International Journal of Engineering & Technology, 7 (3.17) (2018) 163-170

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

End-of-Life Product Recovery Chain Planning and Future Research Needs

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Abstract

Nowadays, there is a significant increase in the productivity of the automotive industry with a variety of vehicle types and models being produced constantly. This in turn, leads to problems with end-of-life vehicle (ELV) management. Even though ELV management occurs at the end of the vehicle life cycle, the design stage plays a pivotal role to ensure the effectiveness of ELV management. Although the relevant parties involved strive to manage and improve ELV recovery by careful design planning using various modelling tools, there are still several issues that need to be addressed such as development of a reliable recovery infrastructure, implementation of ELV recovery policies as well as extended producer responsibility issues. In addition, there is a need for information sharing and collaboration from all stakeholders in the ELV recovery chain due to the fact that many factors are interrelated and subjected to dynamic changes. For this reason, predicting how end-of-life (EOL) strategies affects the effectiveness of ELV recovery is an arduous task, particularly in an export-dependent nation such as Malaysia. In this study, we propose a model that offers a more holistic view of ELV recovery in Malaysia using the system dynamics approach. Our model is developed based on the current scenario of the automotive industry in Malaysia. We believe that our model will facilitate product designers in incorporating EOL strategies during the early stages of product design and development.

Keywords: *Automotive; Conceptual model; End-of-life vehicle management; Extended producer responsibility; Malaysia.*

1. Introduction

All products used by consumers will reach a stage where the products will not function efficiently and therefore, they will be disposed. This means that the product has reached its end of life (EOL). In the automotive industry, vehicles that have reached this stage are known as end-of-life vehicles (ELVs). ELVs are among the major wastes stated in the European Economic Community Directive (75/442/EEC) [1] and for this reason, vehicle manufacturers play a vital role in recovering ELVs. ELV recovery is currently a mandatory practice in member countries of the European Union, as stated in the Directive 2000/53/EC [2]. It is highlighted in this directive that 85 and 95% of ELVs should be reused, recovered and recycled by 2006 and 2015, respectively. However, at present, only European countries are close to achieving this target, with an ELV reuse, recovery and recycling rate of 80% [3]. Malaysia is still lagging far behind in this regard [4]. Reusing, recovering and recycling ELVs is challenging in many countries (including Malaysia) due to various issues such as economies of scale [5], policies [6], lack of knowledge [7] and poor infrastructure [8].

Even though a number of studies (see Table 1) have been carried out to improve ELV management, most of the techniques proposed in these studies do not provide satisfactory solutions since they neglect dynamic changes such as market trends and governing policies. These studies indicate that ELV modelling is progressing well in developed nations, but such is not the case in Malaysia. There is a lack of information regarding ELV management in Malaysia, which is exacerbated by recurring changes in policies that lead to further confusion. As the automotive industry in Malaysia continues to grow with the opening of both regional and global markets through the ASEAN Free Trade Area (AFTA) and Trans Pacific Partnership Free Trade Agreement (TPPA), there is a critical need to establish a model for ELV management in Malaysia. This model will enable manufacturers to plan and predict the ELV viability of their vehicles with respect to changing market trends and policies both internally and externally. In this regard, the aim of our study is to propose a system dynamics model of the ELV recovery chain in Malaysia in order to develop design improvement strategies. We believe that this tool will be useful to support vehicle manufacturers in Malaysia, particularly during the design planning stage.

2. Literature review

The literature review is focused on design strategies, end-of-life (EOL) strategies, the current situation of ELV management in Malaysia, and the existing approaches on product recovery strategies. These topics are discussed in detail in the following sections.

2.1. Design Strategies

There are many designs for X (DFX) strategies available such as design for assembly, design for compliance, design for disassembly, design for manufacturability, design for material logistics and component applicability, design for reliability, design for serviceability and design for testability [9]. According to these researchers, design for environment (DFE) is a part of DFX and it is strategy which takes into account the environmental impact of the product throughout its life cycle from the pre-manufacturing stage to the aftermarket stage.

