Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Resources, Conservation and Recycling 52 (2007) 286–302
Resources Conservation & Recycling
www.elsevier.com/locate/resconrec

Assessing the economics of pre-fragmentation material recovery within the UK

Gareth Coates *, Shahin Rahimifard

The Centre for Sustainable Manufacturing and Reuse/recycling Technologies (SMART), Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough LE11 3TU, UK

Received 5 January 2007; received in revised form 28 March 2007; accepted 3 April 2007
Available online 10 May 2007

Abstract

The 2006 end-of-life vehicles (ELVs) directive target for the recycled and reused material content of an ELV has been undertaken using the current recovery infrastructure within the UK. The current expectation is that the conformance for the 2006 recycling target will be mainly achieved using existing post-fragmentation separation technologies rather than manually disassembling vehicles into their constituent materials. With the economic pressure of the current legislative targets weighing heavily on end-of-life stakeholders, and the further increase of recycling levels for 2015, it is important to understand "when" and "if" manual dismantling activities become economically viable within a dramatically changing vehicle recovery industry. This paper describes a method of costing the dismantling of specific makes and models of vehicle due for retirement in 2015, and discusses the economic implications of such practice and possible strategic directions for pre-fragmentation vehicle recovery.

Keywords: End-of-life vehicles; Dismantling economics; Pre-fragmentation material removal

1. Introduction

Over two million end-of-life vehicles (ELVs) are produced in the UK each year (Kollamthodi et al., 2003), containing a range of metallic, ceramic and polymeric materials.

* Corresponding author. Tel.: +44 1509 227683; fax: +44 1509 227648.
E-mail address: G.Coates@lboro.ac.uk (G. Coates).

0921-3449/$ – see front matter
doi:10.1016/j.resconrec.2007.04.001

The recycling or recovery of these materials at end-of-life has the potential to substantially improve the sustainability of the automobile through resource conservation and waste minimisation. Yet, at present ELV recycling is undertaken by an industry relatively unfamiliar with the various material preparation methods and vehicle manufacturing processes, and one that is unbound by any "direct" producer responsibility. The end-of-life vehicles directive (2000/53/EC), introduced in 2000, has therefore attempted to redress this issue by bringing vehicle manufacturers closer to the recovery of their products via extended producer responsibility (EPR), to facilitate more sustainable closed-loop thinking.

The UK transposition of the ELV directive requires vehicle manufacturers to provide free take-back and treatment for all their own vehicles post 2007, and meet stringent recycling and recovery targets of 85% and 95% by 2006 and 2015, respectively. Vehicle manufacturers have opted to conform to the legislation by moving away from actively getting involved and investing in their own recovery facilities, in favour of utilising the existing infrastructure and waste reclamation processes within the UK. This has lead to the establishment of "collection contracts", whereby the existing vehicle recovery industry has agreed to fulfil the requirements laid down by the ELV directive on the vehicle manufacturer's behalf. The economic support required to fund such an undertaking is estimated to be in the region of £20–41 million per year in de-pollution and site requirements, and £6.5–10.5 million per year in vehicle de-registration (DTI, 2003). It was widely believed by the recovery sector (based on article 5 of the ELV Directive, and lobbied for by the British Metals Recycling Association during the consultation period; Letsrecycle.com, 2002) that this would be subsidised by the vehicle manufacturers, yet during the establishment of these collection contracts it became apparent that no direct financial support would be given to the vehicle recovery sector, given the substantial intrinsic value that ELVs possessed at the time of the contract negotiations.

The UK transposition of the ELV directive has therefore done little to strengthen the relationships between the vehicle recovery chain and the vehicle manufacturers, and it can be argued that this has been counter productive to the core themes of sustainability. Without a subsidised influence from the vehicle manufacturers, any decisions concerning the end-of-life operations carried out on a vehicle will be based solely on process economics as opposed to any long-term environmental benefits. It is therefore vital for the vehicle recovery industry to begin to understand the economics of its own operation, so that future vehicle salvage is based on economic feasibility as well as environmental benefits.

This paper focuses on the pre-fragmentation element of vehicle salvage, and presents the findings of a data collection study undertaken at a UK Authorised Treatment Facility (ATF). Parametric regression analysis is then used to generate vehicle dismantling equations to cost specific assembly removal, and assess the feasibility of future recycling targets with today's markets. The aim of this modelling is to not only assess the economic implications of future directive conformance via dismantling, but to highlight further potential value recovery opportunities in light of the current relationships created by the transposition of the ELV directive.

2. Background

The existing vehicle recovery industry is predominantly led by a handful of large metal merchants, that are primarily interested in recovering the metallic fraction from ELVs. Geographically distributed scrap-yards (ATFs) serve as collection hubs for these large operators, and are required to make the vehicle environmentally safe via a process of “de-pollution”, before passing the hulk on to the metal merchant for shredding. Fig. 1 highlights the main actors within the automotive “value chain” (Roy and Whelan, 1992), and the strengths of the markets served by the vehicle recovery sector. More detailed literature exists as to the ELV implementation strategies adopted by each EU member states (Perchard, 2004) and its specific UK transposition (Edwards et al., 2006).

