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The Integrated Life Cycle Assessment and Optimization Approach for Automotive De-manufacturing Systems

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Abstract

The Automotive Recycling Industry is addressing one of the biggest problems that the environment can face, the reuse and recycling of End-of-Life Vehicles (ELV). Improper disposal of wastes can create a big problem to the environment. The purpose of this paper is to use the Integrated Life-Cycle Assessment (LCA) and Optimization Approach for Automotive De-manufacturing Systems with the aim of to finding out the most efficient and effective method that can be used to improve global ELV recycling. The United Nations Environment Program (UNEP) defines life cycle assessment is a tool that is used for systematic evaluation of the environmental aspects of either a product or service system in the entire stages of its lifecycle. In this research, second hand material research would be used to determine the current methods used for the disposal of the ELVs. Moreover, cost metrics will be used to determine the economic value of the network. This research will look into study background, the problem statement, hypothesis of the study, objectives of the study, literature review and methodology to outline possible research criteria to draw conclusion on the research topic. The research will be very resourceful to the scientific community because it will help to find the optimal location for the centralized processing facility that will minimize cost and avoid hazard in the environment.

Keywords: De- manufacturing, Dismantling, Shredding, ELV

1. Background of the Study

1.1 Automotive Recycling

Recycling is the practice of gathering and processing materials that are recovered from disposed or old products and turning these materials into a new product (Aljaaidi, Almohanna, & Zaid Bin Jumah, 2013). Automotive recycling is the recovering of materials from a motor vehicle that can still be reused and recycled. Its main purpose is to harvest all automotive parts to reuse and salvage the remaining materials and recycle them to make new products that can be used in producing basic materials like plastic, steel, aluminium, copper and brass (Alliance of Automotive Manufacturers, 2010). The so-called ends of life vehicles (ELVs) are recycled into new vehicles. New vehicles can be made of recycled old consumer products and vice versa, old vehicles can be turned to new consumer products. New technology had made an opportunity to reuse and recycle material contents from the old vehicles. There is an estimate of 86% material recovery in a vehicle in the United States (Alliance of Automotive Manufacturers, 2010). Cars can be considered as most recycled consumer product. Recycling Rates 2010 show that vehicles recycling rates are over 95 percent (Alliance of Automotive Manufacturers, 2010) as shown in Figure 1. The difference between recovery and recycling rate is that recovery rate entails reclaiming used parts and materials and delivering them to a processing mill. While recycling rate refers to the level of reprocessing the recovered parts and materials, and it happens when a product has completed its original function where it is reprocessed and converted into useful new material.

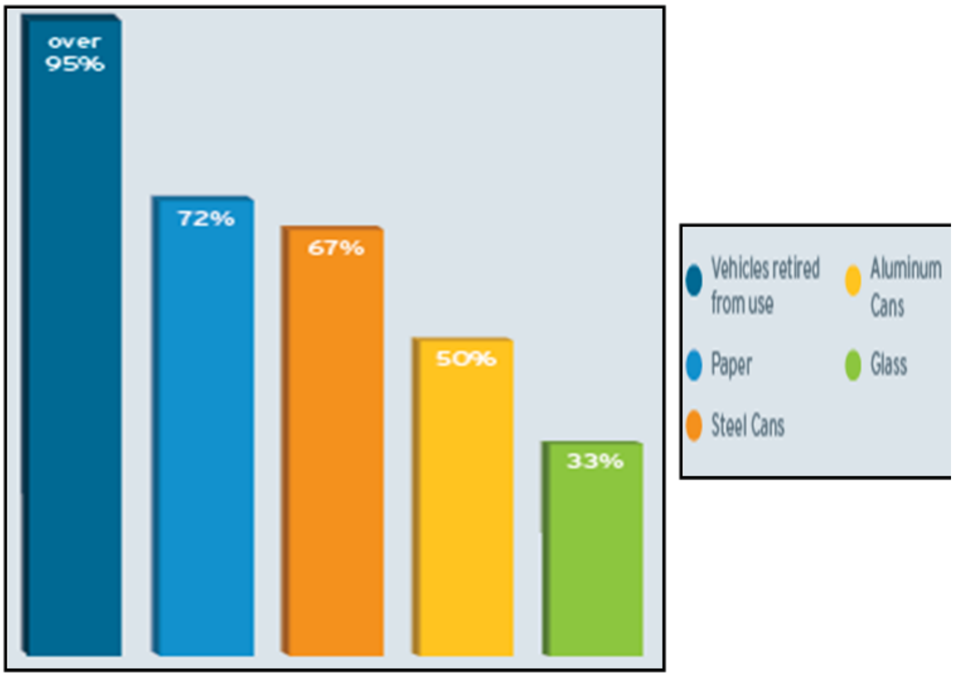

Figure 1. The recycling rates of autos in the year 2010 in comparison to other commonly used materials and parts (Alliance of Automotive Manufacturers, 2010)

1.2 The Recycling Process

Car Recycling would help reduce the amount of waste going to landfill and improve resource use. Cars can be recycled in three steps, dismantling, shredding and resource recovery (US Environmental Protection Agency, 2012). Figure 2 shows the process on how the vehicle is retrieved from the consumer down to the resale of parts, recycling of parts and landfill (International Specialized Skills Institute, 2009). The diagram explains how the recycling process starts.