[10] introduced a new strategy in 1994, which is known as design for EOL product article. Following this, [11] developed a reverse fishbone diagram to be used with the design for product retirement strategy. However, this tool is limited to the designers' information. Three years ater, [12] conducted a survey on the key product characteristics that influence EOL strategies and the results showed that "wear-out life" and "technology cycle" are important in determining EOL strategies. [13] used the design for inverse manufacturing strategy to minimize resource consumption and the amount of wastes and emissions, while maintaining company profits and the quality of life of the individuals throughout the product life cycle. [14] developed a design for recycling tool to evaluate various design options in order to optimize the performance of parts at the end of their life cycle. [15] implemented the design for remanufacturing strategy in order to optimize the remanufacturing process by minimizing the time for disassembly and reassembly.

Design for product disassembly is another strategy used to ensure that the product can be disassembled with minimum cost and effort [16]. [17] determined end of life hair clip components value analysis by evaluated disassembly and recycling level. This analysis provided benefits to designers to improve components accessibility and material can be recycled at the end of lifespan. This statement is supported by [18] whereas single material used is significant to improve material recycling rates and easy to dissembled.

Numerous studies have been carried out to promote a sustainable product life cycle, especially at the end of the product life cycle (i.e. [19; 20; 21; 22; 23; 24; 25; 26; 27; 28; and 29]). [16] defined this strategy as design for revalorization, which consists of design for product recovery, design for product disassembly and design for recyclability principles with the aim of preventing the products from becoming wastes. Thus, the effectiveness of the ELV management process depends on how the product is designed during the early stage of the product life cycle by incorporating DFX strategies.

2.2. EOL Strategies

There are many end-of-life (EOL) strategies currently available which include reuse, remanufacturing and recycling. [30] and [31] provide an excellent treatment of these strategies. [32] defines reuse as a good component after disassembly. However, [33] interprets reuse as a process of using a functional component from a retired assembly. In contrast, remanufacturing involves restoring the product to its original new condition through several processes ([32; 33; and 34]). Lastly, according to [32; 33; and 35], recycling involves reprocessing recyclable materials through several activities such as shredding, separating and smelting so that the material can be used for its original purpose or for different purposes [31]. A number of EOL recovery strategies have been studied by previous researchers ([36; 37; 38; 39; 40; 41; and 42]) however, only reuse, remanufacturing and recycling will be discussed in the following sections.

2.2.1. Reuse

Reuse plays an important role in job creation [43], cost reduction [44] and minimizing downtime [45]. [46] reuse is a highly prioritized recovery option for EOL products compared to remanufacturing and recycling.

2.2.2. Remanufacturing

According to [32], the three primary factors that drive remanufacturing are: (1) ecology, (2) legislation and (3) economics. Unlike [46], [47] perceived that remanufacturing is a more effective EOL strategy in terms of profits. In general, reducing the total cost is of utmost importance in a company in order to promote sustainability [13]. According to [48], strategic decision-making is critically dependent on remanufacturing cost and the cost of remanufactured products is only 50% of that for new products [49]. Remanufacturing cost plays a vital role in competing with new products produced by original equipment manufacturers. Furthermore, remanufacturing is a better EOL strategy compared to other strategies because this process yields the highest residual value for used products. In addition, remanufacturing reduces land use as well as toxicity to humans due to the significant reduction in the amount of harmful wastes ([50; and 43]). However, remanufacturing is influenced by other factors which include government incentives, technological drivers as well as market [49]. It is proven in a previous study that remanufacturing is one of the EOL strategies used to reduce costs such as collection costs, dismantling costs, labour cost and etc. However, there is a need to investigate remanufacturing strategies which take into account uncertainties and holistic view such as timing of returns, quantity of returns and materials recovered, especially in production planning and control in the industry [51; 52; and 53].

2.2.3. Recycling

According to [13], recycling is not an optimum solution to reduce wastes and natural resource consumption due to fluctuations in the price of recycled materials and the inferior quality of recycled materials compared with raw materials. Moreover, recycling does not contribute towards energy savings. Unlike [13], the following researchers ([46; 47; 54; and 43]) perceived that recycling is the best EOL strategy compared to reuse and remanufacturing. However, based on a financial perspective, resale or reuse is the best EOL strategy, followed by remanufacturing and recycling [54]. A number of studies have been carried out over the years on recycling strategies which include material efficiency ([55; 56], recycling policies ([5; 57]), recycling legislation [58] and recycling infrastructure [59]. However, there are no priority-based approaches available for design for recycling strategies because recycling systems are generally dependent on the infrastructure of local recyclers [14].

