End-of-Life Vehicle Directive: A Key Element to the Vehicle Design Process

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Abstract: Nowadays, industrial countries are faced with the consequence of a wide diffusion of consumer goods and shortening of product lifetime, giving rise to an increasing quantity of used products being discarded. This phenomenon will increase the problem of the disposal of used products, with the capacity of landfill sites quickly reducing. Current legislation in many developed countries is increasingly guided by the originator principle, which means that anyone who inflicts harm on the environment should pay for cleaning up the damage and, in turn, will compel manufacturers to undertake efforts of recycling at the end-of-life of their products. This has huge implications on the end-user, the manufacturer and recyclers. As such, environmental issues should be accountable throughout the whole life cycle of a product, i.e. it's design, manufacture, use, service and it's end-of-life. Indeed, it is becoming increasingly important that considerations are given to the disassembly of a product that can allow complete material recycling, along with possible part and subassembly reuse. Hence, this paper discusses the impact of the End-of-Life Vehicle (ELV) Directive in the current environment. It summarises the current literature published in the field. In particular, the implication ELV has on current product design practice is explored. The result of the literature review shows that, in order to successfully implement the concept of ELV, the aspects of disassembly, recycling and environment must be considered more rigorously in the vehicle design process.
Key words: End-of-Life Vehicle, Vehicle Design Process, ELVs Directive, Automotive Industry

1. INTRODUCTION

The level of competition is intensifying as the business environment shifts from being national to global. As manufactured products have become more global, the competitive pressures from multi-national companies have increased substantially. This increase in competition, as evidenced by the growing presence of European, United States and Asian products in the Malaysia market, has often focussed on developing new and improved products to meet specific requirement or legislation besides the customers' needs.

In any case global competition and new concepts of vehicle design, manufacture and assembly are forcing changes in the nature of vehicle design. Also the effect on end of life vehicles (ELVs) recyclability has yet to become apparent, since current vehicles have an expected lifespan of 10 to 15 years.

Currently, there are around 10 million motor vehicles every year that reach the end of their useful lives. This may be due to accident damage, test failure or anything rendering them uneconomical to repair. This situation can equate to a million tonnes of material to be recovered or disposed. So, in the early 1990's the European Union, USA and several other countries identified end of life vehicles (ELVs) as a priority waste stream and a Directive was introduced to reduce the amount of this residue going to landfill (Chatterley, 2002).

Generally, design and assembly are the main activities of vehicle manufacturing. The consideration of recycling at the early stage of vehicle design can make the system more complicated. In addition with introducing many technological innovations and increased interaction between vehicle manufacturers, part or component producers and materials suppliers, there is a real need for careful design management.

Based on that, the current requirement for automotive industries is that they not only produce a vehicle for the purpose of customer's satisfaction but they also have to develop a vehicle to fulfil the recycling requirements.

2. LITERATURE REVIEW

2.1 Vehicle Design Process

The success of automotive companies depends on their ability to identify the customers' needs and also current requirements in the automotive world. Besides that, to quickly respond to produce a vehicle that meet these needs and produce at low cost are the main goals of the automotive companies. Achieving these goals is not solely a design problem or a manufacturing problem or a marketing problem; it is a product development problem involving all of these functions.

According to Fox (1993), the product development process is the set of activities beginning with the perception of a market opportunity and ending in the delivery of a product to the customers with consideration of the end of life situation. The activity of providing product features varies widely.

In relation to that, there are several methods that have been proposed. The difference is in the way each manufacturer utilises and adapts the process based on their technical experience and available resources. Based on the literature study there are a lot of concepts that have been developed in order to cope with the current demand for products. It is not specifically for the vehicles but it can be applied to the vehicle design and development process. The benefits of implementing the right concept in the vehicle developing process are to reduce the costs, give a shorter time to market and increase quality.