To date, the majority of investment has been made by the ATFs in bringing their facilities up to scratch for the de-pollution requirements of the directive. The financial support required to attain the 2006 and 2015 recycling and recovery targets has prompted many discussions among recovery operators, not only as to the ability of current post-fragmentation technologies to achieve the targets, but also the economic viability of the pre-fragmentation alternative. The general consensus from industry is that the 2006 target will be achieved utilising the existing infrastructure and an assumed recycled metallic fraction of 75% (Weatherhead and Hulse, 2005). However, the attainment of the 2015 target is not as easily assured, provoking discussion in both the UK and EU as to whether the latter target should be reviewed (GHK, 2006; SWG-ELV, 2005). Pro-active European investment would sug-

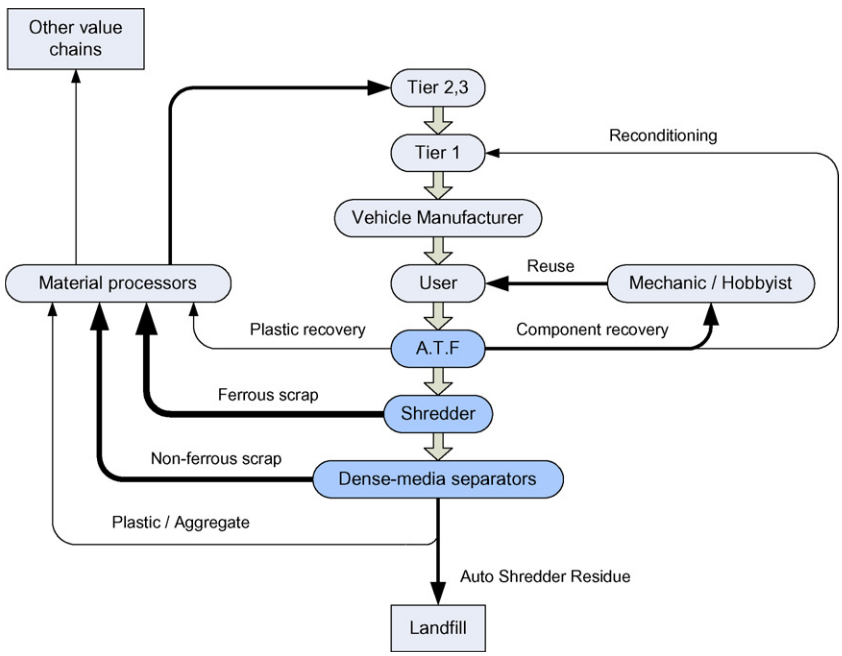

Fig. 1. Main end-of-life stakeholders within the vehicle value chain.

gest that automated post-fragmentation material recovery is the preferred industry option for achievement of the higher recycling and recovery levels, exemplified by Automotive Recycling Netherlands' recent announcement to develop a post-shredder technology (PST) plant in Tiel (ARN, 2007). The UK's largest post-fragmentation material recoverers, European Metals Recycling and Sims Metal that handle approximately 70% of all ELV capacity within the UK (DTI, 2005), have yet to publicly affirm their commitments to the higher 95% target and identify their preferred conformance technologies. It is envisaged that they will use the interim period between now and 2015 to make these decisions. For a more detailed discussion of state-of-art post-fragmentation technologies see Ferrão et al. (2006).

Previous pre-fragmentation data collection exercises have been undertaken in both the UK (Weatherhead, 2005) and the US (Gallmeyer, 2003), and preliminary analysis as to the economic viability of material dismantling carried out. More holistic costing models developed to consider the strategic implementation of the ELV directive have also been considered (Amaral et al., 2006; Ferrão et al., 2006; Johnson and Wang, 2002), in which typical quantities of components to be removed pre-fragmentation were assessed. More generic cost modelling work that has considered the economics of the ELV reclamation as a whole have investigated its optimisation (Reuter et al., 2006; Schaik and Reuter, 2004), its fundamental recycling limits (Reuter et al., 2006) and value analysis of disposal strategies (Gupta and Isaacs, 1997).

With the economic pressure of current legislative targets weighing heavily on end-of-life stakeholders, and the uncertainty as to the stability of future scrap material markets, 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 acceptable. Selective pre-fragmentation material removal could potentially provide this value recovery, but barriers to the widespread adoption of these practices is the level of costing resolution required to give end-of-life operators the confidence to invest and diversify their core competencies. Hence, this paper attempts to provide a vehicle specific costing approach to assess the economics of manual material removal (specifically glass, rubbers and plastics) in the context of value recovery and target attainment.

3. Modelling vehicle dismantling economics

3.1. Pre-fragmentation parts resale

A subset of ATFs within the UK currently remove component sub-assemblies for resale. Despite the economic and sustainable advantages this practice can offer (Coates and Rahimifard, 2006), a survey of ATFs (Coates, 2006) has suggested that component removal cannot make substantial headway into improving the recycling and reuse targets laid down by the ELV directive, as the majority of removed sub-assemblies are metallic and are currently counted within the assumed recycled fraction processed during post-fragmentation (Weatherhead and Hulse, 2005). Therefore, components composed of plastics, rubbers or glass can further support the attainment of the recycling targets, but currently only the head-lamps, door mirrors and tyres were listed within the top 10 of most commonly removed assemblies that fulfil this criterion (Coates, 2006). Hence, recycling and reuse target attainment must come from either further manual plastics dismantling at the ATF, or automated plastics recovery post-fragmentation.

It is widely perceived within the vehicle recovery sector that the economics of manual material removal is not viable based on UK labour wage rates. Hence, the only realistic situation in which further vehicle dismantling will be undertaken is if the 2015 target remains the same and post-fragmentation technology is unable to meet the higher recycling target (85%), or if the value received for recycled plastics increases enough to make dismantling economically viable. This highlights the need to establish vehicle specific costing methods which not only help to determine when and if recycling plastics becomes economically feasible, but also assists in supporting selection decisions when targeting the most removable and valuable materials. The following sections discuss the data collection exercises undertaken and the parametric equations developed to calculate theoretical dismantling times, before assessing the cost of the attainment of the 2015 recycling target and opportunities to identify profitable components for a range of top selling ELVs.

