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A Review on End-of-life Vehicle Design Process and Management

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Abstract: In recent years, many industrial countries face the consequences of a wide flow of consumer goods and limited product life spans, resulting in a continuous increase in the quantity of used manufactured goods. This occurrence certainly increases the problem of disposal of used products. In this study, of particular interest is the disposal of solid waste from used vehicles. With the facilities of landfill sites rapidly declining due to government legislations, problems of solid waste disposal would continue persist. At present, environmental concerns and government legislations in many developed and developing countries are increasingly guided by the inventor principle, which capitalizes that inventors, designers, or whosoever inflict damage on the environment should likewise remove such damage. This, in turn, has compelled manufacturers to undertake recycling efforts at the end-of-life stage of their products. This entire exercise has resulted in huge implications on the product end-users, producers and the end-product recyclers. Designing for the environment is a necessary concern throughout the life cycle of a product. This means, that the recyclability of a product or its parts should be deliberated on from the on-set, namely from the design, manufacture, use or service, until the end-of-life stage. Management of solid wastes from vehicles considers product recycling by reuse, remanufacturing and reassembling, which is collectively known as End-of-Life-Vehicle (ELV) consequently, this study explores the efforts thus far in published literatures, to implement ELV around the world.

Key words: End-of-life-vehicle, recovery materials, design processes

INTRODUCTION

In the initial stages of the product life cycle, the product is supposed to pass through a cycle of birth (Dieter, 2000) as shown in Fig. 1. End-of-life vehicles (ELVs) are produced in two ways, namely, premature or natural. Premature ELVs are vehicles that have come to the end of their helpful lives before the end of their average lifetime. This occurrence may be due to various factors such as fire, theft, flood, vandalism, or accident damage. ELVs have a large number of reusable vehicle parts that can be removed before further processing. On the other hand, natural ELVs are vehicles that have reached the end of their useful lives. Such vehicles are usually in a severe state of repair and the resale value of the parts is at a minimum. A number of health and safety issues must be addressed before de-pollution and subsequent processing. Vehicles are essential products in our society and the demand for them continues to increase. Only 4,120 passenger vehicles were built in 1900 in the United States (the only country that manufactured cars at that time). By 1985, approximately 109 million passenger vehicles are in existence. This number is expected to be six times larger today when dozens of countries participate in automobile production.

Vehicles are utilized as service commodities throughout their life cycle. Thus, they produce a specific negative impact on the environment, including energy and resource consumption, hazardous substance emissions and waste generation. Automotive waste landfills exist in all parts of the world. Countries in Europe and other developed countries prefer to recycle vehicles rather than

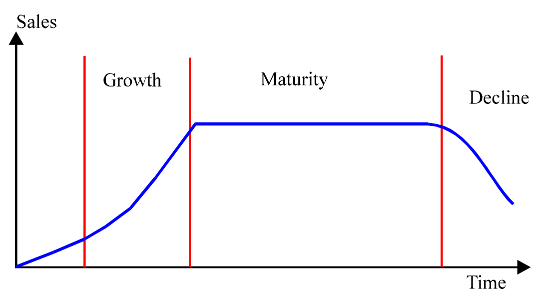

Fig. 1: Product life cycle (Dieter, 2000)

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Fig. 2(a-b): Dead vehicles

throw them in automotive waste landfills. The number of vehicles from these countries recycled by specialized recycling companies is estimated to be approximately 15 million. This large number may be due to accident damage, test failure, or other causes that render the vehicles uneconomical to repair. This situation equates to a million tons of material to be recovered or disposed.

Solid waste management represents important environmental, social and economic challenges for developed and developing economies alike (Nnorom *et al*., 2007). An example of this situation is the 1960s, when abandoned vehicles caused major environmental problems in the EU, as depicted in Fig. 2. This problem was considerably solved with the invention of the crusher machine which grinds the hulk of a vehicle to allow for the recovery of the metallic components.

