resources and are not as easily defined. "Traditional cost accounting" has always attributed indirect costs using direct cost-drivers (such as labour). The inadequacies of such approaches are well documented and have lead to the development of "Activity Based Costing" (ABC) accounting. ABC assumes that activities consume resources, and as such, indirect costs like overheads and equipment depreciation can be directly linked to a machine's utilisation and throughput. The effective capturing of these links (otherwise known as "cost-drivers") allows the attribution of the total operating cost of an activity to unit, batch or line level quantities. An example of the application of the ABC methodology to the vehicle de-manufacturing process can be found within the work of Bras and Emblemsvag [9] and provides a good example of how in-direct costs can be attributed within the ELV cost model.

3.3 Pre-shredder dismantling costs

Aside from the enforced de-pollution process to remove the fluids and hazardous materials from the vehicle, only reusable components are removed from the vehicle pre-fragmentation. Currently, the removal of materials (plastics in particular) is not a widespread practice by the ATFs, and is not considered feasible given the labour intensive nature of the work. However, this is not to say that this will always be the case. The long-term stability of both scrap steel and global oil prices, combined with an unfavourable downturn in the parts resale business has the potential to make the economic viability of such practices more appealing. Therefore, methods of costing both the removal of reusable component and recyclable plastic trim have been included within the model.

3.3.1 Component removal and resale

Standard sub-assembly removal times have been collected via a questionnaire distributed to over 300 ATFs throughout the UK. The preliminary findings have assisted in determining the most frequently removed sub-assemblies and standard removal times. Table 2 provides an example of this data which will ultimately be utilised to cost component reuse, and recycling target achievement within the model.

3.3.2 Plastics dismantling case study

The recycling targets laid down by the ELV Directive did not assume that the recycling quantities would necessarily come from post-fragmentation separation technologies. There are clauses within the directive that require vehicle manufacturers to provide detailed dismantling information for the plastic components that can be removed from an ELV (included within the International Dismantling Information System, IDIS), should the target be achieved pre-fragmentation. Unfortunately, there is no abundant source of publicly available data that catalogues the destructive dismantling of vehicles with which to develop costing equations. Therefore, a study was undertaken within a UK ATF to generate material removal times for a range of top selling natural and premature ELVs. This data would ultimately be combined with manufacturer "tear-down" data, and be used to develop Cost Estimate Relationships (CERs) using parameters available within the IDIS database (weight, attachment count, location, etc…). By utilising parametric regression analysis, the CERs developed are capable of generating an approximate disassembly time (and hence cost) for any component from any make or model held within the database, without the need to physically carry out the work.

3.4 Post-fragmentation costs

Shredders and dense media separation plants are primarily focused at recovering the metallic fractions from the vehicle once it has been fragmented. This is achieved via a series of automated separation technologies that target specific physical and material characteristics within the waste stream that are susceptible to that processes influence. Typical processing equipment used within these facilities include; over-band magnets, floatation tanks, eddie current separators, air cyclones and screening meshes. By identifying the waste stream parameters

Component	Average removal time	Labour cost (€)*	Resale price for a Premature ELV (€)**	Resale price for a Natural ELV (€)**	Improvement in recycling and reuse target***
Engine	1 hour 11 minutes	12.35	607	192	10.48%
Gearbox	52 minutes	9.04	299	163	2.97%
Alternator	15 minutes	2.61	60	36	0.68%
Starter motor	17 minutes	2.96	56	44	0.34%
Distributor	10 minutes	1.74	56	33	0.02%
Head-lamp assembly	12 minutes	2.09	37	19	0.17%
Quarter glass	14 minutes	2.43	37	33	0.64%
Radiator	16 minutes	2.78	54	30	0.42%
Wing mirror	9 minutes	1.56	43	27	0.13%
Totals	**3 hours 37 minutes**	**€37.56**	**€1249**	**€577**	**15.85%**

* Based on € 21,700 per annum mechanic / technicians wage working a 40 hour week.

** Premature refers to a vehicle of 7 years of age (1999), a natural refers to one of 13 years (1993). Top 3 selling vehicles from each respective year researched. (www.carparts-uk.com)

*** Based on the average weight of 1030kg [10]

Table 2: Data used to cost the removal of components for resale and target achievement.

which each of these technologies are trying to target, and utilising process efficiency curves (Tromp/Partition curves) found within the minerals refinement industry, a 'theoretical separation model' can be developed, which can be used to predicted where each material will ultimately end up and its level contamination at that point (see figure 3).

