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THE DFEL VALUE METHODOLOGY: A TOOL FOR DESIGN-FOR-ENVIRONMENT IN AUTOMOTIVE INDUSTRY

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ABSTRACT

In the early 1990's the European Union (EU) identified end-of-life vehicles as a priority waste stream and the EU Directive was introduced to protect the environment. Automotive companies are being pushed by environmental awareness and legislation to recycle, remanufacture and reuse components at the end of life and also to reduce the quantity of manufacturing waste generated. Within this scenario, a design tool is needed for vehicle design processes. Besides that, the role of design in modern manufacturing is becoming even more important with companies adopting design tools as profit generating business elements. Based on this requirement, the need was identified for a new methodology to analyse vehicles when they reach end-of-life situation especially in terms of design assessment and recyclability assessment. The aim of this paper is to give a description of the proposed tool for Design- for-End of Life Value (DFEL Value) in order to fulfil those requirements. There are two methodologies that facilitate the development of the DFEL Value concept; Recycling Function Deployment and Value Analysis. These two interrelated methodologies are primarily developed to assist automotive designers to design a vehicle for end-of-life purposes. This paper starts with the description of the methodology for Recycling Function Deployment analysis, followed by methodology for value analysis and lastly, the development of the prototype for DFEL Value. It takes into account the impact of the EU Directive and the solution to enhance the value of end-of-life vehicles. In the development process, several parameters in the product development process have been considered such as material types, joining techniques, product structure, environmental issues, economic consideration and also recycling technologies and facilities. Lastly, the paper presents an example of an automotive rear bumper as a case study in order to demonstrate and validate the proposed methodology.

Keywords: *End-of-life vehicle, vehicle design process, end of life value, environmental aspects, design-for-environment*

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1.0 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 European market, has often focused on developing new and improved products to meet specific requirement or legislation besides the customers' needs.

The average life span of products is also shrinking fast. New technologies, such as CAD, rapid prototyping and tooling are reducing product development times. Customers can therefore be choosier and change their demands more frequently, stimulated and fuelled by whatever product or new idea that has been introduced most recently. It is difficult for those manufacturers who do not move fast enough or worse still, those which stand still in such a rapidly changing marketplace.

Figure 1 demonstrates the leverage effect of the design phase in automotive industry in terms of total product cost. In a market that is increasingly competitive and has consumers who are becoming more demanding of not only quality but also value, companies must have their product right first time.

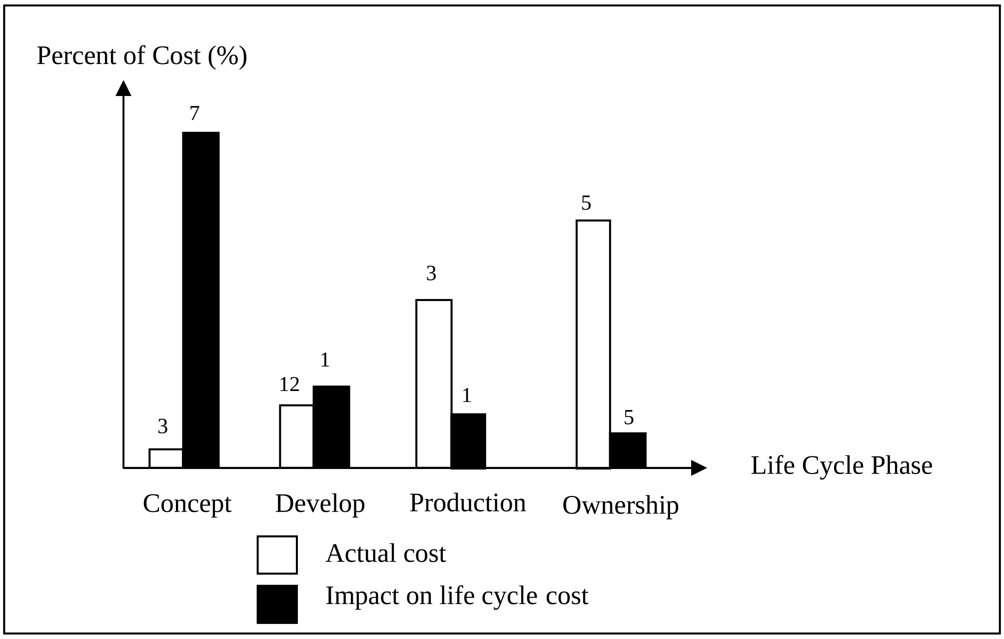


Figure 1: Leverage effect of the design phase on life cycle costs [1]

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 [2].