In the early 1990s, through studies on numerous solid waste disposal systems, the European Union (EU) identified ELV as a priority waste stream. A directive was introduced toward its implementation (Zoboli *et al*., 2000). As we advanced into 21st century, the automotive industry in 2012 turned its attention to issues of environmental-friendly vehicles in response to the implementation of the EU directive for ELVs, which outlines that automobile manufacturers must reuse or recover 85% of ELVs by 2006. At least 80% of this value must be reused or recycled and the remaining 5% can be managed through other recovery operations such as incineration (Goodfellow, 2002; Afrinaldi *et al*., 2010).

This affected all players involved in the vehicle infrastructure:financial investment, operational strategy, design, as well as developmental process. The whole arrangement of automotive industries is projected to change to focuses designing in relation to recycling features. The traditional design process will become more on designing in relation to issues regarding recycling. Furthermore, the old design process would become more advanced as regulation demands the removal of all harmful liquids and components in cars. Nevertheless, some form of plastic, rubber and glass recovery is still necessary, either during the dismantling stage or during the separation stage. This is the big challenges to the vehicle designers. This study then reviews the progress achieved thus far in ELV recovery strategy.

DESIGNS FOR RECYCLING

Design for Recycling (DFR) has a significant role in the vehicle growth process. DFR considers all the recycling aspects and ecological factors at some point in the design stage of a vehicle to increase its recyclables and extend the end-of-life. As the vehicle manufacturers are expected to bear the recycling cost on their own, the types of materials selected for vehicle parts manufacture becomes a key element in the growth procedure. The selection of materials is of great significance, with attention paid to materials problem and how they could be directly reused for ensuing processes. The composition of a characteristic vehicle has substantially distorted in last few years. For instance, ferrous metal components in cars have considerably decreased, whereas plastic materials are increasingly incorporated because of their lighter weight and better fuel efficiency advantages. The average passenger vehicle is assembled from approximately 10,000 parts, comprising a large number of different materials. The majority of materials used are recyclable, although some are more improved than others for various reasons such as quality, demand, reprocessing durability and cost (Khucharoenphaisan *et al*., 2012).

The two main factors that influence the DFR concept in automotive engineering are disassembly and recycling. The fruitful application of this concept in the development of new passenger cars requires the deliberation of several parameters, including material selection, design and characteristics of the components and methods of joining or assembly. A guide for the DFR concept was developed in 1990 by the recycling and dismantling centre of the BMW group to guide designers and improve their capability to meet the environmental criteria and recycling requirements. The guidelines are divided into three main areas, namely, methods of joining and fixing, selection of materials and design of components.

Many researchers and developers focus on creating tools and methods to enable the reuse of vehicle components. The first step toward reuse begins with the proper development of the component parts after disassembly. The ease of component disassembly is known as disassemblability (Mok *et al*., 1997). Disassemblability is also defined by Seo *et al*. (2001) as the optimization of the disassembly process to remove certain parts or components in economic and environmental aspects. Many studies have cantered on the development of disassemble evaluation systems to achieve a design with ease of disassembly. McGlothlin and Kroll (1995) proposed a spread sheet-like chart that measures the ease of disassembly of a product. A report by Kroll and Hanft (1998) extended McGlothlin and Kroll (1995) study with emphasis on disassembly through a time-measurement system called Maynard Operation Sequence Technique (MOST). In other words, the particular components of the product must be assessed and its reliability and lifespan must be predicted to ascertain the reusability of the product. The probability of a component to execute a specific function at specified operational conditions and specific time without failure is called reliability. A model for automotive component optimization and reuse with artificial intelligence has been developed (Wahab *et al*., 2008) for ease of disassembly. The model aims to predict the reliability and durability of the reused components and optimize life cycle cost and reliability with a Genetic Algorithm (GA). This model was proposed for a local Malaysian automotive company, enables the automotive industry to effectively assess potential components for reuse in support of further design and manufacturing improvements. Among the major contributions of this model is the introduction of artificial intelligence methods, such as ANNs and the GA, which could provide satisfactory and acceptable solutions for many complex problems.

According to Go *et al*. (2010), Fig. 3 investigated a design frame work for ELV recovery, namely, the optimisation of disassembly sequence using GA. The study provided a framework with ease of recovery for automotive components. One of the goals of disassemblability is to reduce the impact of a product on the environment. The model was applied as an evaluation tool and was divided into three: element design principles, implementation guidelines and disassembly guidelines. The GA model was utilized to generate the optimum disassembly and end-of-life product disassemblability evaluation. The designed model was utilized to enhance and improve the disassemblability of end-of-life products from the design stage. Amelia *et al*. (2009a) studied the disassembly time evaluation for enhancing the reusability of automotive component. Lashlem *et al*. (2011) also investigated the design assessment for reusability of an automotive safety beam.