This approach allows the modelling of value-added processing operation for each post-fragmentation technology, and results in a *grade* and *recovery* percentage for each waste stream constituent. These percentages can then be cross-referenced with estimated "value vs % contamination" curves for each material and a potential recycling revenue or disposal cost generated.

4 PRELIMINARY MODEL DEVELOPMENT

Each module within the ELV cost model has been implemented within Excel spreadsheets to demonstrate the principles before bringing all of the approaches together. Figures 4 and 5 provide examples of this development.

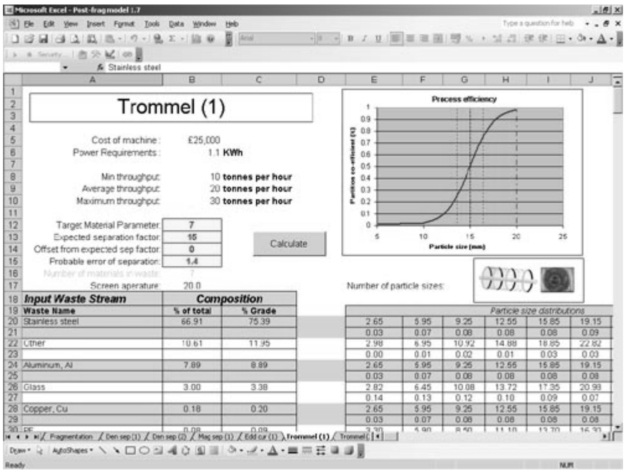

Figure 4: Screenshot from the theoretical separation model, calculating the predicted separation of a trommel.

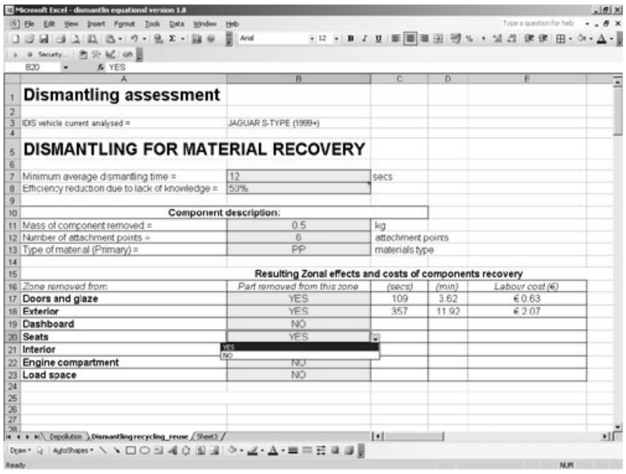

Figure 5: The use of CERs to cost pre-shredder plastics removal.

5 DISCUSSION

Many businesses have long considered sustainability as focusing too heavily on the environmental performance of their products, and the balance between the economic and social pillars of sustainabiltiy have become disassociated with the term. Upstream organisations that promote sustainable practices are often the ones that have tight control over the economic side of their operations, before venturing improvements within their environmental performance. This has seen the adoption of techniques such as Environmentally Conscious Manufacturing (ECM) and waste reduction methodologies within the vehicle supply chain. Yet surprisingly, the stakeholders who have the most active influence over an automobiles level of sustainability are the EOL operators that have made the most investment and understand their processing costs the least.

EOL stakeholders have direct control over how a vehicle is disseminated, and how its components/materials can be reabsorbed into other value chains, whether it be selecting assemblies for reconditioning, through to isolating shredder residue feeds for energy recovery. The