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. For example, with the use of lighter materials such as aluminium, the material recovery at end-of-life (EOL) is not straightforward because it is normally present in the form of alloys. Similarly, recovery of plastics is notoriously difficult, especially when it is present in small parts or attached to other materials.

Throughout the last two decades the demand for safety, comfort and reduced prices for European vehicles has created a decrease in the use of recyclable materials. This resulted in increasing amounts of automotive shredder residue (ASR), composed of plastics, rubber, glass, textiles and various hazardous substances, which had to be disposed of by land filling. So, in the early 1990's the European Union identified ELVs as a priority waste stream and the EU Directive was introduced to reduce the amount of this residue going to landfill [3].

Currently, there are around 2 million motor vehicles every year that reach the end of their useful lives. This may be due to accident damage, technical failure or anything rendering them uneconomical to repair. This situation can equate to a million tonnes of material to be recovered or disposed.

Because of these situations, the spare parts business has become increasingly popular. Consequently, the recycling industry is moving into a new level of importance. Besides the business point of view, addressing these issues is a sensible way of achieving internal and external environmental and economic goals. 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.

2.0 LITERATURE REVIEW

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

2.1 Design Consideration for ELVs

According to Erkki Liikanen, 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 EU Directive on ELVs, even if this results in increased production costs [4].

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 [5] was the first to introduce the recycling concept within a life cycle design concept. This concept is integration between design need, design development, distribution, usage and also disposal and recycling. These are considered simultaneously at each stage of the design process.

Besides that, the major automotive manufacturing companies have taken proactive steps towards the greening of automotive products by emphasising the reduction of parts, rationalisation of materials and reuse of components. One of them is BMW. BMW have established a Recycling Development Centre (RDC) dedicated to research and development of all aspects of effective vehicle recycling including dismantling methods and techniques. It works closely with the design and engineering departments to ensure that recycling is considered in a practical and cost effective way in the development of a new model of vehicle [6].

Another company is the Saturn Corporation, a subsidiary of General Motors, which is attempting to design a vehicle that is potentially 99% recyclable. This is the major part of their comprehensive research on Design for Environment (DFE) [7].

Various analysis tools in design consideration have been developed to assist and evaluate different aspects of vehicle design. For example, Gupta and Isaacs [8] developed an evaluation methodology that enables a vehicle designer to measure disassembly and recycling potential for different vehicle designs. This methodology's called physical programming. Physical programming is an optimisation technique which operates in the environment of multiple criteria and uses a utility function to represent the decision maker's preference. On the other hand, it is a decision tool to optimise the trade offs between technological and economic feasibility and the degree of environmental detriment.

Vujosevic et al. [9] 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,

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

Meanwhile, Diegmann et al. [10] developed a wiring system concept to support Design for Environment (DFE), Design for Disassembly (DFD) and Design for Recycling (DFR) in order to comply with the EU Directive on ELVs. The different design elements can be realised in a wiring harnesses concept, combining known rules with new ideas. The concept had been applied is using a new hook and loop based fastening system. This system can make a wiring harnesses easier assembly and disassembly, elimination of fixation holes in the vehicle body and lead to considerable cost reductions for the product itself, production, assembly and disassembly.

Currently, there is another problem when considering recycling of modern vehicles especially with increasing the number of airbags. The drastic increase in use of airbags is causing concern in the recycling aspect, whilst obviously improving vehicle safety. This is because of once the airbag was deployed, it cannot be reused anymore and in any event it is difficult to recycle because it contains a pyrotechnic device. This situation can create another problem for the automotive designers in producing the new vehicle that can fulfil the environmentally friendly and safety requirements.

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.