3.2. Disassembly costing methodology

Despite the lack of upstream manufacturer data with regard to vehicle dismantling, the in-house dismantling study provides an accurate and consistent data pool with which to consider a more diverse range of costing approaches. Based on the statistical data collated during the vehicle dismantling study it was proposed that a parametric regression approach be adopted. The most beneficial attributes of this cost modelling approach is its ability to generate cost estimate relationships (CERs) that are very quick, and produce a statistically measurable output (providing a good assessment of estimate confidence). CERs can be based on any number of relevant parameters, and can potentially be linked to both upstream design and downstream recovery data sources. Despite the incongruous link between the vehicle manufacturers and the recovery sector (exemplified in the 2006 directives transposition), one such data source that has been made widely available due to legislative requirements is that of the International Dismantling Information System (IDIS). This data source catalogues not only the potentially recoverable materials from each make and model of vehicle, but also provides basic component parameter data for each instance. Given the variation that exists between plastic's location, quantities and type between different makes and model of vehicle, it is advantageous to develop costing equations that allow dismantling times to be generated based on the specific vehicle considered. Therefore, relating IDIS component parameters to the data obtained from the dismantling study using parametric regression analysis, allows CERs to be determined. In brief, if a component's attributes can be statistically linked to its removal time, and those attributes can be determined for any other make or model of vehicle (i.e. catalogued within the database), then a dismantling time and labour cost can be generated without physically having to perform the work (see Fig. 2). With over 1069 vehicle variants and 59,000 components this costing approach is highly advantageous.

3.3. Vehicle dismantling studies for ascertaining component dismantling times

The initial stage of any parametric equation generation is the establishment of a large pool of data with which to assess the links between component disassembly time and various

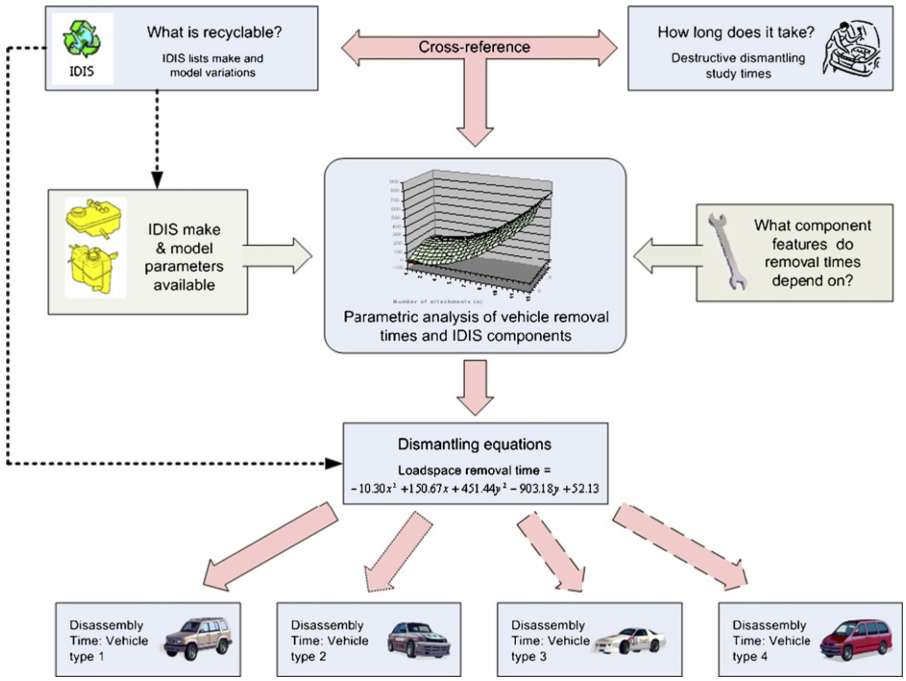

Fig. 2. Costing methodology for developing vehicle specific costing.

component attributes. Unfortunately, destructive plastics dismantling is not a wide-spread practice in the vehicle recovery sector, and apart from manufacturer tear-down data (which is highly proprietary and based on non-destructive dismantling), there is no abundant source of reference data. Therefore, a dismantling study was conducted at a local ATF to generate a range of dismantling times for a number of natural ELVs. These were selected based on the top UK selling vehicles in 1993 (Astra, Escort and Fiesta), which would correspond to the demographic of a natural ELV (13 years) in 2006 (Kollamthodi et al., 2003). IDIS was used to identify and assist the removal of approximately 117 individual components, while separation and stripping times were catalogued for each (see Table 1 for the data collected from the Vauxhall Astra teardown).

Once this data pool was established, an iterative process of testing various component parameters was adopted to investigate if there was a statistical relationship between disassembly time. The methodology used for this iterative process is shown within Fig. 3, and uses an equation development process adapted from Levine et al. (2005).