In brief, strategic planning and management of product recovery is important in order to incorporate EOL strategies into the product. Selecting an appropriate EOL strategy is dependent on various factors such as the product design features, EOL product recovery network, existing policies as well as the availability of infrastructures for recovery of EOL products. This is further complicated by the fact that these factors are country-specific. The degree of success in implementing EOL product recovery is dependent on design strategies to a certain extent and therefore, it is imperative for designers to incorporate EOL strategies during different stages of product design and development. Designers can either incorporate a single EOL strategy (e.g. reuse, remanufacturing or recycling) or even multiple EOL strategies.

2.3. Current Scenario of ELV Management in Malaysia

The agricultural sector, mining and quarrying sector, Manufacturing, Construction and Services and manufacturing industry are source of income in Gross Domestic Product. In 1983, Malaysia started Perusahaan Otomobil Nasional (National Automobile Company), the first national automobile manufacturer, was established in Malaysia. Proton Saga was commercially launched into the automotive market a couple of years after the inception of PROTON, and it is the first car model manufactured by this company [60]. A second national mobile manufacturer was established in Malaysia in 1993, namely, Perusahaan Otomobil Kedua Sdn. Bhd. (PERODUA) [61]. It was estimated that an average of 441,377 vehicles were manufactured from 1980 to 2015, inclusive of passenger cars, commercial vehicles and four-wheel drive vehicles [62]. The current statistics indicate that there is an increase in the number of car registrations by 30.28% in 2015 relative to 2010. With the increasing number of vehicles every year, it is more crucial than ever for a proper ELV management system in Malaysia. There are a number of areas in which ELV management can be improved in Malaysia and one of them is to address the barriers that hinder the success of ELV management, which will be discussed in the following section. At present, the Government of Malaysia is working to enhance the effectiveness ELV recovery by implementing the National Automotive Policy, which came into effect in 2006.

2.3.1. Barriers in ELV Management

Even though the number of vehicles produced and registered are increasing, there is no specific statistical data of ELVs in Malaysia and ELV management networks chain to collect ELVs [63]. ELV recycling practices in Malaysia, it can be reasonably assumed that there are no auto dismantling companies and auto waste shredders in the process flow of recycling ELVs [64] and [65], as shown in Figure 1. A total of 5,000 used parts are imported per month and most of these parts are imported from Japan whereas new non-genuine parts are imported from China and Taiwan [4; 62]. It is evident from Figure 1 that there is a lack of proper ELV management system in Malaysia, as indicated by the red dotted lines. In addition, there are no exact figures on the number of ELVs recovered in Malaysia [66]. Based on the findings of this study, it can be deduced that the recyclers in Malaysia do not comply with environmental regulations or guidelines since engine coolants are discharged freely into drains whereas air-conditioning gases are released into the environment without restrictions.

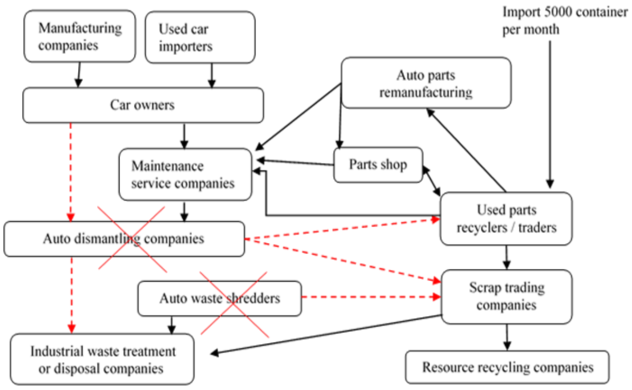

Fig. 1: Process flow for ELV recycling in Malaysia

According to [7], manufacturers in Malaysia typically use new parts when manufacturing new products due to a lack of proper knowledge in implementing eco-design [67]. In addition, most of the respondents who participated in the survey perceived that eco-design requires high capital investment without any positive impact on the environment. A recent study has also shown that local companies are not primarily concerned about design for environment and design for disassembly as important strategies to reduce environmental impact [38]. Apart from the lack of knowledge in ELV management, there are other challenges in ELV management such as organizational and business environment, societal influence, technological availability, existing regulations and policies from the government, financial constraints, and lack of support from suppliers [6]. The National Automotive Policy is continuously improved to tackle the above-mentioned issues.