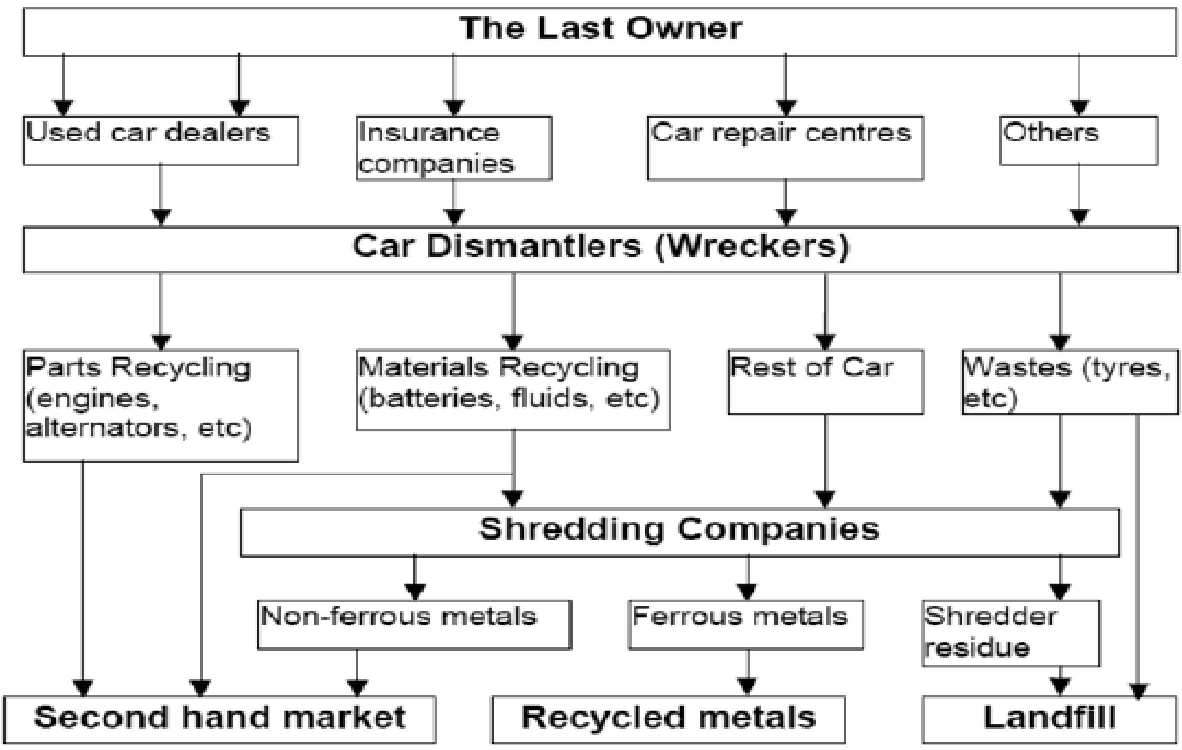

Figure 2. Automotive Recycling Process

From the last owner of the vehicle, the car is turned over by the first level in the diagram, which is the used car dealers, insurance companies, car repair centres and other sources. Then the Car Dismantlers choose what parts can still be recycled from the vehicle. There are a lot of recovered materials from the vehicle. These can be parts or fluids from the car that are being recovered and still have a profitable value in the second hand market. The parts of the car that cannot be recycled by the wreckers are flattened and go through a shredder. Sorting is done by separating the non-ferrous (non-metal), ferrous and shredder residue. Non-ferrous materials go to the second-hand market, ferrous materials are melted and recused and the residue is put in the landfill. The use of recycled scrap iron and steel reduces the use of virgin iron ore. The manufacture of recycled steel saves 74% less energy and 40% less water. It also results in 86% less air pollution, 76% less water pollution and 97% less mining wastes (Royal Automotive Club of Victoria, 2014). For every ton of new steel made of scrap, it conserves 2 500 lbs of iron ore, 1 400 lbs of coal and 120 lbs of limestone (Ecoamisco, 2015). Recycled metals also reduced Greenhouse Gas (GHG) emissions. According to the Automobile

Recycling Industry (2010) there is an approximate of 12.6 million vehicles recycled each year worldwide. Based on this estimate, GHG emissions are reduced by 30 million metric tons per year (Alliance of Automotive Manufacturers, 2010). Through this recycling process, energy is saved, natural resources are conserved, and pollution in the air, water and greenhouse emissions is reduced. Hazardous substances like lead, mercury, oil and unspent fuel can be recycled.

1.3 Global Automotive Recycling Industry

The recycled cars annually produce a lot of potential pollutants that can harm the environment. If these pollutants are not disposed properly by the recyclers, dire consequences can be suffered. Every year, there is an estimate of 27 million cars that reach the end of their useful life (US Environmental Protection Agency, 2012). Five million tons of shredder residue is being dumped in the landfills annually. Table 1 shows an estimate of the total potential pollutants that are being collected, reused and recycled annually.

Table 1. Estimated Amount of Materials recovered annually

Fluid Recovered	Quantity Recovered
Gasoline and Diesel Fuel	100.8 million gallons
Motor Oil	24 million gallons
Engine Coolant	8 million gallons
Windshield Washer Fluid	4.5 million gallons
Lead Acid Batteries	96%
Mercury	9 000 lbs

SOURCE: (Alliance of Automotive Manufacturers, 2010)

The recycling of cars is done worldwide. Government legislations have been implemented in order to address the issue. The European End-of-Life Legislation Directive 2000/53/EC is the most relevant legislative directive in the global automotive industry. The directive aims to put in heavy metal restrictions, recycling and recovery, recycled content usage and vehicle end of life take back schemes (International Specialized Skills Institute, 2009). This legislation aims to recover at least 85% of the materials from the vehicle. An amendment on the directive was also put in place wherein the vehicles may only be sold in the market if the materials are 85% (minimum) reusable or recyclable by mass. Other directives worldwide include the 2002 Japanese Automobile Recycling Law (Japan Automobile Manufacturers Association, 2002), 2008 South Korean regulation for reuse, recycle and recover hazardous substances (South Korea's waste management policies, 2015), 2008 Taiwan's ELV voluntary agreement and 2010 China which launched a technical standard. This standard is a combination of the European and Japanese Legislation. These policies create an importance to the use of recycled materials for new vehicles as well as proper disposal of materials recovered from it. In addition, they also make sure that the new vehicles in the market would be designed to have a minimal impact to the environment.

2. Problem Statement and Research Hypothesis

The number of ELVs is increasing every year and this needs to be addressed in a manner with consideration to financial feasibility and its environmental impact worldwide. The automobiles consist of different materials and as such, different types of recycling facilities must be covered to ensure that good recovery of materials is done.

This research aims to determine a particular approach in order to optimize the materials recovered and minimize the cost of processing of the automobiles being recycled. The statement of the problem is to find out if an optimized automobile de-manufacturing network that is economically and environmentally beneficial to the current disposal methods can be established

The research seeks to determine the effectiveness and efficiency of an integrated vehicle recycling systems. There are a number of questions that the project seeks to answer. Some of the questions that are expected to be answered by the project include the following;

- What are the environmental impacts that are caused by the current methods of vehicle disposal?
- What are the existing legal policies that govern the disposal of ELVs?
- What are the existing disposal mechanisms that are involved in developing an integrated vehicle recycling facility?
- What are the optimal processing mechanisms that can be used to dispose ELVs?
- What are the main raw materials that can be obtained from processed ELVs?
- What are the factors that should be taken into account for cost computation of dismantling and shredding ELVs?

These questions will be answered by the project. The project looks forward to determine the overall benefits that can be accrued from the development of an integrated vehicle recycling facilities.

3. Review of Related Literature

This part of the paper shows the relevant research materials that the researchers had gathered to get more information on the problem at hand. This is also a way to answer some of the objectives of the study and provide ideas to solve the problem under study.

3.1 Reverse Logistics

Manufacturing industries are used to doing forward logistics most of the time. Raw materials are gathered and processed in order to create new products for the consumers. Logistics enters from Raw Materials to manufacturing until it reaches the end consumer. However, the same is not true for recycling materials. In recycling, reverse logistics is used in order to recover raw materials from the product. Reverse logistics is concerned about all procedures or methods associated from product returns, maintenance and repairs, recycling and dismantling for products and materials (Adaptalift Hyster, 2013). Recycling companies use reverse logistics in order to have raw materials for their production. Figure 3 shows the diagram on how reverse logistics work.