The starting point for these relationships requires the estimator to hypothesize as to the standard parameters affecting dismantling time (accessibility, fixturing, etc.), and the availability of these parameters within the obtainable data source (i.e. IDIS). Parameters (explanatory variables) must appear statistically independent of one another to be included within the analysis, and must contribute to improving the correlation between the predicted and actual disassembly times. The equation performance metrics (variance inflationary fac-

Table 1
Dismantling data for 1993 Vauxhall Astra (italics denotes incorrect IDIS listing)

IDIS ref	IDIS name	Removal time (mm:ss)	Cleaning time (mm:ss)	Total time (mm:ss)	Gross weight (g)	Material marking	Material
1.6	Mirror finisher	00:30	02:15	02:45	667	YES	ABS
1.7	Arm rest					YES	PP
		02:00	03:50	05:50	3000		
1.8	Door bin					YES	PP
2.2	Bumper	00:40	01:20	02:00	1022	YES	PP
2.4	Headlamp lens	00:58		00:58	155	YES	*ABS*
2.7	Body side finishers	01:18		01:18	755	YES	PVC
2.8	Rear lamp lens	03:14		03:14	468		
3.1	Glove box					YES	PP
		00:37		00:37	1540		
3.2	Glove box lid					YES	*ABS*
3.3	Ashtray housing	00:40	01:42	02:22	*205*	YES	PPX[a], ABS, PF[a], PP/PE[a]
3.4	Centre console	03:55	01:43	05:38	*1750*	YES	PPX, PP-EPDM
3.7	Air duct	02:17		02:17	*550*	YES	PP
3.8	Instrument pack finisher	02:20		02:20	*170*	YES	PP
3.9	Air vent, defrost and demist	01:34		01:34	250	YES	ABS + PC
3.10	Fuse box lid	00:05	00:10	00:15	85	YES	PP
3.11	Instrument pack lens	00:27		00:27	*110*	YES	
3.12	Steering column finisher	01:00		01:00	*235*	YES	ABS
4.1	Seat mount finisher	00:15		00:15	*115*	YES	PP
4.2	Recline control	00:38		00:38	*40*	YES	*ABS*
4.3	Hinge finisher				*65*	YES	PP
4.4	Squab pad	04:20		04:20	*1260*	NO	
4.5	Cushion pad (front seat)	02:39		02:39	*1200*	NO	
4.6	Cushion pad (rear)	07:32		07:32	*5720*	NO	
4.7	Seat belt	00:15		00:15	*150*	NO	
5.1/5.3	Sill finisher/a post finisher	01:19	00:40	01:59	*490*	YES	PP
5.1/5.3	Sill finisher/a post finisher	02:30	00:40	03:10	*490*	YES	PP
5.4	A post finisher	01:00		01:00	–	YES	PP
5.4	A post finisher	00:24		00:24	–	YES	PP

Table 1 (*Continued*)

IDIS ref	IDIS name	Removal time (mm:ss)	Cleaning time (mm:ss)	Total time (mm:ss)	Gross weight (g)	Material marking	Material
6.1	Air inlet finisher	00:10		00:10	*324*	YES	PP
6.2	Engine finisher	02:54	00:42	03:36	*498*	YES	PP-TD20
6.3	Air cleaner housing	00:25		00:25	490	YES	PP
6.4	Wash fluid tank	00:27	00:10	00:37	282	YES	PE
6.6	Fan housing	05:05	00:55	06:00	*650*	YES	PA
6.7	Fan				1570		
7.2	Access finisher	01:04	00:30	01:34	*1020*	YES	PP
7.2	Access finisher	01:50		01:50	*380*	YES	PP
7.4	Unlisted component	02:15		02:15	580	YES	PP
7.5	Unlisted component 2	02:28		02:28	900	YES	PP

See Table 4 for main material names and abbreviations, additional unlisted materials include.

[a] PPX, Polyparaxylylene; PF, phenol-formaldehyde resin; PP/PE, polypropylene/polyethylene.

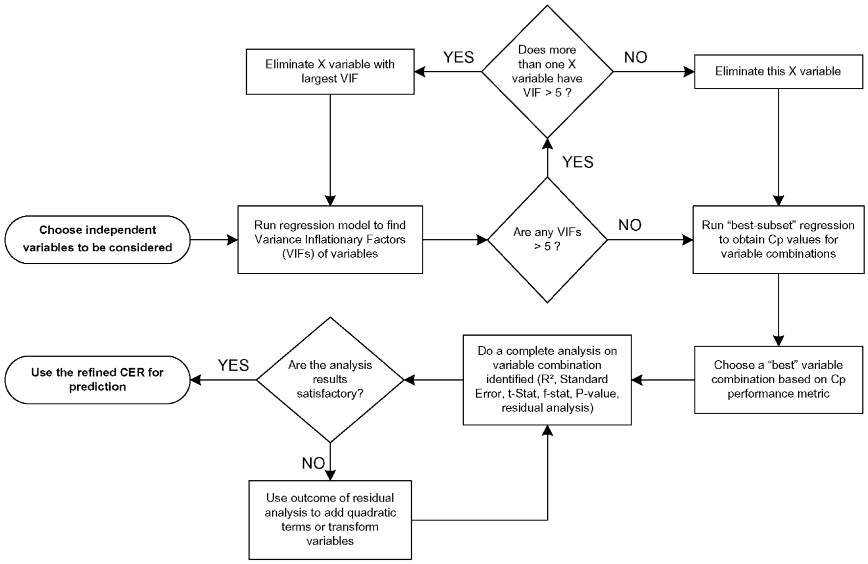

Fig. 3. Parametric equation development process.

tor (VIF), the C_P statistic, coefficient of determination, *T*-stat, *P*-value, *F*-stat) utilised at different stages of the equation development process, assisted in selecting the most appropriate parametric equation based on the available data. For a more detailed discussion of the performance metrics, search algorithms and analyse types identified within Fig. 3 see Levine et al. (2005).

It was decided to consider each of the IDIS zonal areas independently when developing the dismantling equations, as it became apparent during the study that there was a clear distinction between the effort required and the region of the vehicle worked upon. Table 2 provides details of the dismantling equations and statistical significance of their coefficients. For further details, see the parametric estimating handbook (NASA, 1999).