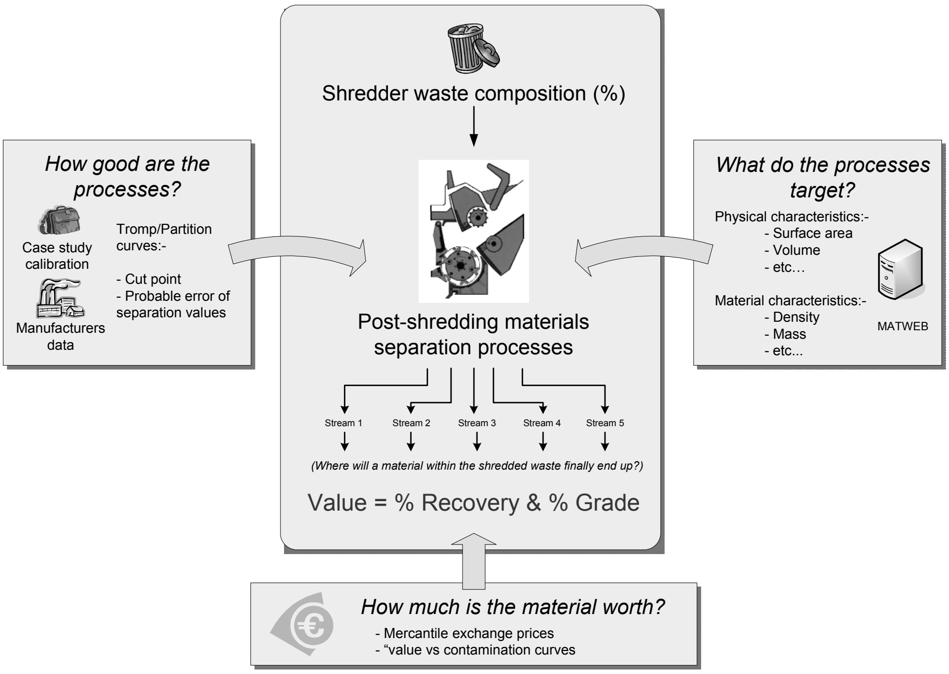

Figure 3: Development of a theoretical separation model to cost the recovery of post-fragmented waste streams

ELV Directive has brought some prescriptive requirements to this process, but the reactive nature of the vehicle recovery industry has meant that many EOL stakeholders have been reluctant to break with traditional practices. Therefore, to expect this industry to move more towards long-term sustainable practices, without first giving them the assistance to understand the economic implications of their operations, will forever mean that an EOL stakeholder's financial stability will always take priority over any environmental considerations.

The main goal of this research is to model the economics of vehicle recovery as the waste is disseminated by the various EOL stakeholders. The short-term aim of the model is to suggest value improvement opportunities in the wake of the substantial investment made by the industry in conforming to the ELV Directive. The establishment of a tailored, "as-is" base model for a particular EOL stakeholder, gives them a better understanding of how much it costs to process a vehicle in terms of cost traceability and value-added processing. This current modelling has the potential to support micro level (day-to-day) decisions at each of the stakeholders, from producing estimated service prices based on the cost of processing, to outlining prescriptive de-pollution and removal operations to meet the current recycling and reuse target. The long-term aim is to utilise the model in a predictive capacity ("to-be" modelling), which will allow the costing of various processing scenarios to be investigated before the actual investment is made. This can be undertaken in the context of conformance costing for the 2015 recycling and reuse target (currently set at 85%), further value recovery via process optimisation, or the consideration of sustainable development within the vehicle recovery sector via the inclusion of better environmental practices.

5.1 Dismantling versus shredding

The previous sections have discussed some of the techniques and studies utilised in developing various modules of the EOL model. Although the integration of these approaches into one holistic end-of-life decision support system is still in development, some preliminary analysis can be undertaken looking at the current economics of material recovery pre and post-fragmentation.

Given that the recovery of the metallic fraction of a vehicle is based on established separation technologies that have high throughput and good yield rates, the industry is currently focused on trying to recover the plastics fraction from the remaining residue. The debate is centered around whether this should be achieved before or after the vehicle has been shredded. Plastics segregated pre-fragmentation tend to produce higher value materials more suited to closed-loop recycling, while plastics recovered from post-fragmentation residue are more applicable to lower-level recycling (e.g. aggregates) or energy recovery applications.

Looking at this material value from the ATFs perspective, the euro per kilo price of selective plastics is substantially greater if removed before fragmentation, than if the ATF leaves the plastic to be counted as part of the hulks overall weight (see figure 6). The question, that has moved the industry more towards post-fragmentation separation, is whether the economics of manual disassembly, cleaning and transportation, justifies this increased value. Figure 7 utilises a metric developed by Coulter [11], referred to as the Value Removal Rate (see equation 1) and is based on the data collected via the dismantling study.

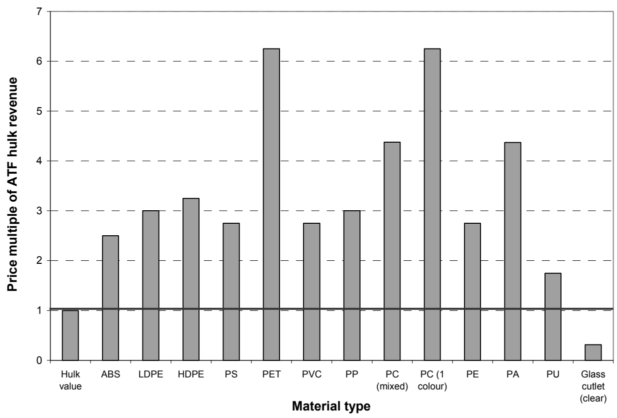

Figure 6: Chart comparing the per kilo value of various plastics to that of the price received by the ATF for the vehicles hulk.