Krishnan (1994) stated that the traditional product development process is of the sequential type in which the product goes through recognition of need, design, analysis, manufacturing and sales. Basically, this concept is not suitable for the current industrial environment (including automotive) because this sequential process of decision making results in increased costs and is time consuming through the duplication of engineering effort, mostly through redesign in order to achieve the requirements. Most of the requirements of the product need fast decisions in order to become competitive in the market and also the life cycle of the product getting short. Where a short product life cycle means it has to reach the market quickly to be competitive.

Based on that, the evolution of an idea into a new product generally consists of major steps leading to a final product design that is released for unrestricted sales and full production. These steps comprise the development for the product (Thomas, 1997). Note that although this guideline is a sequential process, in practice the stages may sometimes overlap. Depending on the nature of the development project and the issues encountered, there may be times when the next stage is started before the prior one is completed especially in the design and development of a complex product such as a vehicle. Several elements need to be considered from the concept design to the end of life situation. As much of the determination as possible has to be clarified at the beginning of the design process.

The Ford Motor Company proposed a new concept of vehicle development process, called 'The Ford Product Development System' (FPDS) (Nevins and Winner, 1999). It was launched in January 1995 as part of the Ford 2000 plan with an aim to reengineer the vehicle development system and also to improve all of Ford's practice especially in quality, cost and time to market. It is a cross-functional process that involves all Ford's activities and suppliers. Team events and milestones are defined to communicate progress at various points throughout the vehicle development process through the incorporation of new computer assisted design/manufacturing/engineering processes within Ford and linked to its suppliers.

The vehicle design and development system introduced by the Manufacturing Feasibility Group of the Chrysler Corporation is slightly different (Brunnermeier and Martin, 1999). It is called Whitney's vehicle design and development process. It consists of three stages; Concept Design, Product Design and Process or Factory Design. The vehicle development process is more sophisticated because it requires multiple iteration between phases and among activities within each phase. Besides that, feedback loops require an efficient exchange of information between phases.

The design process proposed by Dieter (Dieter, 2000) consists of three phases with eight steps process. The three main phases are conceptual design, embodiment design and detail design. Conceptual design is the phase which requires the greatest creativity and coordination among many functions in the business organisation such as identification of customer needs, problem definition, gathering information, conceptualisation, concept selection, refinement of the product development system and design review. Meanwhile, embodiment design is the phase in which, a structured development of the design concept takes place. At this time, all the decisions are made such as strength, material selection, size, shape and spatial compatibility. It is concerned with three major tasks; product architecture, configuration design and parametric design. Lastly, detail design is the phase during which design is brought to the stage of a complete engineering description. It includes dimension, tolerances, materials, manufacturing processes and all the drawings such as part drawings and assembly drawings.

Currently, the Institute for Innovation and Design in Engineering (IIDE) at Texas A&M University proposed a new innovation about the product development process for general products (Karuppoor et al., 2002). It called IIDE design process. This concept incorporates methods and techniques from a variety of sources to provide a cohesive approach to the design process.

As a summary, with the trend toward green design, vehicle manufacturers are faced with the challenge of improving vehicle recyclability while reducing product cost and increasing the value at end of life. To cope with these challenges, the vehicle design and development process has to be integrated with disassembly and the recycling consideration.

2.2 End of Life Vehicle

Every product goes through a cycle from birth, into an initial growth stage, into a relatively a stable period and finally into a declining state that eventually ends in the death of the product as shown in Figure 1. Based on that figure, in the product introduction phase, the market is uncertain and it may not be profitable to the company. This situation happens again at the end of life phase. The company cannot avoid this situation because it is natural for every product. The only way to reduce this effect is to reduce the time frame for that particular stage through the implementation of the Life Cycle Analysis concept.