3.4. Costing the 2015 recycling and recovery target and value recovery via dismantling

The aforementioned equations and the additional parameter data located within IDIS has been utilised to predict the expected direct labour costs of meeting the 2015 recycling and recovery target for a range of top selling vehicles, under current market conditions. Given the average natural life of a vehicle is 13 years, vehicles produced in 2002 will be ready for scrapping in 2015. Recent governmental reports estimate the deficit to the 2015 recycling target to be approximately 5.18% of a vehicle's weight (Weatherhead and Hulse, 2005), hence one possible option to make up this shortfall is to consider and optimise component removal. Assemblies can be selected from a vehicle based on two different metrics, either the mass removal rate as shown in Eq. (1), or the value removal rate as shown in Eq. (2) (Coutler et al., 1998). The use of these metrics to select plastic components should be based on the goal of the dismantler. If target attainment is required, the material removal

Table 2
Zonal dismantling equations and statistical significance of coefficients

IDIS zonal area	Dismantling time equation	R^2	R^2_{adj}	S.E.	F-stat	Parameters		Coeff	SE	t-Stat	P-value
Dashboard (20 observations)	$Y = 26.76X_1 + 123.47\sqrt{X_2} - 132.27$	0.59	0.54	52.89	11.36	No. attachments	(X_1)	26.76	7.18	3.73	1.84E−03
						Cleaning effort	(X_2)	123.47	32.53	3.80	1.59E−03
						Intercept		−132.27	54.04	−2.45	2.63E−02
Door and glaze (four observations)	Limited datasets available										
Seats (nine observations)	$Y = -14.12X_1^2 + 158.26X_1 + 8.81$	0.94	0.92	40.54	50.65	Mass	(X_1)	158.26	33.52	4.72	3.25E−03
						Mass^2		−14.12	5.66	−2.49	4.70E−02
						Intercept		8.81	20.44	0.43	6.81E−01
Exterior (12 observations)	$Y = 118.88X_1^2 + 52.08$	0.78	0.76	63.76	38.75	Mass	(X_1)	118.88	19.10	6.22	6.49E−05
						Intercept		52.08	25.66	2.03	6.74E−02
Interior (12 observations)	$Y = 459.94\sqrt{X_1} - 129.73$	0.79	0.77	39.63	42.16	Mass	(X_1)	459.94	70.83	6.49	4.47E−05
						Intercept		−129.73	37.46	−3.46	5.30E−03
Engine compartment (seven observations)	$Y = 879.62\sqrt{X_1} - 448.07$	0.65	0.57	92.77	9.10	Mass	(X_1)	879.62	291.62	3.02	2.95E−02
						Intercept		−448.07	206.77	−2.17	8.25E−02
						No. attachments	(X_1)	91.72	27.40	3.35	4.41E−02
Load space (eight observations)	$Y = -637X_1^2 + 91.72X_1 - 239.94\sqrt{X_2} + 53.35$	0.85	0.69	24.83	5.49	No. attachments^2		−6.37	1.95	−3.26	4.72E−02
						Mass	(X_2)	−239.94	108.01	−2.22	1.13E−01
						Intercept		53.35	40.66	1.31	2.81E−01

Cleaning effort was a quantitative measure developed during the study that categorises the level of additional post-removal cleaning required. No. attachments refers to the number of mechanically removable fastenings (e.g. clips, screws, bolts).

rate should be used, as this identifies the heaviest and easiest components to remove first, and gives a better mass-versus-labour return. Alternatively, if a dismantler is interested in knowing if there are any components on a vehicle that can return a profit (when compared to a worker's wage rate (€/s)), then the value removal rate should be used, as this considers the value of the component removed as well as its weight.

$$\text{material removal rate (kg/s)} = \frac{\text{material (kg)}}{\text{time (s)}} \tag{1}$$

$$\text{value removal rate (€/s)} = \frac{(\text{material (kg)} \times \text{value (€/kg)})}{\text{time (s)}} \tag{2}$$

Table 3 demonstrates both of these scenarios, which include the use of the material removal rate to select components to fulfil the 5.18% deficit to the 2015 recycling target, and the use of the value removal rate on the same vehicles to select components capable of returning a profit. The vehicles selected are the top UK selling vehicles of 2002, representative of typical natural ELVs in 2015.

The worker's wage rate adopted is taken from ATF interviews undertaken in 2006 and uses a rate of €10.36 per hour (€8.62 per hour in wages and €1.74 per hour in fringe benefits). Fig. 4 provides a sensitivity analysis around this adopted rate to demonstrate its impact on the resulting net revenue (recycling revenue minus removal cost).

An additional cost that must also be considered when assessing the dismantling of components is the logistical cost of transporting the removed materials to a recycling facility. Previous dismantling studies have assumed a flat transport fee of around €74 per tonnes (Weatherhead, 2005), which based on the average mass removed per ELV within both methods (i.e. 51.26 and 7.24 kg, respectively, see Table 3) equates to €3.79 per vehicle for scenario 1 (i.e. material removal rate) and €0.53 per vehicle for scenario 2 (i.e. value removal rate).