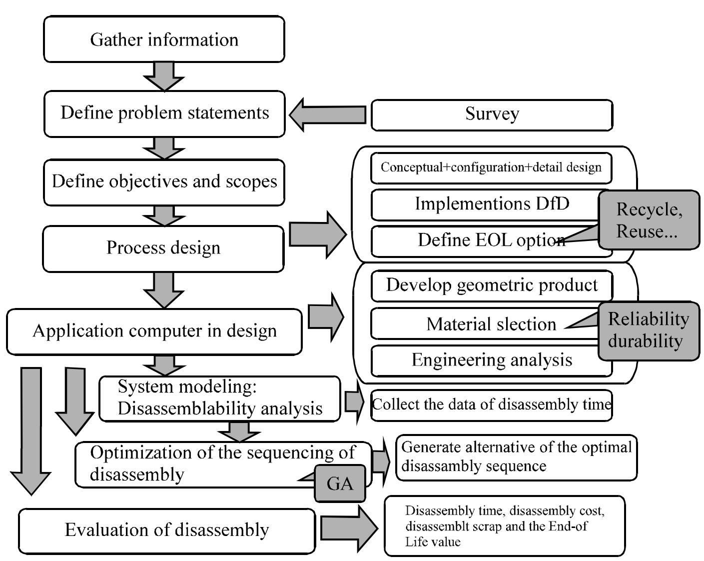

Fig. 3: The proposed model (Go *et al*., 2010)

RECYCLING TECHNOLOGY

Recycling is a process by which used materials are remade to form a new product (Altschuller, 1997). The process of ELV recycling is defined as follows:

Dismantling: The recycling value of the components is highly increased in the dismantling process and allows the reusability of the product. The dismantling industry has a great potential. However, the full implementation of the EU directive for ELV dismantling is highly limited at present because it is labor intensive and uneconomical. Only a few high value components are removed the vehicle before sending to the shredding process. Dismantling companies can be branded into two types of businesses, the first comprises high value parts businesses that remove and inventory the useful and high value parts for resale. The other comprises scrap yard businesses that store the ELVs while the parts are gradually removed and then sold to local repair shops as well as Do it Yourself (DIY) owners.

De-pollution processes: De-pollution processes are seen as the removal of hazardous substances, battery, fluids, tyres etc. It is good to note that high value components are removed via manual disassembly. Several small facilities separate pure stream plastic for direct selling to recyclers and re-processors. The rest of the vehicle body is subjected to shredding operations for post-fragmentation recovery. Once the ferrous content has been recovered, the non-ferrous scraps are removed through dense media separation processes. The remaining components are sent to landfills.

Shredding process: This is another process of ELV disposal. Shredding industries can process large quantities of ELVs at capital-intensive sites. The main output from this process is ferrous metal, which is sent to steel industries for recycling (Mat Saman and Blount, 2008). In the shredding process, rotating hammers rip a part the compressed ELV, dropping it easily from the output grid where the light materials are separated from the heavy materials (such as plastic from steel). However, the process efficiency depends on the characteristics of the applied design. Therefore, recycling success can be increased by considering the hierarchies of the recycling process in the early design stages. Such hierarchy can be divided into four components, namely reuse, recycle, recovery and waste as shown in Fig. 4. The figure indicates that the component reuse is the first priority in product design processes. If the product cannot be reused directly, then it might need some additional work