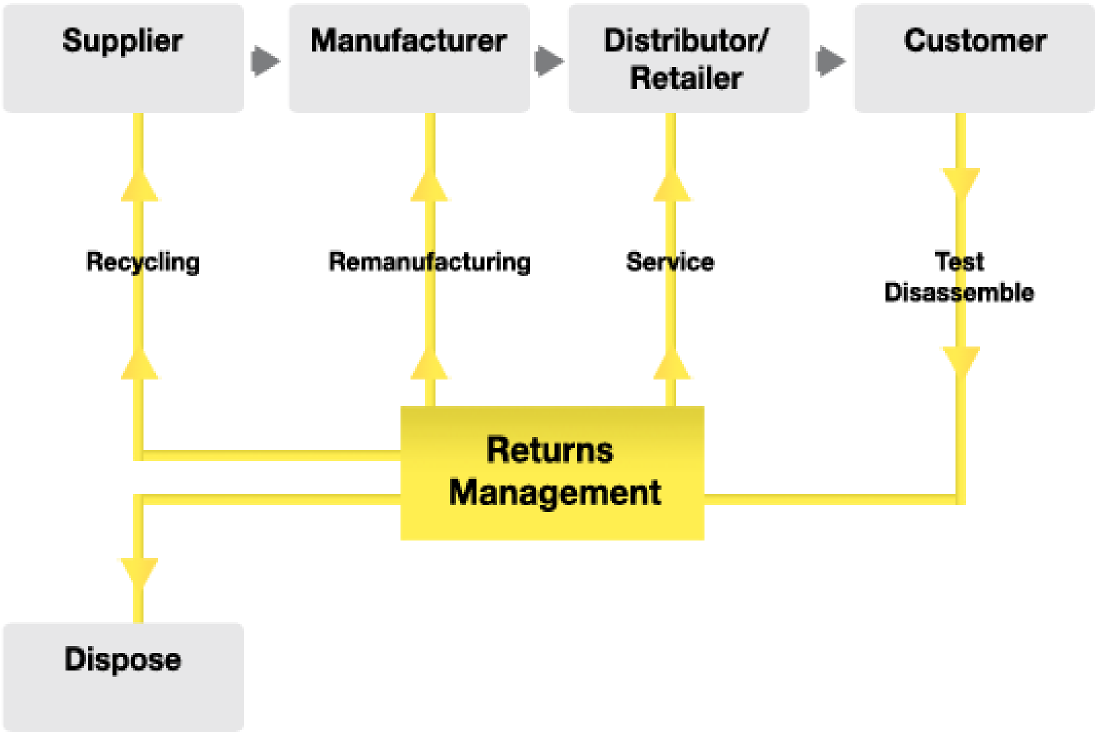

Figure 3. Reverse Logistics flow (Adaptalift Hyster, 2013)

All activities in the Reverse Logistics System incur costs. These must be considered in the design of the model for the system. Activities that incur cost in the system are as follows: transportation, product collection, disposal of products, remanufacturing and recycling of the products and the labor costs for the retrieval of the product (Sanket, 2009).

3.2 ELV Recycling

Automotive Recycling has three primary areas of recovery for reverse logistics. First, the working components, these are sold as what they are to the market. Second, recoverable components or auto parts which are refurbished before they are sold in the market and lastly, unrecoverable components, these materials are reclaimed through crushing and shredding.

3.2.1 Parts and Suppliers De-manufacturing

An article from Holden Australia had cited the procedure on to how the vehicles are recycled in general. Batteries are first disconnected. After the disconnection, all fluids must be drained out of the car. Pyrotechnic devices are also removed; these devices include airbags. It is advisable to remove them because pyrotechnic devices contain ingredient that represent explosion hazards (Autoparts Recycle Association of Australiar; Greenfleet; Holden, 2014). There is a standard initial handling procedure that automotive companies follow during the de-manufacturing process. Table 2 shows a list of manufacturers and their procedures in ELV recycling. These 3 companies were chosen because information is readily available to the public.

Table 2. Standard handling procedure of recycling per manufacturer

BMW (BMW Group, 2009)	TOYOTA (Toyota Motor Corporation, 2014)	HOLDEN (Autoparts Recycle Association of Australiar; Greenfleet; Holden, 2014)
1. Neutralization of Pyrotechnic Devices 2. Removal of Vehicle Fluids 3. Removal of Hazardous Materials 4. Dismantling 5. Removal of Core Scrap 6. Compacting 7. Shredding Process 8. Post Shredder Technologies	1. Chlorofluorocarbons CFC Collection 2. Airbag Collection and Recycling 3. Removal of Parts in Good Condition 4. Press 5. Shredder 6. Sorting of Ferrous, Non-ferrous and Anti-Slip Regulation (ASR) 7. Reuse as materials, energy, ferrous and non-ferrous metals.	1. Disconnect and Remove Battery 2. Drain fluids and gasses 3. Remove pyrotechnic devices 4. Cleaning 5. Storage 6. Reuse materials, energy and other collected materials from the ELV 7. Disposal

Each manufacturer has a different way of recycling materials. However, all of the above is focused on removing the hazardous materials inside the car. Appendix B is a list of Recycling Auto parts that could be removed from the car. The list contains the component of the vehicle, the materials used to manufacture the component, the method of dismantling, the storage area where these components must be stored in, disposal of the said component and safety precautions. This information is provided in the article of Holden Australia (Autoparts Recycle Association of Australia; Greenfleet; Holden, 2014).

The following is a brief description of the process, as soon as the vehicle is dropped off,

- Hazardous materials such as the CFC and the airbags are removed.
- Parts that are in good condition are removed;
- Parts are sorted according to reusable ones, ferrous materials and non-ferrous materials.
- After this recovery, the cars are pressed and go through the shredder.
- The shredded parts would be classified as either ferrous or non-ferrous and shredder residue.

Ferrous and non-ferrous metals are melted and reused; ASR or shredder residue is either used as a material or as energy. Figure 5 shows the after processing of the ELV from the shredder to the ASR Recycling Plant (Toyota Motor Corporation, 2014).

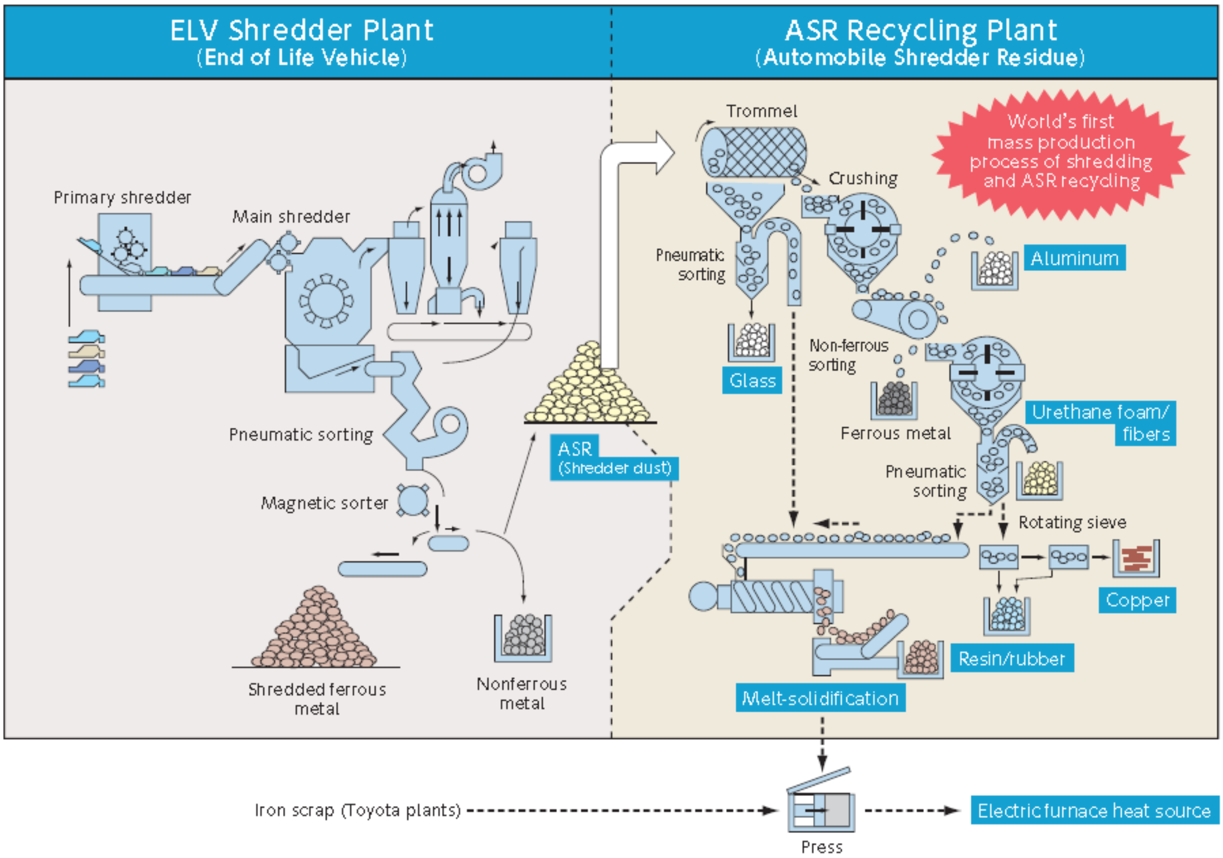

Figure 4. ASR Process after ELV Shredding

As of the moment, Toyota can recover and reuse the ELV materials 99% its body weight (Toyota Motor Corporation, 2014), in Holden Australia the ELV materials recovered is around 75% and 25% is dumped in the landfill (Autoparts Recycle Association of Australia; Greenfleet; Holden, 2014) and BMW is expected to recover at least 85% of its materials (BMW Group, 2009). However, Europe has a directive that recovery target level must reach 95% by this year, 2015 (European Commission, 2005).