2.3.2. National Automotive Policy (Nap)

The Malaysia Automotive Institute (MAI) is a government agency established three decades ago in order to formulate policies in the transportation sector which encompass automobiles, coaches and buses, light transport vehicles, trucks and containers, and railway coaches [68]. The National Automotive Policy was introduced in 2006 to promote a sustainable domestic automotive industry, especially for national car manufacturers, in line with the European Union Directive. The ELV management program was launched on November 2016 [69], which is known as 4R2S. The term “4R” stands for repair, reuse, recycle and remanufacture, whereas the term “2S” stands for service and spare parts [70; 71]. Even though there are many challenges in implementing the 4R2S program, this is one of the first initiatives implemented by the Government of Malaysia to improve ELV recovery.
The effectiveness of an ELV management system depends on how the product is designed during the early stages of product design and development, and how the product affects recovery effectiveness. This is due to the fact that an EOL strategy is dependent on the product design features. The requirements stipulated in the European Union Directive should be taken into consideration in order to boost the effectiveness of ELV recovery in Malaysia. This can be accomplished by introducing 4R2S strategies among the key stakeholders of ELV management such as remanufacturers, service centers and second-hand automotive spare part dealers one step at a time.

2.4. Existing Approaches on Product Recovery Strategies

There are various approaches proposed by researchers to improve product recovery strategies such as multi-objective optimization techniques, multi-criteria analysis techniques, simulation techniques and qualitative assessments, as summarized in Table 1.

Table 1: Summary of published works on product recovery strategies

Approach	Description	Conclusions and recommendations for future works	Ref.
GA	The authors proposed an optimum material selection strategy in order to achieve a lightweight design for an automotive body assembly taking into account recyclability characteristics.	The authors recommended that other design aspects such as product structure and manufacturability should be integrated with the material selection strategy.	[55]
	The authors performed optimization of an assembly and disassembly sequence.	-	[72]