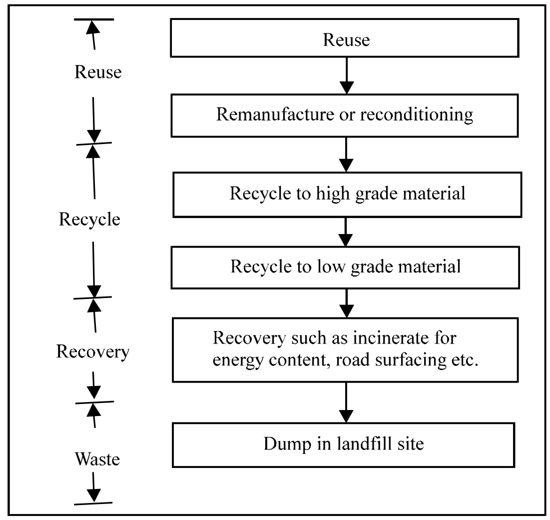

Fig. 4: The hierarchies of recycling (Mat Saman and Blount, 2006)

on the same form/pattern or another form/pattern is necessary. This is called remanufacture or reconditioning.

The second tier in this hierarchy is recycling, which in this case means the processing of components to produce a raw material. This component processing can be divided into two categories, which are high grade and low grade materials. The next process that requires consideration is recovery, recovery with is the use of waste for useful purposes, such as energy recovery, road surfacing and so on. Then, the last consideration is waste material that is sent for disposal in landfills. Currently, most ASR is sent to landfills for disposal. The reduction of this waste stream through the recovery and recycling of plastics is the focus of most current research (Mat Saman and Blount, 2008). Figure 5 presents the summary of the de-pollution waste processes. Based on these recycling technologies and others, several key elements can be concluded in managing the recovery of ELVs.

GOVERNMENT LEGISLATION AND MANAGEMENT OF ELV IN SOME COUNTRIES

ELV management in EU countries: The EU countries are among the foremost to propose legislative measures aimed at tackling environmental problems created by ELVs. At moment, most of the developed countries have set new legislations, to force vehicle manufacturers to recover and recycle their products at the end-of-life. In April 2002, a new directive for EU countries came into effect, compelling governments to enforce the responsible

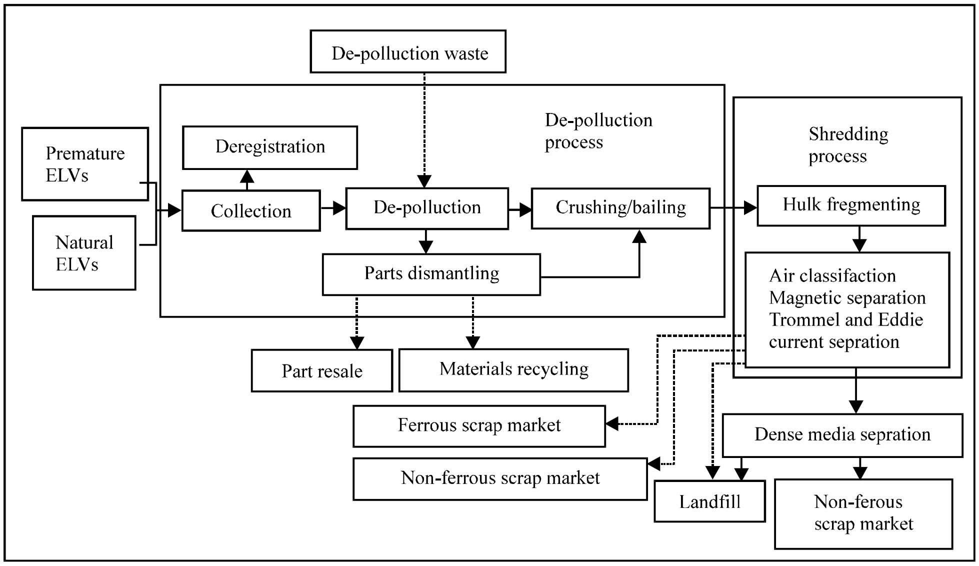

Fig. 5: Current vehicle recovery infrastructures (Edwards *et al*., 2006)

disposal of vehicles that have come to their end-of-life. According to the UK Department for Environment, Food and Rural Affairs (DEFRA), 300,000 vehicles are simply abandoned by UK owners each year and between 8 and 9 million tons of wastes are generated from ELVs in the EU (Mat Saman and Blount, 2006). Among such waste, are 75% ferrous metal, which is recycled through traditional metal dealers to produce new steel or other ferrous products and 25% other materials that go to landfill sites.