2.2 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. As mentioned before, recycling of plastic is very difficult when it is present in small parts or attached to another material. Similarly, recycling of aluminium is not straight forward 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 [11]. 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.

Selke [12] found that increasing the plastic content makes the component difficult to recycle. The number of plastics used must be reduced; they only can be mixed if they can be separated using current technology. A joining technique should be used that makes the disassembly process simpler and quicker and enables the part to be removed before crushing and shredding. Besides that, plastics must be marked with type and grade to enables rapid identification because this is part of the Directive.

Meanwhile, Singh [13] specifically studied plastic material for vehicle components. The conclusion was that plastic material cannot be completely remade into products with the same quality as the original. It can only be remade into either a lesser grade plastic or mixed with different materials.

BMW evaluated the recyclability of new materials combinations or components for new models at an early stage of the vehicle development process [14]. They identified any special tools that may have to be developed to suit the recycling of the new model. Besides that, they also developed any new joining technology. Using this approach, the materials used can be minimised and the need for material intensive joints reduced.

Mercedes Magazine [15], 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 (e.g. 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 (e.g. natural gas) can make a significant environmental contribution.

The latest finding on vehicle materials reported by Professional Engineer [16], describes the prospect of low cost vehicle components made from powder metal titanium. The cheaper processing of titanium was developed by British Titanium of Cambridge and the Department of Materials Science and Metallurgy at the University of Cambridge, and is called the Fray-Farthing-Chen (FFC) Cambridge Process. Titanium materials can be used for engine valves, turbocharger wheels, front and rear bumper support, drive shafts, exhaust pipes and coil springs. Typically, titanium is as strong as steel but lighter. It can reduce the weight of the vehicle and at the same time reduce the fuel consumption. In additional, titanium can be categorised as a high value material. So, this situation can make ELVs more valuable at EOL.

Another vehicle material that makes a large impact on the environment is rubber for tyres. According to the article from The Times [17], every year in Britain 25 to 30 million tyres are discarded. Only half of these are recycled to used as part worn tyres and as a substitute fuel to other fossil fuels in the generation of electricity, in the production of cement and other thermal industrial processes. It is seen that half of the waste tyres are send to landfill. This is a dismal situation for ELVs.

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 [18] 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. [19] 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.

In relation to that, Nissan Technical Centre, Europe and Lotus Car [20] are investigating alternative composites because of rising steel prices. They found that the use of natural fibres with thermoplastic resins would be easier to separate compared to the use of carbon fibres and thermosetting resins. This can increase the ease of recycling.

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.

2.3 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 [21].

Rose and Evans [22], 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. [23] 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. It would be a simple task to reach 85% to 95% recyclable or recovered material from the current design of vehicle but the situation now is that it is not economical. To recycle plastics and fluids the infrastructure must be in place to achieve the economies of scale needed to compete with virgin materials on cost (environmental and monetary). The environment will not benefit if more resources are used to recycle than when using virgin materials.

2.4 Directive Requirements

The new movement for improved vehicle recycling has its origin in the EU Directive on ELVs [24]. 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 as well as the European Union Council.

Having demonstrated compliance with the Directive, the manufacturer makes a 'declaration of conformity'. In the UK the regulations will be enforced by the trading standards departments of local authorities, with enforcement being complaint driven. Penalties for contravening the regulations include fines and imprisonment and the authorities will have the power to seize and destroy apparatus.

2.5 Review of Design Concept Available

Currently the factors of environmental and recycling will become more important in the vehicle design process. Furthermore, the introduction of the EU Directive on ELVs, means that these two factors are the core of the Directive, and thus cause the vehicle design process to become more complicated. The success of automotive companies depends on their ability to respond to these requirements. Hence, the integration of effective and efficient design methods and tools are the main factors that contribute to producing the vehicles that fulfil the environmental and recycling needs.

Several design methods and tools, such as Pugh's Total Design Concept [25], The Ford Product Development System [26], Whitney's vehicle design and development process [27], the design process proposed by Dieter [28], the IIDE design process [29], Quality Function Deployment [30], Failure Mode and Effect Analysis [31], Design for Manufacturing and Assembly [32], Design for Disassembly [33], Design for Recycling [34] and Design for Environment [35] have been reviewed. The results showed that there is potential to improve the vehicle design and development process by establishing a new methodology with consideration of all the current needs such as environmental, disassembly, recycling and financial.