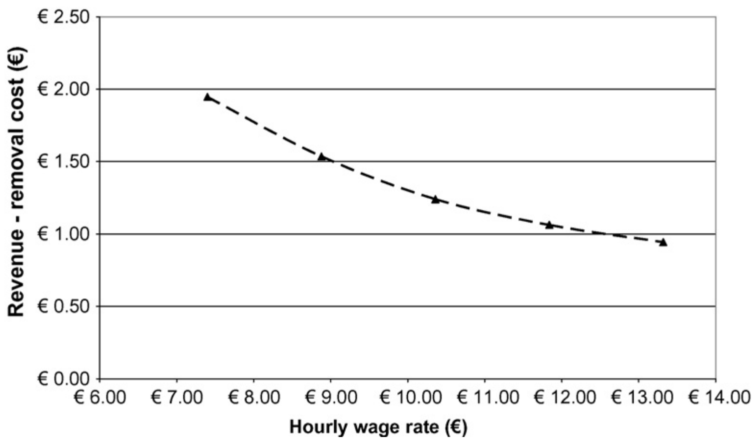

Fig. 4. The impact of hourly wage rates on the average net revenues obtained per ELV for all the vehicles considered.

Table 3
Estimating the achievable costs and revenues for natural ELVs based on MRR and VRR

2002 sales	Vehicle	Weight (kg)	No. of components	Dismantling time	Labour cost[a]	Revenue[b]
Material removal rate used to identify components up to 50.30 kg (5.18%)[c] of a vehicles weight						
1st	Ford focus 1998+	50.70	33	1 h 40 min	€17.38	€9.56
2nd	Vauxhall Corsa	50.45	20	1 h 38 min	€17.01	€11.36
3rd	Vauxhall Astra	50.38	21	1 h 50 min	€18.97	€9.23
4th	Peugeot 206			Data unavailable in IDIS		
5th	Ford Fiesta	53.49	20	1 h 52 min	€19.34	€9.66
	Averages	51.26	24	1 h 45 min	€18.18	€9.95
Value removal rate used to identify components that return a profit when compared to an hourly rate						
1st	Ford focus 1998+	12.20	7	20 mis	€3.37	€4.99
2nd	Vauxhall Corsa	7.41	6	8 min	€1.33	€2.91
3rd	Vauxhall Astra	2.61	2	3 min	€0.59	€0.92
4th	Peugeot 206			Data unavailable in IDIS		
5th	Ford Fiesta	6.75	7	9 min	€1.58	€2.77
	Averages	7.24	5	10 min	€1.72	€2.90

[a] Labour costs based on an hourly rate of €10.36.
[b] Material value data taken from letsrecycle.com and interviewed plastics recyclers (January 2006).
[c] Average vehicle weight based on 971 kg (Weatherhead and Hulse, 2005).

Table 4
The main types and quantities of material removed during the dismantling study

Material	Abbreviation	Mass per vehicle (kg)	Total possible per month (tonnes)	Total possible per year (tonnes)
Polypropylene	PP	11.45	5.8	69.1
Polyurethane	PUR	8.12	4.1	49.0
Acrylonitrile-butadiene-styrene	ABS	3.78	1.9	22.8
Polypropylene-talcum 20%	PP-T20	1.57	0.8	9.5
Polyamide	PA	0.83	0.4	5.0
Polypropylene-ethylene-propylene diene terpolymer	PP-EPDM	0.82	0.4	4.9
Poly(ethylene terephthalate)	PET	0.65	0.3	3.9
Poly(vinyl choride)	PVC	0.50	0.3	3.0
Polycarbonate acrylonitrile-butadience-styrene blend	PC + ABS	0.25	0.1	1.5
	Total	27.97	14.1	168.7

3.5. *Material yield rates via dismantling*

A further consideration as to the feasibility of manual material removal is that of achievable material yield rates. The aforementioned value removal rate utilises material value estimates based on minimum recycled quantities. Hence, to realistically consider manual material removal a consideration must be made as to the vehicle throughput required to achieve minimum re-processor specifications. During the study, 22 different material types were removed, with the 9 most abundant materials (>0.25 kg) producing 28 kilos per vehicle. These quantities can then be factored up based on the typical number of vehicles processed at an ATF per day (17 vehicles; Coates, 2006), and are listed within Table 4.

The data catalogued within the above table is representative of those materials found within natural ELVs, but it is envisaged that the material types and quantities will be reduced over time as more “design for recycling” considerations filter through in successive vehicle designs. The current quantities obtained via the study would suggest that only a few key material types (identified in Table 4 as PP, PU and ABS) would produce enough material to satisfy the minimum quantities required by plastic re-processors, and justify their removal.

4. Discussion

The purpose of this paper is to not only describe a means of costing pre-fragmentation vehicle dismantling, but to offer analysis as to the cost of meeting the 2015 recycling target and the potential for using pre-fragmentation dismantling as a means of obtaining value. Table 5 provides an aggregated summary of the costs and revenues associated with the dismantling of vehicles for target attainment (scenario 1), and the dismantling of vehicles for value recovery (scenario 2).

If ELV operators were to meet the 2015 recycling target today through further manual dismantling, it would result in an estimated net cost per ELV of around €12. The additional investment costs of new equipment and storage facilities would also need to be factored into

Table 5
Summary of costs and revenues incurred via different processing scenarios

	Scenario 1		Scenario 2	
	Dismantling for meeting the target	Percent of vehicle weight removed (≥5.18%)	Dismantling for value recovery	Percent of vehicle weight removed
Removal costs	−€18.18		−€1.72	
Recycling revenue	+€9.95		+€2.90	
Logistical costs	−€3.79		−€0.53	
Per ELV	−€12.02	5.28	+€0.65	0.75

this if an ATF decided to adopt this practice. What this estimate indicates is the substantial cost burden that will be required to meet the future target if the recycling levels remain the same and the investment and technology in UK post-fragmentation facilities is not significantly improved. It must be stated that the likelihood of this eventuality (achievement of the 2015 target via material dismantling) based on the strategic direction of other more proactive EU member states, would suggest that this will not be the case in the UK. Given the achievable throughput rates of automated waste stream technologies, it is envisaged that post-fragmentation processing will provide the most economical viable point at which to recover the additional rubbers, glass and plastics, which are currently sent to landfill. As to whom within the vehicle value chain will ultimately be financially responsible for either of these scenarios is yet to be made clear. Previous investment and de-pollution costs have been offset by extremely strong scrap metal prices, but questions as to this market's long-term stability may negate the possibility of scrap revenue supporting the vehicle recovery sector in the future.