Although full implementation is still a few years away, the EU Directive on ELVs now weight heavily on most vehicle manufacturers in Europe. The directives were issued in stages; the first stage was announced on September 18th, 2000. This directive was aimed at reducing the amount of ELV content that are sent to landfills. The second stage was implemented in October 2002. In the EU, up to 10 million vehicles a year reach end of their first useful life. According to Mat Saman and Blount (2008), the German and Dutch authorities introduced the concept of 'Producer Responsibility', which obliges car manufacturers to re-claim their ELVs. This practice aims to control the disposal of ELVs. Improving the recyclability of vehicle parts reduces the burden on the environment. However, when the EU directive required that manufacturers claim and treat ELVs at no cost to the last owner, intense opposition ensued from the manufacturers. Manufacturers would shoulder significant financial cost in such procedure.

A general position was reached in 1999 after some key points of the original directive were adapted. The directive was finally implemented in October 2000. The main provisions cover aspects such as the promotion of awareness, inclusion needs related to de-pollution and dismantling of ELVs reuse, recycling and the materials recovery from ELVs, set up of collection networks, outline of quantitative targets for recovery and recycling until 2015, as well as the demanding member states to create laws, regulations and (enforceable) agreements by April 2002.

ELV management in the United States of America (USA): In the USA, no specific legislation focuses on the management of ELVs. All materials, either waste or recycled materials, are considered as solid wastes. Thus, the recycling industry has received much less interest. Currently, the abundance of land causes no shortage in waste disposal sites, a situation that could lead to low costs of waste disposal. Furthermore, no standard waste legislation exists for the entire country. Each state has its own legislation and thus the target and implementation varies. Nevertheless, Ford, Daimler Chrysler and General Motors have provided a special programme that study methods to improve the recyclability rate and to decrease the current ASR burden. Most of the recycling industries in the US belong to the automotive industry. It has been reported that Ford purchased over 25 vehicle recycling operation in the United States of America in 2001 and the number is expected to increase even more. The also has an experimental dismantling centre in Germany (Bandivadekar *et al*., 2004).

ELV management in Japan: Most of the vehicle manufacturers in Japan are branching out into the recycling business and developing easy to recycle vehicles in response to a new automotive recycling law that was implemented in 2004. The first legislation was, introduced in 1990 and promoted the use of recycled resources, applying particularly to automotive industries. In 1996, quantified targets for recycling ELVs was set at 85% by 2012 and 95% by 2015. Similar to Europe, Japan has considered the issue of ELVs recycling as a priority. According to the Japan Automotive Manufacturing Association (JAMA, 2004), the waste disposal law specified that shredder residue is a waste that requires specially controlled landfills. Few such landfills meet the strict standards, leading to an increased cost of land-filling. Despite such scenario, approximately 50% of ELVs are still traded at a profit due to the value in metals that offset the cost of land-filling with the waste (JAMA, 2004; Mat Saman and Blount, 2006).

ELV management in Australia: In the management of ELV in the Australia, no regulation requires the last owner of an ELV to enter the recycling infrastructure. More so, the last owner does not need to deregister the ELV. However, currently being introduced in all local councils are new requirements for ELVs that would provide full authority to local councils to act regarding ELVs that cause a health or fire hazard, or a loss of amenity to other residents. The requirements apply even though the ELVs are stored on private properties. Comparative to this directive, several states as in Western Australia have emphasized abandoned vehicles as being of a broader concern.

These vehicles cost local authorities several weeks of storage before they could dispose of them. With the aim to reduce costs, some local council have introduced collection points for ELVs. The proportion of ELVs that reach recycling facilities appears to be over 90% (Puri *et al.*, 2009).

ELV management in Mexico: The state of ELV management in developing countries, such as Mexico, is highly different from that in the EU and other industrialized countries. The management of products at their end-of-life stage has not yet been addressed by environmental authorities as an important issue. In the case of ELV, specific legislations and plans to manage such products are lacking. In addition relevant data about on Mexican vehicular fleets are scarce (Cruz-Rivera and Ertel, 2009).