	The authors performed optimization of a disassembly sequence.	The authors recommended the use of Generator software to validate the results	[45]
	The authors developed a new genetic algorithm and design for recycling software tool for dismantling strategies.	-	[14]
GP and GA	The authors analyzed the effect of product design parameters on the environmental impact of the product.	The authors proposed that there is a need to investigate the effect of other factors (besides product design parameters) on the environmental impact of the product.	[73]
IP	The authors analyzed the best EOL options for parts in order to enhance EOL product recovery.	The authors suggested there is a need to determine the best EOL options of parts in terms of the recovery cost and recovery quality.	[74]
MILP	The authors analyzed the economic value of ELV wastes in order to minimize the harmful effect of ELVs on the environment by reducing the volume of landfill wastes.	The authors highlighted that there is a need to examine the forward and reverse activities of the CLSC. In addition, cost analysis needs to be carried out.	[75]
IPCCP	The authors developed an IPCCP model for EOL product management.	The authors proposed to use a mixed integer programming approach for ELV management.	[76]
FL	The authors examined a number of EOL strategies for retired product components based on the perspective of designers coupled with the dimensions of economic, environment and social	-	[43]
DEMATEL and FEAHP	The authors analyzed sustainability characteristics in order to evaluate a number of alternatives for ELV management.	The authors recommended that data collection should be carried out from multiple sources.	[54]
LCA	The authors analyzed recycling route concerns for EOL products.	-	[21]
	The authors evaluated the environmental impact of ELV recycling process.	The authors proposed to use an automatic dismantling and sorting process.	[77]
LCI, LCA, LCC, MAUT	The authors analyzed the environmental and economic impact of finished products throughout the product life cycle.	The authors suggested that social impact should be evaluated based on a metric approach.	[78]
LCA, QFDE, TRIZ	The authors explored effective environmentally conscious product designs.	The authors highlighted that the methodology needs to be verified including the steps after evaluation of the product concepts. The authors recommended that there is a need for a quantitative evaluation regarding the impact of environmentally conscious product designs on the consumers as well as environment. The authors also recommended to use a computerized methodology.	[37]
HOQ, LCA, LCC	The authors examined the environmental aspects of product development in terms of costs and consumer preferences.	-	[79]
TOPSIS	The authors analyzed the EOL scenarios of a product during the early stages of product design.	-	[50]
SD	The authors evaluated the impact of ecological factors and ecological innovations on the long-term behavior of a closed-loop supply chain with recycling activities.	The authors suggested that there is a need to investigate the impact of the product pricing and profits on environmental management.	[5]
	The authors developed a policy decision tool in order to facilitate stakeholders in the automotive recycling sector to compare policy options.	The authors proposed that there is a need to develop a model for other sectors of the industry such as connections and scrap sales.	[57]
	The authors examined the impact of policies on recycling and remanufacturing industries.	The authors proposed that there is a need to examine various forms of subsidies and the amount of the subsidy given to the remanufacturers and consumers. In addition, the authors highlighted that there is a need to identify the best combination of subsidy policies based on a certain budget allocation.	[80]
	The authors proposed a model to examine the behavior of automobile recycling infrastructure.	-	[59]
	The authors studied the impact of pricing, design and promotion decisions on the revenue of refurbishers, recyclers and manufacturers of new products.	The authors proposed that there is a need for public policies as well as incentives to reward companies that meet these benchmark.	[81]
	The authors investigated the relationship between reduce, reuse and disposal in the car market.	The authors proposed that government tax should be imposed on car exports.	[82]
SD and LCA	The authors proposed an integrated approach based on SD and LCA for green supply chain design.	The authors proposed to combine the completion date policy and customer location policy in order to achieve optimal results.	[83]

Note: GA: Genetic algorithm; GP: Goal programming; IP: Integer programming; MILP: Mixed integer linear programming; IPCCP: Interval-parameter chance-constraint programming; FL: Fuzzy logic; DEMATEL: Decision-making trial and evaluation laboratory; FEAHP: Fuzzy extended analytic hierarchy process; LCA: Life cycle assessment; LCI: Life cycle inventory; LCCA: Life cycle cost analysis; MAUT: Multi-attribute utility theory; QFDE: Quality function deployment for environment; TRIZ: Theory of inventive problem solving; HOQ:House-of-Quality ; TOPSIS: Technique for order performance by similarity to ideal solution; SD: System dynamics; CLSC: Closed-loop supply chain.

It is apparent from Table 1 that most of the studies on product recovery are primarily focused on the product life cycle. Based on the information in this table, it can be deduced that:

1. There is a need to incorporate EOL strategies into the early stages of product design and development since the product design features will affect recovery effectiveness of the product at its end of life.
2. There is a need to collect data from the key stakeholders of the ELV recovery system.
3. It is essential to identify the factors that influence the effectiveness of the ELV recovery system in Malaysia.
4. It is crucial to develop a computerized methodology for the ELV recovery system. Even though this is not a necessity, a computerized methodology is certainly advantageous.

These key points are important to bridge the gaps on ELV management within a Malaysian context. In addition, there is a critical need for a more holistic research in this area.

3. Application of System Dynamics in Product Recovery

System dynamics (SD) was invented by Jay Wright Forrester to simulate and gain insight on the behaviour of social systems, as well as design effective policies to improve system performance. SD is an interdisciplinary approach that is centred on understanding the behaviour of complex systems using non-linear dynamics and feedback control theories [84]. SD is used to solve dynamic problems, examine the interrelated factors that affect the system performance, as well as evaluate the cause and effect of systems that are inherently complex such as product recovery systems.

SD has been implemented to solve problems in various fields and some of them are indicated in Table 1. [82] developed an SD model consisting of 27 parameters in forward logistics and reverse logistics. The results showed that levying tax on used car exports offers a means of con-trolling car exports to a certain extent. In addition, the results showed that levying tax boosts economic opportunities for manufacturers, remanufacturers, recyclers, consumers as well as the Government of Japan.