The previous analysis has also offered an opportunity to assess the feasibility of ATFs disregarding the 2015 target (assuming post-fragmentation conformance), and only dismantling components that can offset the incurred labour costs of their removal. These would be large, heavy sub-assemblies (such as bumpers and internal trim) that are relatively easy to remove. In these instances, the recycling revenue generated (€2.90, see Table 5) is capable of offsetting the direct labour costs incurred (€1.72, see Table 5), producing a net revenue per ELV of around €1.18. This revenue is reduced when the material recovered is transported to a recycling facility for shredding and granulation, resulting in an overall net profit of €0.65 per ELV. This analysis was undertaken using a wage rate of €10.36, Fig. 5 presents the variation in net profit when considering wage rates either side of this value.

Unlike the smooth trend seen within Fig. 4 the resulting net profit seen in Fig. 5 fluctuates substantially. This is due to the number of competing parameters that affect the final cost. A lower wage rate reduces the threshold at which the value removal rate selects components, as more components are capable of offsetting the direct labour incurred. Material type determines the obtainable revenue, while the quantity of material removed increases the logistical costs of transportation.

The variation between Figs. 4 and 5 highlights the significant economic impact of transportation costs, in addition to commonly reported negative environmental impacts associated with reverse logistics. This would perhaps suggest a strong case for a more geographically

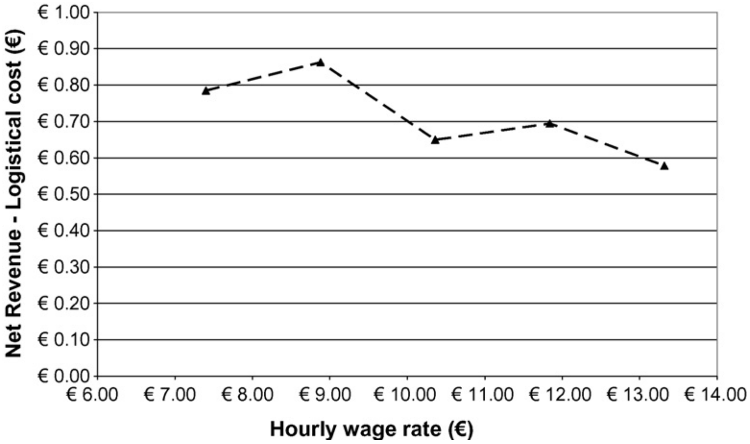

Fig. 5. The impact on average overall profit per ELV for different wage rates when the logistical costs of material transport is included.

concentrated approach to vehicle recovery and material recycling. If ATFs were to diversify their core competencies to incorporate plastics recycling this could potentially allow them to sell reprocessed granulate directly back to the product suppliers and attain high revenues. These recycling activities need not be exclusively focused on recovering just automotive polymers, but could also encompass additional product waste streams (consumer packaging, industrial scrap, plastic from WEEE) that will become increasingly more abundant as end-of-life legislation becomes more established.

Despite the low achievable revenue for manual dismantling of plastic components (based on today's market prices), it should be noted that the quality of the polymer produced is also substantially better than that achieved during post-fragmentation separation, promoting the possibility of more sustainable closed-loop recycling. Questionable drawbacks to this approach are the material yield rates that one ATF alone can achieve ($\approx$7.24 kg per ELV), suggesting that this option would be more suited to larger ATF operators with a greater throughput. An additional barrier is the lack of distinction made between the beneficial qualities of automotive polymers compared to those currently considered to be recycled plastics (curbside collection consumer packaging). This problem is further aggravated by the lack of cheap and accurate analysis equipment to produce material specifications to form the basis of price negotiations.

5. Conclusion

This paper has demonstrated the substantial cost burden that the 2015 recycling and recovery target will bring to the automotive industry if target attainment is to be achieved via pre-fragmentation material removal. It has also demonstrated that despite the commonly held perception that manual material removal is not economically viable, the targeted removal of a certain components for recycling is. Questionable barriers to the widespread adoption of these techniques are the achievable material yield rates, and the lack of value distinction made between other plastic recycling sources (consumer plastic wastes).

The costing methods described within this paper have attempted to provide a foundation on which future "what-if" scenarios for vehicle recovery assessment can be undertaken. The current cost drivers affecting the vehicle recovery sector (e.g. scrap steel prices, labour costs, recycled material prices, etc.) are constantly changing, and only at the point at which legislation is fully implemented can the economic viability of pre-fragmentation material recovery be truly assessed and compared to its post-fragmentation alternative. As to whether vehicle dismantling will ever become a part of the standard operations carried out by an ATF either due to necessary target attainment or activity diversification is yet to be seen, but if and when this does occur, accurate methods are required to economically assess and optimise any removal activities.

Acknowledgements

This work has been carried out as part of a collaborative research programme at Loughborough University, funded by the Engineering and Physical Science Research Council (EPSRC), entitled "Cost-oriented Approach to Design and Recovery of Vehicles to meet the requirements for the End-of-Life Vehicles Directive". The authors would like to acknowledge the contributions and support of Mrs. D. Allen and Mr. R. Kirk of Albert Looms Derby, and Mr. P. Owen and staff of Rozone Ltd.