The current management of ELV in Mexico is driven by market conditions, where mostly valuable materials and components are recovered from ELV, because major operators' aim obtains large profits. The ELV chain remains disaggregated, due to the scarcity of commercial relationships among stakeholders. The main reason for this is the lack of consolidated networks adding value to

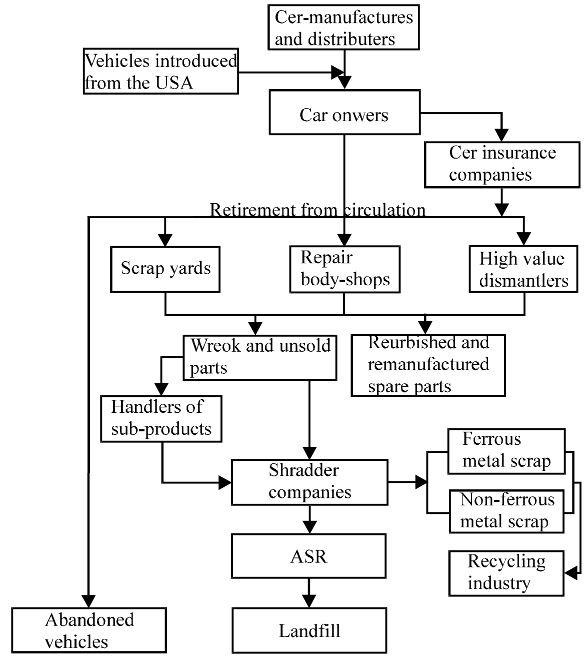

Fig. 6: A general configuration of ELV management in Mexico (Cruz-Rivera and Ertel, 2009)

ELV (Cruz-Rivera and Ertel, 2009). The lack of legal incentives and disaggregation, results in mainly unstandardized operations for ELV management. In many cases, this lack of standardization promotes malpractices in ELV management activities. In turn, these practices lead to negative effects on the recovery value of an ELV, such as contamination of shredder material by operative fluids. This scenario affects the efficient recovery of value from ELV, as the steel industry rejects shredded metal from such vehicles. Figure 6 depicts general configuration of ELV management in Mexico.

Regarding take-back activities, the de-pollution and dismantling processes are conducted by an undetermined number of businesses, which are composed of a majority of automotive repair, body shops and scrap-yards. Most of these businesses perform non-standardized operations, as only valuable material and components for re-sale are dismantled. The remaining wastes are sent to shredders and landfills. These undertakings cause a number of strong impacts on the environment, particularly those related with the improper management of operative fluids from ELV.

ELV management in Egypt: The report published by the Industrial Development Authority states that, over the last 20 years, the vehicle assembly sector has expanded from three assembly plants, which relied almost exclusively on imported components, to 17 businesses that employ 27 assembly lines manufacturing a range of passenger cars, light commercial vehicles, trucks and buses. The vehicle assembly production continued to grow and reached 101,319 vehicles in 2007, an increasing percentage of approximately 118% from 2003 with over 360 factories manufacturing automotive components. When comparing data from the Egyptian Automotive Manufacturers Association (EAMA) it indicated that the total number of vehicles demanded in Egyptian auto market increased from 70,834 units in 2003 to 227,488 units in 2007 and this number is expected to have increased. This increase is more that 200% in five years (Harraz and Galal, 2011). The recent growths in the automotive industries are connected to the financing schemes made available by vehicle distributors and banks. Nevertheless, old cars are usually not abandoned, but rather sold on a second hand market to continue its use stage. These data are presented based on the report published by the information and decision support centre, 2007; to provide an idea of the structure of the Egyptian vehicular fleet (Harraz and Galal, 2011). More than a quarter of the currently registered vehicles are more than 30 years of age, indicating that the registration of the new cars does not mean deregistration of the old cars. The latter continues its circulation through another owner. The previous value also demonstrates the elevated amount of generated pollution. Private cars constitute approximately half of the number of all vehicles. Report credited to the Ministry of Interior Affairs, 26.4% of the circulating cars are older than 30 years and 25% are manufactured in the period between 1980s and 1990s. These numbers indicate the amount of pollution caused by operating these vehicles, in addition the report showed that 36.1% of the all the vehicles are located in the large cities.