3.2.2 Cost of Recycling

Nowadays, cars are created to be more fuel efficient and to do that lighter materials are chosen. The metallic fraction of the automobiles is reduced resulting to higher components of polymers, fabrics and glass. There is a high demand for metal scrap but for the other materials there is no demand in the form where it emerges from the shredder. Disposal of the materials are done through landfills. If the cost of the landfill is low, then the cost of operating the shredder is just a fraction of the cost amount in operating the shredder. However, if the landfill cost is high, the cost in operating the shredder may not be able to cover the costs (Field, 1993). There are five factors that a dismantler must take into account for cost computation. The following factors are

- The cost of getting the ELV (End-of-Life-Vehicle)
- The cost of extraction, storage and distribution of parts that can be sold,

- The price of the used parts that can be sold,
- The cost of extracting and removing the parts that the shredder does not need in the stripped car, and
- The price of the stripped car that would be sold to the shredder.

Given that the dismantler and the shredder are not in the same company, then there are also five factors to consider in shredding the vehicle. These includes the

- The cost of the hulk to be obtained,
- The operating cost of the shredder and the ferrous separator,
- Disposal cost of the automotive shredder residue,
- The asking price that the shredder gets from the steel processed and lastly
- The asking price for the mixed non-ferrous metal blend (Field, 1993).

A lot of researches had been done using Reverse Logistics as a tool to formulate mathematical models to support the recovery plan and disassembly sequence in automobiles.

Technical cost models of ELV processing operators were developed and the results show that removing of 14% of the ELV mass results in a recycling rate of 80% (Zarei, Mansour, Kashan, & Karimi, 2010). A simulated model to examine the effects of future changes in the vehicle was developed. The model yielded that the recycling target of 95% by the year 2015 would be unreachable unless changes would be done in vehicle material composition (Zarei, Mansour, Kashan, & Karimi, 2010).

The conceptual model was developed by Zarei, Mansour, Kashan, and Karimi and had included the production of new vehicles and recovery of used ones. In this model, it was assumed that the whole network is conducted by a vehicle manufacturer. Distribution-collection centres are assumed. Collection of ELVs is assigned to these distribution centres. The model developed was to minimize the costs of setting up network and raw materials flow between different facilities (Zarei, Mansour, Kashan, & Karimi, 2010).

Elwany, Fors, Harraz, & Galal (2007) in their article “Reverse logistics network design” reviewed different review of models and solution techniques were reviewed in an article for reverse logistics. Four different modelling technique classifications were identified in the study. These are the following:

i. Classification based on order type of flow

There are two models consider; and these are the forward and reverse networks. These two models two different entities and are designed in succession. The other approach in this type is the combination of these two flow types in the design process.

ii. Classification according to model type

These models are based on the type of programming used. Model can be a mixed integer linear programming or mixed integer non-linear programming. Mixed integer models represent integer variables such as facilities and continuous variables; they also represent the amount of material flow between the different facility types. The Mixed integer non-linear programming accounts for the aspects discussed in mixed integer models combined with time.

iii. Classification according to objective function

The objective function classifies the models according to the numbers and type of model. The model can answer one objective or multiple objectives depending on the researcher. Most objective function models are considered to have a location allocation problem with a single objective either to minimize cost or maximize revenue.

iv. Uncertainty in Reverse Logistics

Some models used for reverse logistics incorporated uncertainty variables in their models. There are four approaches that can incorporate uncertainty in the models, and these are:

- Sensitivity analysis, this is used to determine how the output of the model will be changed if uncertainties are present in the model inputs.
- Scenario Based Approaches, this is an extension of the sensitivity analysis. The model is iterated until an individual solution that performs best is arrived at.
- Robust Optimization, the uncertainty is represented through different scenarios, the model aims to minimize the measure of deviation of the resolution from the objective function value from the best solution achieved for each scenarios created.
- Stochastic Programming, this is a mathematical programming process that deals with stochastic elements in the data. Probability distributions are used as the main element in the model.

The program applied in network design problem is considered as the recourse type. There are two stages of approach to this type of model. Stage 1 determines the set of decision variables and Stage 2 determines the recourse action after a random event has taken value. The action in stage 2 makes sure that the constraints in the models are in place.

3.3 Automotive Recycling Association

A lot of countries around the world are conscious on the growing problem of vehicle recycling. In order to address the problem, these countries had joined movements such as the Automotive Recyclers Association in order to learn and share ideas about ELV recycling. The association was founded in 1943, and has a global presence being an international trade association representing the automotive industry with a focus on efficient removal and reuse of automotive parts. The following regions and countries have different legislations and directives to follow. Each point would be explained through the legislation, recovery rate and the law directives. The regions and countries have been chosen because they have the most elaborate legislations and directives regarding ELVs.

Table 3. Country/Place and the directives or laws regarding ELVs

EUROPE (Directive 2000/53/EC, 2005)	Law/Legislation	Directive 2000/53/EC
	Recovery Rates	85 – 95% by 2015 5% of ASR will go to landfill
	The Law	• Manufacturers must reduce the use of hazardous materials when designing or producing a vehicle • Emphasize on increasing the use of recycled materials • Producers must use ISO guidelines for labelling the parts • Collection of ELVs and deadlines for material recovery will be implemented • permits must be obtained by dismantlers
JAPAN (MInistry of Economy, Trade and Industry, 2005)	Law/Legislation	End of Life Vehicle Recycling Law
	Recovery Rates	85 – 95% by 2015
	The Law	• A network must be established between car owners, ELV collecting business, manufacturers and car importers to recycle ELVs properly • Fees shall be paid upon purchasing new cars for those who purchase new cars from January 2005, the case of disposing of cars without undergoing a periodic inspection, fees shall be paid to ELV - collecting businesses when ELVs are handed over to them
KOREA (RSJ Technical Consulting, 2007)	Law/Legislation	Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles
	Recovery Rates	85 – 95% by 2015
	The Law	• Restriction on the use of hazardous materials • Improvement of materials and structure in products for easy recycling • Separate collection of waste products for easy recycling • Manufacturers or importers of vehicles receive an annual recycling rate by joining a vehicle association • Establishment of Recycling Information Network
Canada (Automotive Recyclers of Canada, 2011)	Law/Legislation	Canadian Auto recyclers Environmental Code
	Recovery Rates	94% recovery rate
	The Law	• Dismantling and Recycling of vehicles is more environmentally friendly • Manufacturers are mandated to produce new vehicles with a view to increased recyclability
UNITED STATES (Staudinger &	Law/Directive	Automobile Recycling Study Act of 1991 (HR 3369).
	Recovery Rate	95% recovery rate

Keoleian, 2001)	The Law	• Identify potential problems in recycling and develop new solutions to the identified problems • Recyclability must be incorporated in the plans and designs of newly manufactured autos • Determine possible substitutes to hazardous substances used in vehicles. • Create design standards for autos that would result in phasing out of hazardous and non-recyclable materials • Examine methods for creating more recyclable plastics for use in autos

In order for these laws to take into effect, the main focus of recycling must be with the producer which can either be the vehicle manufacturer or the professional importer of the vehicle. The link from supplier of the cars to the collector, dismantler and shredder is necessary in order to meet all the regulations directed by law (Kanari, Pineau, & Shallari, 2003).