$$VRR = \frac{Material(kg)xValue(€/kg)}{DismantlingTime(\sec)} \quad (1)$$

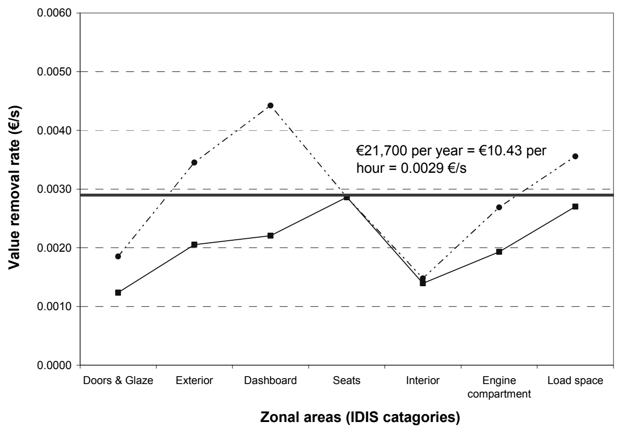

Figure 7: Graph showing the value vs effort metric VRR for stripped and un-stripped components, relative to the cost of direct labour.

The data has been broken down into zonal locations (as specified within IDIS), with average value removal rates calculated for each zone. The dashed line represents the VRR without the time taken to stripping any contaminants from the components, while the solid trace includes this additional processing stage. The thick base line within the graph highlights the direct labour cost. Anything below this line would suggest the effort-to-value return of removing components from that zone is uneconomical, while points above this line would suggest that components from that zone could potentially make money if suitable quantities could be recovered and the logistic costs absorbed.

Based on current material market prices, the preliminary data would suggest that the economic feasibility of pre-shredder material removal is uneconomical. Although some zonal areas of the vehicle have plastics that are easier to remove than others, the additional time required to strip contaminants (fasteners, screws, adhesives, other plastics, etc…) seriously affects any potential profit. However, some of the limitations of the assumptions used within this analysis must be made clear.

- Material prices for plastic components recovered from the vehicles are the same as those given for household plastic wastes, despite the improvements in quality when using engineering plastics. (Currently, the plastics recycling market within the UK is not established enough to make this distinction.)
- Dismantling was undertaken with no perspective removal aids (aside from IDIS), and times dramatically increased with experience.
- Stripping was assumed to be manual labour, and the inclusion of grinders and automated separation technologies (over-band magnets, eddie current devices) were not considered.

Additional long-term parameters that will also affect the viability of these practices, include increases in virgin polymer costs due to higher oil prices, and the stability of both the scrap steel and part resale markets.

6 CONCLUSION

The ELV Directive has proven to be the catalyst for substantial reform within the vehicle recovery sector, and has clearly brought EOL stakeholders into the vehicle value chain. The challenges and pressures of being part of the extended enterprise have required huge investment within an industry that has traditional seen little intervention from either Government or vehicle manufacturers. Indirectly charged with the responsibility of meeting the reuse, recovery and recycling targets laid down by the directive, the recovery sector has made considerable headway in fulfilling the 2006 target, but there is still a long way to go if the 2015 target remains in place.

To date, the majority of investment, and the inclusion of environmental operating procedures (de-pollution), have been undertaken by the EOL operators due to Government legislation. This will ultimately change once the directive is in full operation, and further prescriptive legislation has ceased. Therefore, to continually promote sustainable practices within the vehicle recovery industry the economic implications of their inclusions must be understood. Only then will EOL operators realistically consider them. The research reported within this paper is attempting to address this by developing a cost model that provides economic transparency, and a means of supporting further value recovery under the constraints of the current and future legislative targets.

Although still in the intermediary stages of implementation the ELV directive has been the catalyst for substantial environmental improvements within the recovery sector, yet at the same time it has been unable to close the product life-cycle loop and bring manufacturers closer to the issues regarding the disposal of their products. As a means of attributing producer responsibility its aim has become distorted by the recovery sectors economic needs, and the manufacturers unwillingness to make vehicle recovery part of their core competency. Therefore, future sustainable practices within this industry will always be promoted and supported by the vehicle manufacturers, but real change will only come from those EOL operators who can identify genuine opportunities and rewards.

ACKNOWLEDGEMENTS

Many thanks to D. Allen and R. Kirk of Albert Looms Derby, for there support and assistance during the ATF dismantling study. Also thank you to P. Owen and staff of Rozone Ltd, for providing additional support and equipment during the study.

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CONTACT

Gareth Coates

The Centre for Sustainable Manufacturing and Reuse/recycling Technologies, Wolfson School of Engineering, Loughborough University, United Kingdom.

G.Coates@lboro.ac.uk