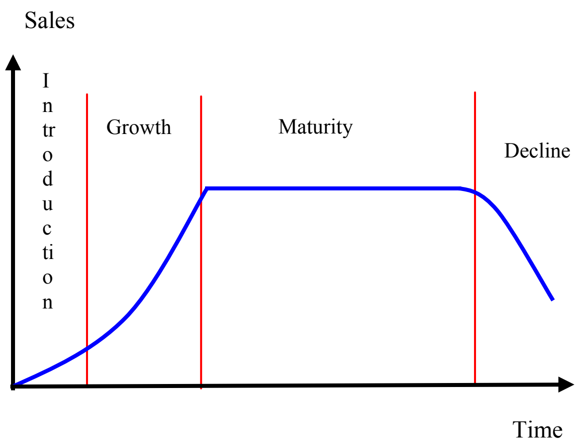

Figure 1: Product life cycle (Dieter, 2000)

In relation to that, Westkempter et al. (2001) proposed the Life Cycle Management (LCM) and assessment approaches towards sustainable manufacturing. This concept will be considered in the design phase of the product. In general, LCM is an organisation concept to ensure the interaction of the design, manufacturing and life cycle activities achieve the maximum benefit for each technical product (Alting and Legarth, 1995). All the activities must consider the factors of environment, regulation and standard.

In this LCM concept, the principal stages of the product life cycle are design, manufacturing, reuse or recycling. To maximise the product performance in every stages of its life cycle, proper methodologies are needed. This is what is called 'towards sustainable development'. According to the World Commission on Environment and Development (1987), sustainable development is a concept that meets the needs of the present without compromising the ability of future generations to meet their own needs.

In 2005, the World Commission on Environment and Development launched a new strategy for sustainable development with more focus on environmental aspects such as recycling, reuse, climate change and natural resources protection (Sustainable Development, 2005). Basically, it is focussed upon the entire life of products. Also, currently the environmental focus in industry has shifted from processes to products and their life cycles. The demands for environmentally friendly products and also recycling and reuse of products are dramatically increasing.

As a summary, the element of life cycle design concept is very important in the new era of manufacturing. Furthermore, the implementation of the new regulations such as environmental protection, waste management, take back responsibility etc., have influence in the designing of new products. There are strong reasons to change the emphasis of the product development process. The concept of life cycle design must be taken into account at the early stage of a product's design.

2.3 Legislation Consideration

Currently, most of the developed countries have set new legislation, which is planned to force vehicle manufacturers to recover and recycle their products at the end of their life. For example, a new directive for European Union (EU) countries which became effective in April 2002 compels governments to enforce the responsible disposal of vehicles that have come to the end of their life (Table 1).

Year	Event
2000 (September 2000)	EU Directive on ELVs was signed by the European Parliament and Council of Ministers
2002 (7/1/2002)	Free of charge take back of new vehicles
2003 (7/1/2003)	Use of certain heavy metals forbidden: Cd, Cr(VI), Hg, Pb
2005 (1/1/2005)	Type approval: OEMs have to prove that vehicle meets 2015 recycling or recovery quotas
2006 (1/1/2006)	Dismantlers have to meet following quotas: $\geq$ 80% recycling, $\leq$5% energy recovery, $\leq$15% landfill
2007 (1/1/2007)	Free of charge take back of all ELVs
2015 (1/1/2015)	Dismantlers have to meet following quotas: $\geq$ 85% recycling, $\leq$10% energy recovery, $\leq$5% landfill

Table 1: Summarised of the ELV Directive on (Directive 2000/53/EC, 2000)

Although it is a few years away from being fully implemented, the ELV Directive is already weighing heavily on the mind of most vehicle manufacturers in Europe. The first stage was introduced on 18 September 2000 to reduce the proportion of ELVs content going to landfill and then a second stage in October 2002. There are up to 10 million vehicles a year in the EU reach the ends of their first useful life.

The introduction of the directive will affect all players involved in the management of ELVs in terms operational strategy, infrastructure and financial investment. The whole structure of automotive recycling is expected to change. The directive has resulted in major investment in research and development, especially in areas of recyclability and investigation into new techniques and technology for disassembly and recycling.