3.4 Summary of Review of Related Literature

Reverse Logistics is the control process flow of raw materials, inventory and finished goods from the end user to the point of origin to recapture value or disposed waste properly. Reverse Logistics is also the foundation of the mathematical models formulated for ELV network design. Reverse Logistics System for Automotive Industry is usually designed in order to minimize cost and optimize materials recovery. Different models and techniques were formulated by past researchers in order to determine the optimal solution for the problem at hand. Reverse Logistics is the basis of the models being created by the previous researchers. Different techniques include Mixed Integer Programming, Non-Linear Programming, and Order type of flow models, Objective function models, and models that consider uncertainty. In this study, legislative orders, processes and recycled materials are taken into consideration to determine the feasibility of creating a new vehicle recycling facility.

In dealing with ELV recycling, one must study the different parts that auto manufacturers disposes and sells in the market so as to determine the different costs and profit around the system. Each car manufacturer deals with a different kind of approach in ELV recycling. Toyota, BMW and Holden are only examples of manufacturers who does ELV recycling. These car manufacturers together with brilliant minds in the world and different recycling associations had joined in order to create the Automotive Recycling Association (ARA). Since each parts of the world deal with ELV differently, the ARA can be a good way to share ideas and make the recycling of vehicles in each country more efficiently done. Different laws also apply in each country but the most effective law that has been referenced from is the European Law, directive 2000/53/EC. Most countries and car manufacturers have adapted with this particular directive.

4. Methodology

This chapter deals with the research design and the methodology carried out throughout the study. The project puts emphasis on different methods and techniques that are known to be effective in developing an integrated vehicle recycling facility. The vehicle recycling system is also expected to improve the willingness of vehicle owners toward adopting good disposal mechanisms of ELVs. It is expected to establish recycling facilities at different regions in the world. These facilities will be established close to ELVs prone regions. The project will also focus partly on research that has been done in the past in relation to the disposal techniques of ELVs hence is based on the secondary source of data. This implies that the project will involve a wide scope in deriving the solution to the problem of environmental pollution that is realized from poor disposal mechanisms of ELVs. Both qualitative and quantitative approaches will be involved in deriving a concrete solution. The following diagram can be used to illustrate the key steps that will be involved in the design of an effective development methodology. Both the research and effective historical practices have been incorporated in the methodology.

Before discussing the methodology paradigm, it is important to understand the advantages and disadvantages of vehicle recycling facility before delving into the steps that should be taken in the methodology.

Advantages of vehicle recycling facilities:

There are many benefits that can be realized from the use of vehicle recycling. To start with, a vehicle recycling system is expected to reduce the wastes that are disposed to the environment as a result of the ELVs. The ELV landfills are expected to reduce with the implementation of the project. This implies that the overall negative impacts that are realized on the environment as a result of poor disposal methods of ELVs will reduce significantly.

The vehicle recycling system is also expected to improve the willingness of vehicle owners toward adopting good disposal mechanisms of ELVs. It is expected to establish recycling facilities at different regions in the world. These facilities will be established close to ELVs prone regions.

The mechanism proposed in this project is also expected to earn some income to vehicle owners. Vehicle owners are expected to be paid scrap value of the vehicle they are disposing. Additionally, the facilities will also create job opportunities all over the world. This will directly improve the living standards of people working in such facilities (Mathieux & Brissaud, 2010) .

The adoption of vehicle recycling facilities is expected to create a new channel of standardized scrap metals and spare parts. The spare parts that will be retrieved from ELVs will be passed through thorough assessment to ascertain their operational standards. This is considered to boost the automotive industry with availability of spare parts that have extended life. The scrap metal obtained from the facilities will also be used as raw materials in other different industries (Hatayama, Daigo, Matsuno, & Adachi, 2012).

Disadvantages of vehicle recycling facilities:

The only disadvantage that is associated with this project is the reduction in the prices of spare parts. The establishment of vehicle recycling facilities will introduce many spare parts which will be readily available in the market. This will definitely reduce the overall price and demand for the spare parts.

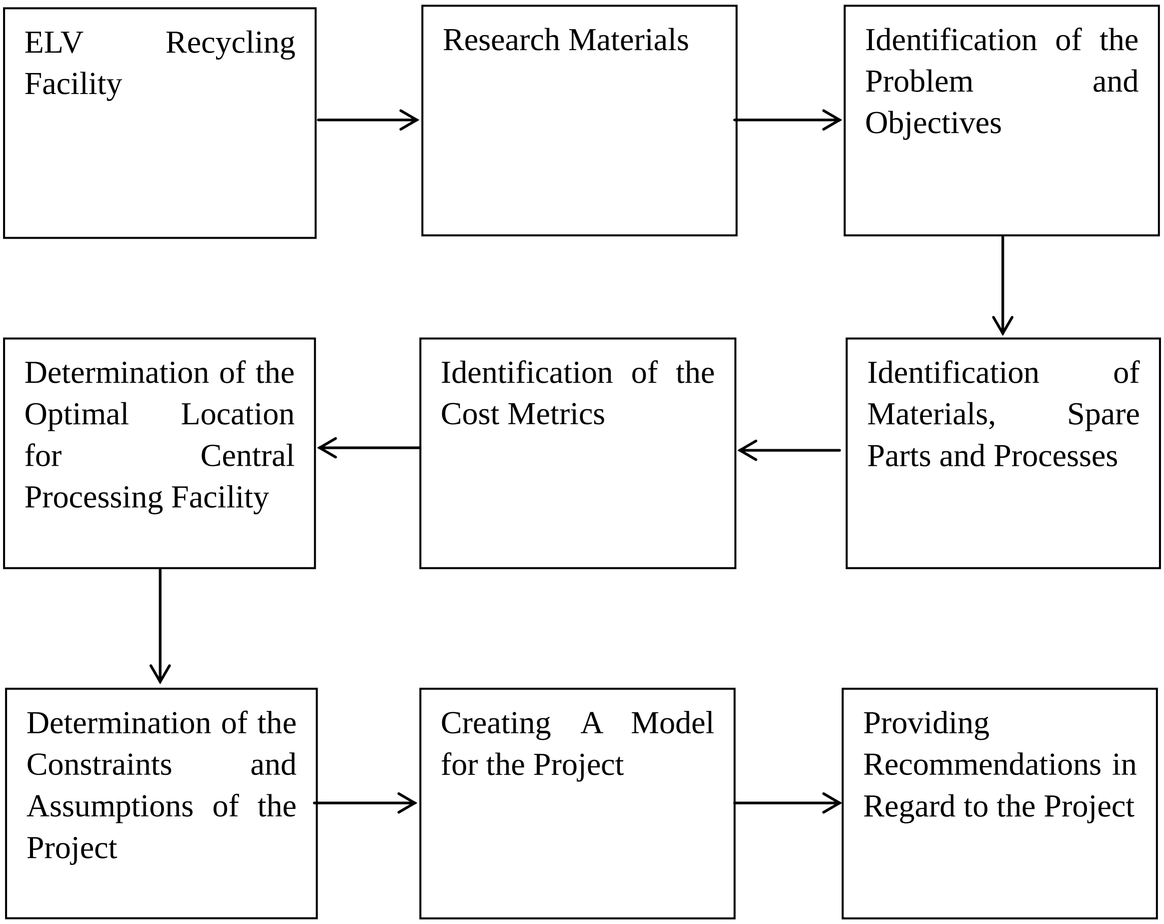

Figure 5. Methodology Paradigm

4.1 ELV Recycling Facility

The researchers have determined the industry of interest as ELV recycling facility. The recycling of ELVs is of interest to the researcher because it poses a threat to the environment. Aside from the threat to the environment, a number of materials can be recovered from vehicle recycling. This facility can save a lot of energy and resources from the environment and as such is a good topic of interest.