[5] studied the different stages of the product life cycle in the electronic equipment industry in Greece. They developed an SD model to evaluate the effects of various policy options. The results showed that green image factors remain up to 250 weeks and these factors decline gradually after this period. The authors highlighted that there is a need to develop policies for take-back obligations, implement proper collection campaigns, and green image in or-der to improve the environmental impact of electronic equipment.

[57] used the SD approach to evaluate automotive recycling activities. They studied the causal loops and scenarios for ELV sourcing from an economic perspective and the results showed that auto recyclers and operators who are willing to make changes are able to remain longer in the business.

In general, SD is a powerful tool to examine the behaviour of complex systems and it offers a more holistic view of the design strategies and supply chains, as well as policy and economic impact of product recovery systems (i.e. [85]; [86]; [87]). Hence, in this study, we propose the factors that influence the effectiveness of EOL product recovery in Malaysia using the SD approach. We limit the scope of our study to the automotive industry in Malaysia and therefore, our focus is on ELVs. We also develop an initial causal loop diagram that shows how these factors relate to one another and how these factors influence re-covery effectiveness.

4. Proposed Framework

The main focus of our model is to evaluate how various design strategies (specifically design for environment, design for reuse, design for remanufacturing and design for recycling) affects the effectiveness of ELV recovery. In this model, we examine the critical factors that influence the effectiveness of ELV recovery based on the perspective of designers, remanufacturers, recyclers, second-hand automotive spare part dealers and policy makers in Malaysia, and these factors are summarized in the form of a causal loop diagram, as shown in Figure 2. The definition of each term is presented in Table 2.

Table 2: The factors that influence the effectiveness of ELV recovery in Malaysia proposed in our study.

Proposed factor	Definition of term	Ref.
Ownership transaction	This process involves returning a product by the last owner into the EOL product recovery network.	[88]
Life of spare parts	This refers to the product life cycle.	[89]
Remanufacturer	This refers to a firm that conducts remanufacturing activities. The remanufacturer can either be the original equipment manufacturer or a third-party remanufacturer.	[82;80; 32]
Remanufactured product	This refers to a used product that is restored to its original new condition through a series of processes which include dismantling the product, performing diagnostic tests to detect defects and faults, and replacing parts that are either obsolete or defective beyond repair.	[90]
Value of spare parts	This reflects how the spare parts bring benefits to the customers.	[14]
Collection of parts	This process involves collecting EOL parts from the end users.	[91]
Second-hand automotive spare part dealers	This refers to the people who collect second-hand automotive spare parts from the end users or internal suppliers.	[92;57]
Volume of second-hand automotive spare parts	This refers to the total number of second-hand automotive spare parts collected.	[81;57]
Competition	This refers to competition between second-hand (used) products and new products.	[91]
Demand for original products	This refers to the customer demand for products manufactured by the original equipment manufacturers.	[5]
Raw material use	This refers to the extraction of raw materials from the earth.	[5]
Energy use	This refers to the amount of energy consumed during the production process to transform raw materials into finished goods.	[93]
Material efficiency	This refers to the consumption of materials with zero or minimum wastes.	[82]
Renewable materials	This refers to alternative materials that can be used in replacement of the original materials, and these materials are replenishable.	[5]
Use of recovered materials	This refers to the consumption of green products.	[94;78]
Formal recycling centre	This refers to a legal recycling centre with knowledge and capabilities regarding the management of EOL products.	[89]
Recycling activities	These activities involve collecting recyclable items.	[89]
Recycling management	This refers to availability of recycling infrastructures in EOL product networks.	[5]
Recovery effectiveness	This parameter indicates the percentage level of reuse, remanufacturing and recycling EOL products.	[14;94]
Designer awareness	This involves promoting awareness among consumer demands for green products by increasing the value of spare parts.	[67]
Design for environment practices	This involves incorporating DFX practices such as design for remanufacturing, design for reuse and design for recycling elements	[5]
Level of reusable parts	This involves measuring the level of reusable parts.	[57]