3. KEY ELEMENTS FOR VEHGICLE DESIGN PROCESS IN THE CURRENT SITUATION

Based on the several papers published in the field of end of life vehicle, there are four main end-of-life requirements that vehicle designers have to consider during the vehicle design and development process; design consideration, material used, economic aspect and directive requirements.

3.1 Design Consideration

According to Erkki Liikanen (Kimberley and Glover, 2004), the Commissioner with responsibility for enterprise policy for BMW, it is essential for the vehicle manufacturers to incorporate the recycling aspect at the early development stage in producing new vehicles. This is in order to demonstrate its commitment to producing more environmental friendly vehicles, to protect the environment and to fulfil the ELV Directive even if this results in increased production costs.

It is clear that design consideration is a main element in the ELVs concept. Design decisions on the part of vehicle designers can make automotive recycling a safer and more efficient process by eliminating the presence of hazardous substances. It also can make them more easily dismantled and enable components to be remanufactured several times. This later aspect is because the various vehicle parts can be recycled in a closed-loop. Closed-loop recycling is a concept where a product is remanufactured into the same type of product without the addition of any first-use materials. In this case, Alting and Jorgensen (Alting and Jorgensen, 1993) was the first to introduce the recycling concept within a life cycle design concept. This concept is an integration between design need, design development, distribution, usage and also disposal and recycling. These are considered simultaneously at each stage of the design process.

Vujosevic et al. (1995) suggested the procedures and methodologies for product design that can be easily disassembled. These procedures and methodologies are for the identification of disassembly sequence, animation of human technicians in performing the disassembly sequences, tool selection, time and cost analysis at the early stages of the mechanical system design. It is in the form of a computer based system. Every component will be evaluated on feasibility based on the following requirements,

- the disassembly sequence satisfies time and cost requirements
- access can be gained to any component or subassembly to be removed
- human technicians are able to carry out a disassembly activity that requires a certain level of human strength

It is hoped that design for recycling, dismantling and environment are becoming an essential aspect of modern automotive industry and their consideration has become a more important element in the vehicle design and development process.

3.2 Material Used

Nowadays, the accelerating change in materials composition, for example the increasing of the fraction of plastic and aluminium, of modern vehicle can create new problems in the recycling process of ELVs. Recycling of plastic is very difficult when it is present in small parts or attached to another material. Similarly, recycling of aluminium is not straightforward because it is normally present in the form of alloys. Based on that scenario, material choice is one of the key elements in vehicle design in order to make the concept of ELVs successfully implemented. This is basically because the different materials have different techniques for disassembly and recycling.

In relation to that, several researchers have studied the material aspect especially plastics to ensure that the ELVs concept is met. Plastic contributes around 9% of the weight of an ELV and this is increasing as vehicle manufacturers continue to develop lightweight vehicles to improve fuel efficiency (DTI Report, 2003). The recycling rate of plastics needs to be improved because most of the plastic material from an ELV arises at the shredder as shredder fluff. Furthermore, the plastic materials are very difficult to extract for recycling unless they can be removed prior to shredding but this normally is costly unless easy removal is part of the original design.

Mercedes Magazine (Spring 2002), reported that they have taken over 18 months to analyse thousands of processes, components and materials relating to the end of life situation especially to reduce the impact on the environment. They started the process at the extraction and transportation of the new materials to the subsequent processes used to produce steel, aluminium, plastic and the vehicle components. For instance, they considered the use of lightweight materials (eg. aluminium or magnesium) for energy consumption used in manufacture and the potential of vehicle fuel saving. The production of aluminium from alumina using low emission energy sources (eg. natural gas) can make a significant environmental contribution.

However, the situation for glass is more dismal than that for rubber. The majority of the glass is sent to landfill. This situation has happened because the removal of the glass is time consuming and it has little value except when its can be sold as a spare part. Furthermore, according to a CARE report (CARE Report, 2003) 15 vehicles per hour need to be processed in order to cover the removal costs, which are not feasible using current methods.