4.2 Research Materials

The methodology for this project involves research in the internet and other related materials from online libraries. A section of the project will be developed on the basis of the information received from already existing recycling facilities. The following table can be used to summarize the methodology that will be employed in the study.

Table 5. Concepts are derived from other related materials

Concept	Description	Source
Determination of Effective Network for ELV Recycling	1. ELV Recycling	• (Alliance of Automotive Manufacturers, 2010) • (US Environmental Protection Agency, 2012)
	2. Reverse Logistics	• (Adaptalift Hyster, 2013) • (Sanket, 2009)
Identification of Process and Materials	1. Typical ELV Process	(Zhaoanjian & Yang, 2014)
	2. Parts and Suppliers De-manufacturing	• (Toyota Motor Corporation, 2014) • (Autoparts Recycle Association of Australiar; Greenfleet; Holden, 2014) • (BMW Group, 2009)
	3. Factors that must take into account for ELV's Recycling Cost	(Field, 1993)
Identification of the constraints and laws	1. EUROPE Directive 2000/53/EC	(Kanari, Pineau, & Shallari, 2003)
	2. JAPAN End of Life Vehicle Recycling Law	(MInistry of Economy, Trade and Industry, 2005)
	3. KOREA Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles	(RSJ Technical Consulting, 2007)
	4. Canada Canadian Auto recyclers Environmental Code	(Automotive Recyclers of Canada, 2011)
	5. UNITED STATES Automobile Recycling Study Act of 1991 (HR 3369).	(Staudinger & Keoleian, 2001)
Mathematical Models	1. Technical Cost model of ELV Processing Operators	(Zhaoanjian & Yang, 2014)
	2. Conceptual Model of a network handled by vehicle manufacturer	(Zarei, Mansour, Kashan, & Karimi, 2010)
	3. Four Modelling Technique classification	(Elwany, Fors, Harraz, & Galal, 2007)

4.3 Identification of the Problem and Objectives of the Project

The problem and objectives of the project were identified based on the research materials gathered from the industry statistic and second hand information materials. The objectives of the study were based on how the solution can be arrived at to solve the problem of the study.

4.4 Identification of Materials, Spare Parts and Processes

This stage involves determination of the materials and processes involved in the vehicle recycling network. It will seek to identify different raw materials that can be retrieved from the ELVs. It will also determine the operational standards of spare parts obtained from ELVs. Table 5, shows how the raw materials, spare parts and the processes can be determined.

Table 5. Identification of Materials, Spare Parts and Processes

DETAILS	MATERIALS	SOURCE
Materials and Spare Parts	Recycled Vehicle Fluids	Check local directory for end users of Vehicle Fluids (Yellow Pages, interview with local wreckers)
	Hazardous Materials from ELV	Check with local government departments if there are any special procedures in dealing with hazardous materials from ELV (Online and Interview with local government units)
	Recycled Spare Parts from ELV	Check local directory for end users of recycled Spare Parts (interview with local wreckers)
	ELV Car Chassis, Compacted Scrap Metal Shredded Materials (Ferrous and Non-ferrous)	Check local directory for shredders and compacting facilities in the area. It would be helpful to ask local car dealers if they are acquiring ELV from customers and how they deal with this
Process	Acquiring ELV	Ask Car dealers if they are acquiring ELV, Check local directory for car junk yards on how they acquire ELV
	Neutralization of Pyrotechnic Devices	Inquire about this with car dealers, local car wreckers and car junk yard
	Removal of Vehicle Fluids	Inquire about this with car dealers, local car wreckers and car junk yard
	Removal of Hazardous Materials	Inquire about this with car dealers, local car wreckers and car junk yard
	Dismantling	Inquire about this with car dealers, local car wreckers and car junk yard
	Removal of Core Scrap	Inquire about this with car dealers, local car wreckers and car junk

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		yard
	Compacting	Inquire about this with car dealers, local car wreckers and car junk yard. Research on compacting facilities for cars
	Shredding Process	Inquire about this with car dealers, local car wreckers and car junk yard. Research on Shredding facilities for cars
	Post Shredder Technologies	Inquire about this with scrap metal dealers and shredding facilities or even local waste management unit

4.5 Identification of the cost metrics for vehicle recycling process.

This stage involves determination of the costs involved in the vehicle recycling facilities. The cost associated for each process should be determined in order to create the proposed model for the project. Each cost can be used as a variable in the model formulation. It will also determine the overall benefits that are associated with the establishment of the vehicle recycling facilities. Table 6, illustrates how the costs incurred in the vehicle recycling system can be determined.

Table 6. Possible costs incurred during the ELV recycling

Cost Metric	Source
Cost of Acquiring ELV	Interview with car dealers (if they are de-manufacturing), car wreckers, car junk yard
the cost of extracting, storing, and distributing the parts that can be sold	Interview with car wreckers and car junkyard
Price of Parts that can be sold	Interview with car wreckers and spare part auto resellers
Cost of extracting and removing the parts that the shredder does not want in the stripped car	Interview with car dealers (if they are de-manufacturing), car wreckers, car junk yard
Price of the stripped car that would be sold to the shredder	Interview with car shredder facility, car wreckers and car junk yards
Cost of metal scrap	Interview with metal scrap dealers
Operating cost of the shredder and ferrous separator	Interview with shredding facilities
Disposal cost of Automotive Shredder Residue	Interview with shredding facilities and local waste management unit
Asking Price of shredded ferrous metal blend	Interview with scrap metal dealers and shredders
Asking Price of the mixed non-ferrous metal blend	Interview with recyclers that deal with on-ferrous metal blend
Cost of Acquiring a new shredder	Research online and interview with shredder facilities
Cost of acquiring a ferrous separator	Research online and interview with shredder facilities

4.6 Determination of the optimal location for central processing facility

Based on the review of related literature and the cost metrics identified, the researchers must determine what practices must be done and where the optimal location of a central processing facility could be established. The network will facilitate the market of the scrap metals and spare parts obtained from ELVs. It will also boost the willingness of owners in disposing their vehicles through the facility.

4.7 Determination of the Constraints and the Assumptions of the Project

This stage will involve determination of the establishment limits that are associated with implementation of vehicle recycling facilities. All the constraints including cost, sensitization and review of different legal parameters in different countries will be evaluated in this stage. Constraints can be something that the government had created and assumptions can be ideal conditions that the process takes place in.