Demand for reusable parts	This refers to the customer demand for reusable parts.	[57]
Diagnostics	This involves evaluating the product performance through a series of tests.	[32]
Quality	This reflects the product performance after some modifications have been made to the product through remanufacturing activities.	[91]
Appearance of remanufactured products	This represents the physical attributes of the product.	[32]
Demand for remanufactured products	This refers to the customer demand for remanufactured products.	[91]

he initial causal loop diagram (Figure 2) shows how the design strategies (indicated by Box A) implemented by the manufacturer during the early stage of product design affects the effectiveness of ELV recovery (indicated by Box B). Based on this diagram, it is essential to obtain information from all of the key stakeholders of the ELV recovery network to ensure that the model is representative of the real scenario in Malaysia. This will increase the reliability of the SD model to simulate the "cause and effect" of the product design strategies on the effectiveness of ELV recovery. For this reason, we will gather information from industrial experts and other key stakeholders involved in the ELV recovery system in Malaysia. We will attempt to answer the following research questions:

1. What are the factors needed to establish a model for ELV recovery strategies?
2. What is the relationship between these factors in order to enhance the effectiveness of ELV recovery?
3. How do design strategies (specifically design for environment, design for reuse, design for remanufacturing and design for reuse, design for remanufacturing and design for recycling) affect recovery effectiveness?

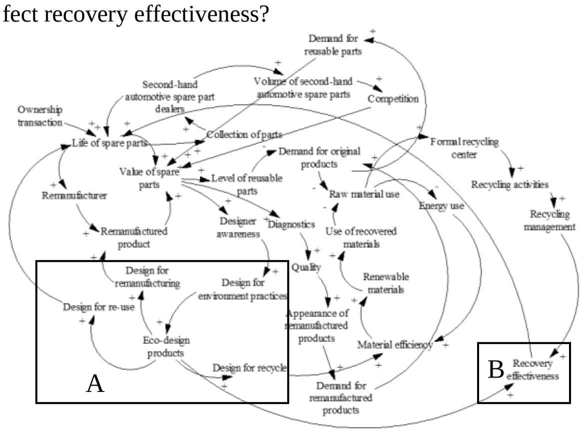

Fig. 2: Initial causal loop for the ELV recovery model

5. Conclusions

With the increasing number of manufactured vehicles and number of registered vehicle owners each year, it is more important than ever to develop an effective ELV management system in Malaysia since ELVs are among the major wastes in developing countries. ELV recovery products is not an easy feat since it involves a variety of variables that are subject to dynamic changes with complex interrelationships. Hence, it is imperative to predict the effectiveness of ELV recovery under such conditions of uncertainty in order to improve the current ELV management scenario in Malaysia.

In this study, we proposed the factors that influence the effectiveness of ELV recovery in Malaysia based on the perspective of the key stakeholders involved in ELV management such as product designers, remanufacturers, recyclers and second-hand automotive spare part dealers. We then developed a model based on the system dynamics approach which will facilitate product designers in analyzing how these factors affect the effectiveness of ELV recovery from a holistic point of view. With this model, product designers are also able to analyze how EOL strategies (specifically design for environment, design for reuse, design for remanufacturing and design for recycling) affect ELV recovery, and these strategies should be incorporated during the early stages of product design and development.

Based on our model, the degree of success of ELV recovery in Malaysia is largely dependent on information and collaboration from the key stakeholders. At present, there is a critical need for eco-design products in order to minimize wastes at the end of the product life cycle. Indeed, information sharing from the key stakeholders is essential in order to identify the factors that will promote (as well as hinder) the effectiveness of ELV recovery, and this includes EOL design strategies. Product designers can use the valuable information provided by the various key stakeholders in order to design environmentally conscious products which will boost ELV recovery in Malaysia and benefit our nation in the long term.

Acknowledgement

We wish to express our greatest appreciation to University of Malaya for funding this work under the University of Malaya Research Grant Scheme (Grant no.: RP033C-15AET) and Ministry of Education Malaysia under the Fundamental Research Grant Scheme (Project no.:FP0592016. We also wish to extend our appreciation to Malaysia Automotive Institute (MAI) for giving their full cooperation as well as to the stakeholders who participated in this study for their valuable time and effort.

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