Pugh's Total Design Concept and The Ford Product Development System consider the environmental and disposal factors but have no financial consideration. However, the design tools provide direction on how the vehicle should be developed in order to achieve certain requirement such as Design for Assembly, to assist the vehicle designers to design a vehicle that can be easy to recover materials and Design for Manufacture will enable vehicle designers to investigate manufacturing processes that are simple and low cost.

Design for Recycling aims to get a better utilisation of vehicle components through of reusing and reprocessing. Design for Disassembly would assist vehicle designers to design a vehicle that is easy to disassemble during the dismantling processes. Meanwhile, Design for Environment is the systematic approach of environmental consideration during the vehicle design process in the context of environmental requirements. The others tools such as Quality Function Deployment and Failure Mode and Effect Analysis can be integrated with the above mentioned design tools in order to produce vehicles that fulfil the current requirements.

As a summary, it is clear that all the elements that have been reviewed are very important aspects in this context, Design for End of Life Value (DFEL Value). This is in order to overcome certain weaknesses of the current methods in order to fulfil the current needs and requirements in the automotive industry especially in the contexts of recycling, environmental, financial and legislation. With the trend to improving vehicle recyclability and value in terms of revenue and cost at end of life, the review shows that there are no methods and tools that can cope with this challenge. As mentioned above, Pugh's Total Design Concept and The Ford Product Development System appeared to be good methods because they considered the end of life situation but unfortunately have no financial consideration. The other design tools considered lack of financial justification especially when that vehicle reaches the end of its useful life. So, this is an opportunity for this project to develop a systematic design tool to cope the problem at end of life for the vehicle.

3.0 DEVELOPMENT OF THE DFEL VALUE METHODOLOGY

3.1 Development of the Methodology

The structure of the DFEL Value methodology is a conceptual approach for integrating recyclability concern at an early product design phase as shown in Figure 2. This approach is intended to provide an organized process that allows designers to identify and understand the recyclability needs and how to measure recyclability during the design process.

3.2 Software Prototype for Design for End of Life Value

The flow chart for the development of software prototype is shown in Figure 3a, Figure 3b and Figure 3c. It shows the detail of the process on how the system works from input data until the decision making process. The system has been designed to make sure that all relevant information such as materials type, assembly techniques and product structure is taken into consideration.

It begins with an investigation of the current design or current requirements for a new design in terms of recycling and environmental aspects. A Recycling Function Requirement (RFD) analysis is then performed to determine the recyclability performance of that particular design. The judgement is based on the absolute revenue and absolute cost from the recycling process. These values will be translated into a ratio to identify which part or component has to be further developed in order to improve the recyclability performance.

For a good vehicle, this will proceed to the Value Analysis, (B) on the flow chart, to determine the value at end of its useful life and Investment Appraisal to determine the defined returns. Meanwhile, for the product which has a potential improvement, this goes to the design improvement stage, (A) on the flow chart. In this stage, there is a mechanism to help vehicle designers improve the product with the right selection of material, right method of joining and better design of component characteristic.

The Design Tool enables a vehicle designer to explore various characteristics in order to get the best combination of all parameters involved in the design assessment and recyclability assessment. Also the results from analysis will give a greater confidence of achieving the specific performance, in particular to fulfil the EU Directive on ELVs requirements.