4.8 Creation of the model project

A synthesized model will be created to establish de-manufacturing network for end-of-life vehicles. The model will constitute all the parameters that are expected to be involved in the implementation of the project and will comprise of preliminary and actual necessary operations. The mathematical model would be able to allocate material flows within the network and determine the optimum locations of the central shredding facility that can minimize the total cost related to vehicle recycling. The criteria of optimization are the cost of transportation, storage, dismantling and shredding of ELVs. The model inputs would be cost of acquiring and collecting ELV, cost of dismantling ELV, cost of compacting and shredding ELV, and transportations costs within the network. Figure 6 shows the structure of the proposed de-manufacturing network. There are direct economic and environmental contributions of this de-manufacturing network of end of life vehicles. The economic benefits include the promotion of resource efficiency as it will provide incentives for innovation not only in vehicle design, but also in the treatment of ELVs. In addition, it will lead to an improved efficiency in the treatment sector; the case study reports an improved professional and technical approach, with investments that will lead to higher operational efficiency; it will also secure its long term future. The practical contributions to the environment include an increase in the number of vehicles in the integrated vehicle recycling facility. It will also lead to an increased level in how different materials are treated. There will also be continuous improvement in the quality of the environment as the approach becomes more fully implemented.

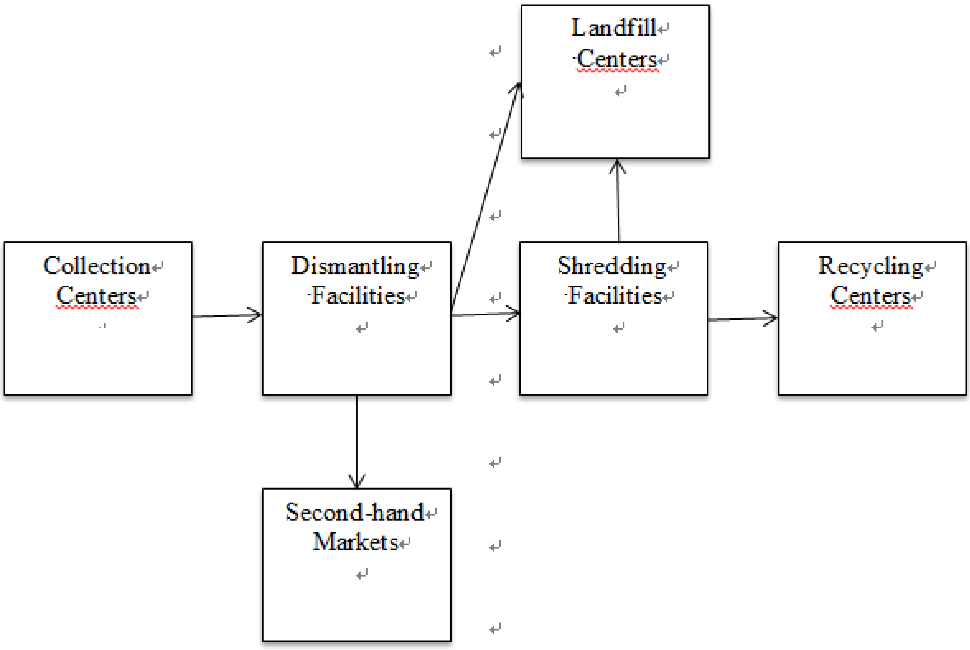

Figure 6. ELV De-manufacturing Network

4.9 Providing Recommendations in regard to the project

Recommendations for further study will be discussed after create the model. Implementation of the solution will also be discussed in this particular part of the paper.

5. Conclusion

Automotive de-manufacturing systems are important for ensuring sustainability and affordable cost for the newly produced cars. This is because it will lead to an increase in operating standards of the recycling facilities even where there is no full compliance with ELD guidelines. Moreover, it will lead to a control of ELV currently disposed of. In addition, it will lead to the use of recovered as opposed to virgin materials. This is critical in avoiding the environmental impacts arising as a result of production of virgin materials. The model will lead to an idea situation where there will be higher recycling rates which like noted, will be environmentally beneficial for global warming potential. And this is largely due to positive contribution posed by the recycling of ferrous and non-ferrous metals. In addition, when diversions from the landfill are considered, there will be benefits that are even higher. Moreover, the Integrated Life-Cycle Assessment (LCA) and Optimization Approach will considered the system boundaries for each end-of-life option, and these include reuse, recycling, recovery and landfill. The logistics process usually begins from raw materialsto manufacturing, up to the end process at the consumer level. On the contrary, reverse logistics is is a process that begins from dismantling of the equipment before reclamation and recovery. All these processes and activities in reverse logistics systems incur costs and must be included in the design of the system. The project put more emphasis on the different methods and techniques that are known to be effective in developing automotive de-manufacturing systems.

6. Future work

Future work will include the development of the optimization model on a place where end-of-life vehicles' legislations and laws are implemented. It will also be directed to compare between the costs of traditional methods versus de-manufacturing. A sensitivity analysis would be used to understand the overall change in automotive de-manufacturing economics.

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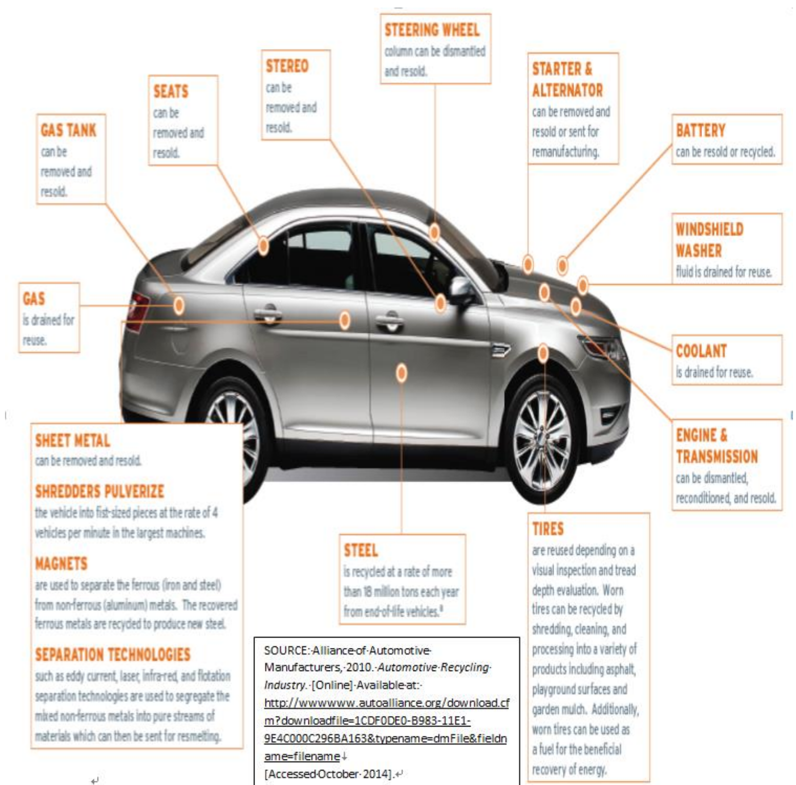
Appendix

Appendix 1. Parts of vehicles that are Recycled and reused



SOURCE: Alliance of Automotive Manufacturers, 2010. *Automotive Recycling Industry*. [Online] Available at: http://wwwwww.autoalliance.org/download.cfm?downloadfile=1CDF0DE0-B983-11E1-9E4C000C296BA163&typename=dmFile&fieldname=filename
[Accessed October 2014].