Bell et al. (2002) studied the environmental aspects of the use of carbon fibre composites for vehicle components. Currently, there is no commercial recycling technology available for the composite materials. Traditionally, carbon fibre composites tend to use epoxy resins that are very difficult to recycle. Several methods were employed to characterise different qualities of recovered fibres. The result shows that the recovered fibre shows similar properties to the virgin fibres. This gives an indication that the recovered fibres have potential for reuse as partial or full replacement of virgin carbon fibre.

It is clear that the right material selection for the vehicle components is an important aspect in order to meet the current requirements of vehicle design. The use of recycled materials is increasingly important as product take back and producer responsibility legislation are implemented.

3.3 Economic Aspect

Currently, vehicle disassembly and recycling were became to be of high ecological and economic important. To comply with the increasingly tightening automotive recycling legislation and to make the automotive recycling business economically competitive, the process has to be automated to the highest possible extent (Tzafestas et al, 1997).

Rose and Evans (1993), pointed out the long term economic benefits of products' Design for Recycling can be assessed by total life cycle cost. These benefits are represented by the higher post-purchase value, which might have been hidden by a higher pre-purchase cost. Pre-purchase cost is given by material, manufacture and assembly costs. Meanwhile, post-purchase value can be obtained by subtracting all recycling cost.

Design changes are a major problem in this issue especially in order to cope with the ELVs requirements. Swift et al. (1997) stated that design is the key to ensure that product will fulfil the fixed requirements such as customer needs, specification, cost and quality in every stage of a product's life cycle. In this case, ELV requirements need to be properly considered at the early stage of vehicle design to ensure that recycling is profitable.

3.4 Directive Requirements

The new movement for improved vehicle recycling has its origin in the ELV Directive. This Directive was devised mainly to avoid the vehicle crisis and motivated by environmental consciousness. Design decisions on vehicle manufacturing are steered by this Directive to areas such as the use of environmentally friendly materials and also to design vehicles with reuse, remanufacturing and recycling in mind.

Basically, there are many legislative agencies in the world such as the Environmental Protection Agency in USA, the Ministry for International Trade and Industry in Japan and also the European Union Council.

4. CONCLUSION

The study shows that there is potential to improve the vehicle design process by establish a new methodology with consideration of the elements of environment, disassembly, recycling and financial decisions.

The Ford Product Development System seem to be complete design methodologies based on the current situation except for having no financial element. It is beneficial to the automotive industries if the proposed design methodology can consider the financial decisions for ELVs. This element has become important to the automotive industries with the implementation of the free take back obligation of end of life vehicles by vehicle manufacturers. They can make decision either to set up their own recycling facilities or send the end of life vehicles to dismantlers or recyclers.

In relation to that, there is a strong need for a systematic vehicle design and development process in order to fulfil the ELV Directive that will be fully implemented in 2015. This design tool could provide assistance in making decisions at the early stage of the vehicle design and development process in order to avoid the costs and time consumed through later redesign. There needs to be a fast and correct decision in order to remain competitive in the market.

Based on the current situation, it will be possible to meet the ELV Directive reuse, recycling and recovery targets by 2006 with the existing organisational systems; however, the Directive sets more ambitious targets for 2015. The technology is insufficient and uneconomical at present. Meeting this target is likely to require significant costs and research and development in areas such as design concept, technology, automotive shredder residue and restructuring of infrastructure.

Overcoming the challenges to improve the recyclability of end of life vehicles will requires a carefully planned strategy with full dedication from the key players involved in ELVs management. A monitoring system must be developed to track the Directive's progress. The actors involved must come together to share the cost of the development of new technology and to promote recycling infrastructure development. Vehicle manufacturers must continue to incorporate reuse, remanufacturing and recycling into the design of new vehicles. Uses for recovered materials must be developed. Investment in infrastructure and building on existing infrastructure is essential to achieve the recyclability goal.

It can be concluded that several elements in the vehicle development process need to be further developed especially in the early stage of the process in order to increase the efficiency of the recycling process.

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