References

Amaral J, Ferrão P, Rosas C. Is recycling technology innovation a major driver for technology shift in the automobile industry under an EU context? Int J Technol Policy Manage 2006;6:385–98.

ARN. PST plant to be built in Tiel. Automotive Recycling Netherlands homepage; 2007. http://www.arn.nl/engels/5pers/521.php [accessed 20th February, 2007].

Coates G. An Authorised Treatment Survey: Issues and trends within the vehicle recovery sector. A report produced as part of the ESPRC project entitled cost oriented approaches to the design and recovery of vehicles by the centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART), Loughborough, UK; 2006. http://www.lboro.ac.uk/smart [accessed 3rd August, 2006].

Coates G, Rahimifard S. Cost models for increased value recovery from end-of-life vehicles. LCE 2006 Towards a closed loop economy. In: Duflou JR, Dewulf W, Willems B, Devoldere T, editors. Proceedings of 13th CIRP International Conference on Life Cycle Engineering; 2006. p. 347–52.

Coutler S, Bras B, Winslow G, Yester S. Designing for material separation: lessons from automotive recycling. J Mech Des 1998;120:501–9.

DTI. Full regulatory impact assessment (RIA) for the DTI's SI transposing articles 4, 5, 6, 8, 9 and annexes I and II of directive 2000/53/EC of the European parliament and the council on end of life vehicles (the "ELV" directive) in the UK; 2003.

DTI. Full regulatory impact assessment (RIA) for the DTI's SI transposing articles 5 and 7 and annexes of directive 2000/53/EC of the European parliament and the council on end of life vehicles (the "ELV" directive) in the UK; 2005.

Edwards C, Coates G, Leaney PG, Rahimifard S. Implications of the end-of-life vehicles directive on the vehicle recovery sector. Proc Inst Mech Eng Part B: J Eng Manuf 2006;220:1211–6.

European Commission. Directive 2000/53/EC of the European parliament and of the council of the 18th September 2000 on EOL vehicles. Official J Eur Communities 2000;L269:34–42.

Ferrão P, Nazareth P, Amaral J. Strategies for meeting EU end-of-life vehicle reuse/recovery targets. J Ind Ecol 2006;10:77–93.

Gallmeyer WM. USCAR U.S. field trial for automotive polymer recycling. In: SAE, editor. Sustainability of Environmental Systems & Materials: SP1788. SAE 2003 World Congress & Exhibition: Sustainable Materials. SAE international; 2003. p. 93–104.

GHK. A study to examine the benefits of the end of life vehicles directive and the costs and benefits of a revision of the 2015 targets for recycling, re-use and recovery under the ELV Directive. Report Number J2232 produced for DG Environment by GHK in association with Bio Intelligence Service, Birmingham, UK; 2006.

Gupta SM, Isaacs JA. Value analysis of disposal strategies for automobiles. Comput Ind Eng 1997;33:325–8.

Johnson MR, Wang MH. Evaluation policies and automotive recovery options according to the European Union directive on end-of-life vehicles (ELV). Proc Inst Mech Eng Part D: J Automobile Eng 2002;216:723–39.

Kollamthodi S, Hird AB, Elghali L, Johnstone K, Wayman M, McColl V. Data required to monitor compliance with the end of life vehicles directive. Project report PR SE/483/02 prepared for DEFRA by TRL Ltd., UK; 2003.

Letsrecycle.com. Government works on new option to end ELV impasse. In: Eminton S, editor; 2002. http://www.letsrecycle.com/legislation/news.jsp?story=1612 [accessed 12th February, 2007].

Levine DM, Stephen D, Krehbiel TC, Berenson ML. Statistics for managers using Microsoft excel. NJ, USA: Pearson Prentice Hall; 2005.

NASA. Parametric cost estimating handbook. In: Brundick B, editor. Third edition produced by the International Society of Parametric Analyst. NASA; 1999. http://cost.jsc.nasa.gov/PCEHHTML/pceh.htm [accessed 15th January, 2007].

Perchard D. Transposition of the ELV directive in other EU member states. Report produced for the DTI by Perchards, St Albans, UK; 2004.

Reuter MA, Schaik AV, Ignatenko O, de Haan GJ. Fundemental limits for the recycling of end-of-life vehicles. Miner Eng 2006;19:433–49.

Roy R, Whelan RC. Successful recycling through value-chain collaboration. Long Range Plann 1992;25:62–71.

Schaik AV, Reuter MA. The optimization of end-of-life vehicle recycling in the European Union. J Operat Manage 2004:39–47.

SWG-ELV. Stakeholder consultation on the review of the 2015-targets on reuse, recovery and recycling of end of life vehicles. A consultation report produced by Stakeholder Working group on ELV for the European Commission considering revisions to entries of Annex II of the ELV Directive, Brussels; 2005. http://ec.europa.eu/environment/waste/pdf/elv_final_report_051104.pdf [accessed 20th December, 2006].

Weatherhead T. Plastics reprocessing validation exercise 2. A report produced for the Consortium for Automotive Vehicle Recycling (CARE) by JEMA Associates Ltd., UK; 2005. http://www.prove-recycling.org/downloads/PROVE2%20v4%20MMSG.pdf [accessed 15th January, 2007].

Weatherhead T, Hulse D. A study to determine the metallic fraction recovered from end-of-life vehicles in the UK. A report produced for the DTI by JEMA Associates Ltd., UK; 2005.