Attempts to control the environmental hazards are not enough; ELVs practices exist but are scattered and unsystematic. At present, such practices are limited to scattered small sized workshops and scrap yards. Figure 7 depicts the ELV route in this category. The arrows represent the material flow through the network. Money flow goes in the opposite direction of materials. Unlike other industrialized countries, Egypt does not implement the export option of ELVs, due to fact that most of the industrialized countries set very high standards for circulation of used cars. Used cars in developing countries do not meet such standards due to the excessive usage of cars. Unlike in the EU where the lifespan of a vehicle is estimated to last 10 to 14 years, some developing countries use cars for nearly twice that period. Another problem faced by developing countries is the lack of regulation concerning the ELV treatment

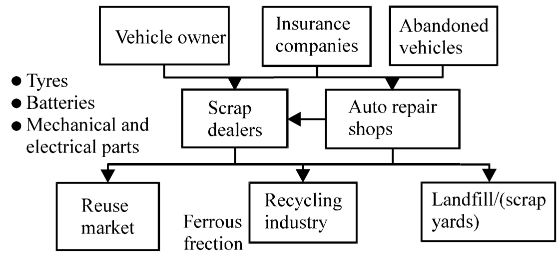

Fig. 7: Typical ELV path in Egypt (Harraz and Galal, 2011)

operation in their own countries, which requires control to meet the objective of decreasing environmental burdens caused by vehicles.

People retain their old vehicles due to limited resources, despite the high operating cost, inefficiency in fuel consumption and traffic problems. The implementation of ELV management requires consideration of the ELV owner hence, the criticality of the government role. On one hand, old vehicles cause the increased environmental burden and traffic congestion, while on the other hand ELV owners and dismantlers have conflicting interests. In other to promote ELV, a reasonable amount of profitability must be safeguarded to engage automotive manufacturers in ELV practices in Egypt. Furthermore, the study of the management of such a recovery network is vitally necessary to assure economic profitability and social benefits of different stakeholders, in addition to environmental preservation.

ELV management in Malaysia: Though Malaysia is the largest producer of automobiles in South East Asia, the National Automotive Policy has not dealt with the environmental impact of the development of the automotive industry. To date, directives or legislation on ELV for the automotive industry have not been established. In the EU and other countries, such the directive is considered as a driver factor for the establishment of an environmentally conscious automotive industry. As this industry develops, its impact on the environment also increases. The life of vehicles is between 10 and 15 years, after which, they enter the retired phase. In Malaysia, cars as old as 25 and even 30 years remain on the roads (Amelia *et al*., 2009b). However, the issue in this study is how to deal with wastes from retired vehicles. In other countries, several vehicle manufacturers have developed an end-of-life recovery program, such as reuse, remanufacturing and recycling. For example, Volvo Genuine Exchange Parts System, a remanufacturing program established in 1945 by the Volvo Cars Industry accounts for approximately 13% of the total spare parts turnover (Volvo., 2008). The concept of reuse is still new in the local automotive industry. Automotive manufacturers and the Department of Environment in other countries should adhere to the ELV policies.

CONCLUSION

A review of ELV design protocols and management was investigated. The following is a summary of conclusions:

- Based on the current environmental awareness, meeting the directive on ELV reuses, recycling and recovery target is possible with the existing organizational system. However, in 2015 a trend that will require many of the objective and more determined. At present, the technology is insufficient and uneconomical, especially in the developing and even in industrialized countries. Thus, meeting these targets is likely to require substantial cost, research and developments on areas such as design concepts, technology and restructuring of reuse infrastructure
- The fundamental problem with recycling ELVs is that the vehicles were not originally designed for recycling. This problem may be addressed by incorporating recycling purposes during the design stage. Vehicle manufacturers must then continue to consider reuse, remanufacturing and recycling into the design of new vehicles
- To improve recyclability of ELVs, require a highly efficient strategy with full commitment from the involved in ELV management
- A monitoring system is necessary to track the progress of the ELV directive
- The stakeholders involved must come together to share the cost of the development of new technology and to promote recycling infrastructure development and research
- Investment in infrastructure and building on existing infrastructure is essential to achieve the goal of recyclability
- Uses for recovered materials must be developed
- Dismantling is labour intensive and thus improving its efficiency would help make material and component recovery more economical
- Many component parts in the vehicle development process require further development especially in the early stage of the design process to increase the efficiency of recycling

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