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Appendix 2. Dismantled Auto Parts of ELV

SOURCE: (Autoparts Recycle Association of Australiar; Greenfleet; Holden, 2014)

Recycling Auto Parts

Initial Procedure

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Batteries	Case - plastic or rubber. Contents - lead, sulphuric acid	Remove from vehicle as appropriate	Under cover, off ground storage	For Collection Contact: Phone:	Avoid sulphuric acid fumes or contact with skin. Gas is explosive - keep away from ignition sources
Brake Fluid	Primarily diethylene & polyethylene glycol-mono alkyl ethers	Collected in steel or plastic drain pan only used for that purpose	Under cover, bunded area, to appropriate storage drum or tank	For Collection Contact: Phone:	Corrosive, highly toxic to environment
Fuel	ULP (unleaded petrol) LP (leaded petrol) Diesel	Siphon mechanically from tank to avoid spillage	Under cover in appropriate sealed drums	For Collection Contact: Phone:	Erect fire hazard warning signs with approved fire control equipment at hand. Avoid fumes
LPG	Liquid Petroleum Gas	Mechanically decant before tank is removed from vehicle	In approved LPG tanks, in appropriately ventilated area	For Collection Contact: Phone:	LPG is an explosive product and is heavier than air. Do not allow LPG to accumulate in low areas
Oil	Engine, transmission and differential	Drain to bulk container in bunded area. Use compressed air or spill free movement to storage	Under cover, bunded area, to appropriate storage drum or tank	For Collection Contact: Phone:	Appropriate fire hazard warning sign
Air Conditioning Gases	R12 Freon, 134A **R12 is hazardous to the environment**	Reclaim by accredited operator	To approved storage containers	For Collection Contact: Phone:	Provide safe area for minimum chance of gas escapes
Air Bag (undeployed)	Plastics, metals **igniters and explosives**	Removal by competent operator	Under cover secure area. **Must be stored face up**	For Collection Contact: Phone:	Handle with care, contains explosive. Adopt manufacturer's recommendations for reuse and general handling. If unit is scrapped it must be rendered inoperative by intentionally deploying or by removing trigger source

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Plastics

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Bumper Bar Cover	Various. Some are identified for recycling	Remove from car where appropriate	Racked or binned for recycling	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!
Grilles	Plastic or metal. Some are identified for recycling	Remove from car where appropriate	Racked or binned for recycling	**For Collection: As listed for other metals and plastics**	Do not burn. Fumes are toxic!
Internal Trim and Plastic Fittings	Various. Some are identified for recycling	Remove from car where appropriate	Racked or binned for recycling	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!
Plastic Drums (empty)	Various. Some are identified for recycling	N/A	Where appropriate. Contain residues	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic! Contain residues
Plastic Panels	Various. Some are identified for recycling	Remove from car where appropriate	Racked or binned for recycling	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!
Polythene Film (packaging)	High Density Polyethelene (HDPE) or Low Density Polyethelene (LDPE)	N/A	Waste bin	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!
Seats	Various	Remove from car where appropriate	Appropriate storage	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!
Trim Interior & Exterior	Various. Some are identified for recycling	Remove from car where appropriate	Racked or binned for recycling	**For Collection Contact:** **Phone:**	Do not burn. Fumes are toxic!

Metals

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Air Conditioning Cores	Aluminum, copper	One piece, using normal hand tools	Rack or appropriate bin	**For Collection Contact:** **Phone:**	Handle with gloves
Aluminium & Aluminium Alloys	Various types	Normal hand tools and cut-off saws	Rack or appropriate bin	**For Collection Contact:** **Phone:**	Handle with gloves
Magnesium	Wheel rims and other mechanical components	Normal hand tools	Rack or appropriate bin	**For Collection Contact:** **Phone:**	Warning! Fire hazard and gives off toxic fumes when burned. Avoid cut-off saws and oxy-acetylene equipment
Car Bodies & Panels	Steel and plastics	Normal hand tools and cut-off saws where appropriate	Rack or stack safely in a secure area	**For Collection Contact:** **Phone:**	Use of oxy-acetylene to a minimum, may ignite plastics, rubber, grease which produces dense black fumes detrimental to health and air quality
Catalytic Converters	Contain toxic heavy metals. Only active when hot	Normal hand tools or cut-off saw to adjacent pipes	Rack or appropriate bin	**For Collection Contact:** **Phone:**	Avoid heat e.g. The use of oxy-acetylene equipment
Copper	Radiators, heater cores and electrical wiring etc	Normal hand tools and cut-off saws	Rack or appropriate bin	**For Collection Contact:** **Phone:**	Handle with gloves. Do not burn electrical wiring insulation. Fumes are toxic
Drums (empty)	Steel	Appropriate handling equipment	In bays with lids securely in place. Bund area to contain residues	**For Collection Contact:** **Phone:**	Possible hazardous fumes and explosive potential. Contain residues
Oil Filters (drained)	Steel, paper and fibres	Use normal hand tools. Contain any residues	In leak-proof drums to contain residues	**For Collection Contact:** **Phone:**	Contain residues

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Metals

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Radiators	Copper, aluminum and plastic	Remove to contain coolant residues, using normal hand tools	Bund area to contain coolant residues	For Collection Contact: Phone:	Warning sign! Radiator coolant is toxic to environment, especially waterways. Handle with gloves
Steel and Steel Alloys	Steel and steel alloys	Normal hand tools and cut-off saws, in preference to oxy-acetylene cutting	Rack or appropriate bin	For Collection Contact: Phone:	Handle with gloves

Liquids

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Coolant	Includes phosphoric acid, hydrazine, ethylene glycol and alcohols	Collect in bunded spill containment area	Transfer to appropriate storage drums in bunded area	For Collection Contact: Phone:	Warning sign! Radiator coolant is toxic to environment, especially waterways
Interceptor Waste and Oil Separator Waste	Oils, grease, water, chemicals, detergent and sludge	Pump to dedicated holding tank	Pumped to dedicated holding tank in bunded area for removal by contractor	For Collection Contact: Phone:	Warning sign! Hazardous Waste!
Caustic Cleaning Solutions	Caustic Soda (usually hot tank application)	When cool, transfer to storage in bunded spill containment area	Under cover, bunded area to appropriate storage drum or tank	For Collection Contact: Phone:	Warning sign! Corrosive - highly toxic to environment
Solvents	Oil and grease removal, general parts cleaning	Drain into dedicated container in bunded spill containment area	Under cover in dedicated container for collection by contractor	For Collection Contact: Phone:	Appropriate fire hazard warning sign. 'Hazardous Chemical' sign

Tyres

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Tyres	Rubber, steel and fabrics	Remove as appropriate	Fenced area. Check maximum permissible storage numbers. See local authorities	For Collection Contact: Phone:	Ensure minimum quantities stored. Keep away from ignition sources
Inner Tubes and Rubber Components	Rubber, hoses, mounts etc	Remove as appropriate	Collection bin as appropriate	For Collection Contact: Phone:	Keep away from ignition sources

Hazardous Materials (other than liquid)

Adhesives, Gasket O-Rings & Seals including Fluoroelastoma Sealants used between panels e.g.Viton	Fire wall to body adhesives, etc **Extremely dangerous to skin when hot**	Keep away from oxy-acetylene flame or any other heat source	Leave intact where possible as on fire wall etc	**For Collection Contact:** **Phone:**	Extremely dangerous to skin when hot: Clear liquid hydrofluoric acid forms on top of burned components. Clean with detergent solution and use heavy duty neoprene gloves

Other Wastes

COMPONENT	MATERIALS	DISMANTLING	STORAGE	DISPOSAL	SAFETY
Overalls, Gloves and Cleaning Rags	Cotton polyester/leather. Oil impregnated	N/A	Under cover to dedicated storage for waste collection or cleaning	**For Collection Contact:** **Phone:**	Keep away from ignition sources
Paper and Cardboard	Packaging and newspapers	Package in manageable piles	Under cover	**For Collection Contact:** **Phone:**	Keep away from ignition sources
Windscreen and Side Glass	Safety glass. (This can be used as asphalt filler). Laminated Glass	Remove as appropriate	In dedicated bin or racks	**For Collection Contact:** **Phone:**	Handle with care