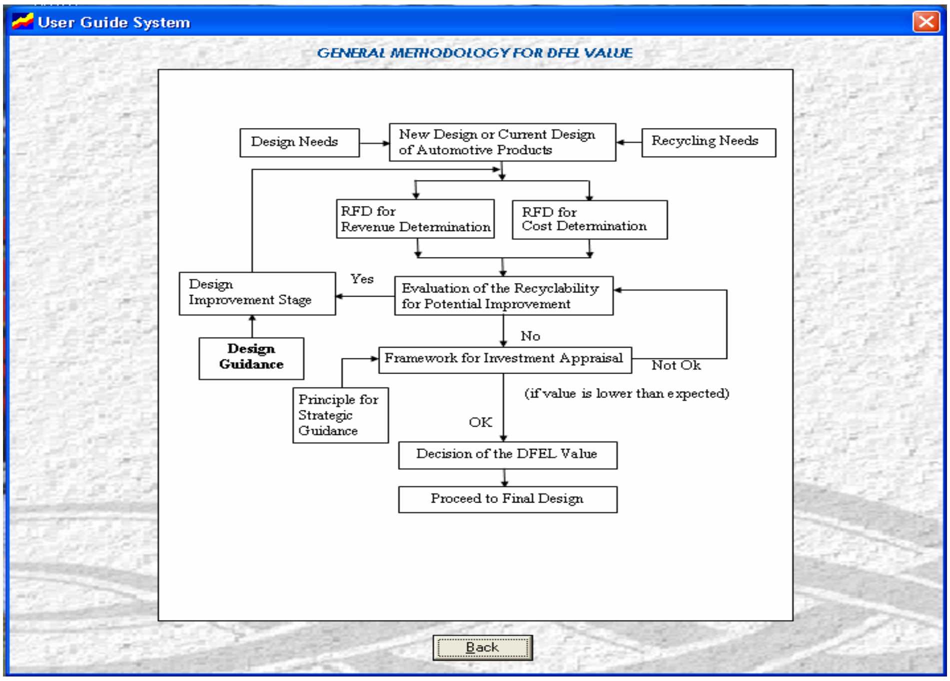


Figure 2: General methodology for DFEL value

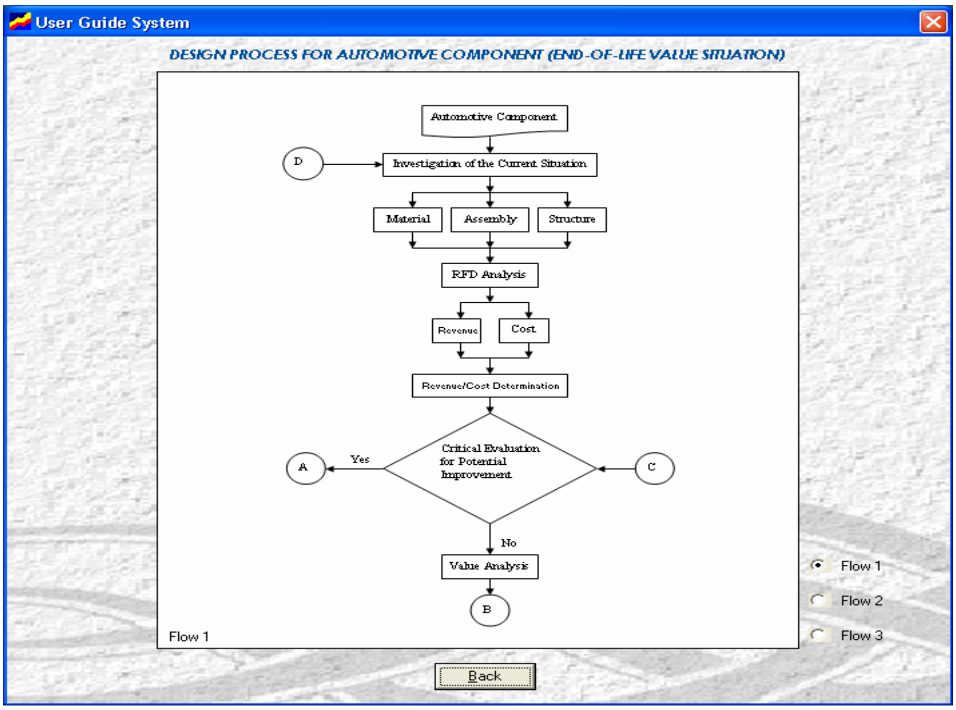


Figure 3a: Software prototype flow chart (continued overleaf)

4.0 CASE STUDY

The rear bumper is for the current Jaguar X100. It consists of five main components; main plate, side mounting, rear mounting, parking distance panel (Parking DP) and foam barrier (Figure 4). This bumper was made from plastic material with the several steel clips and screws. The summary of materials proportion is shown in Table 1.

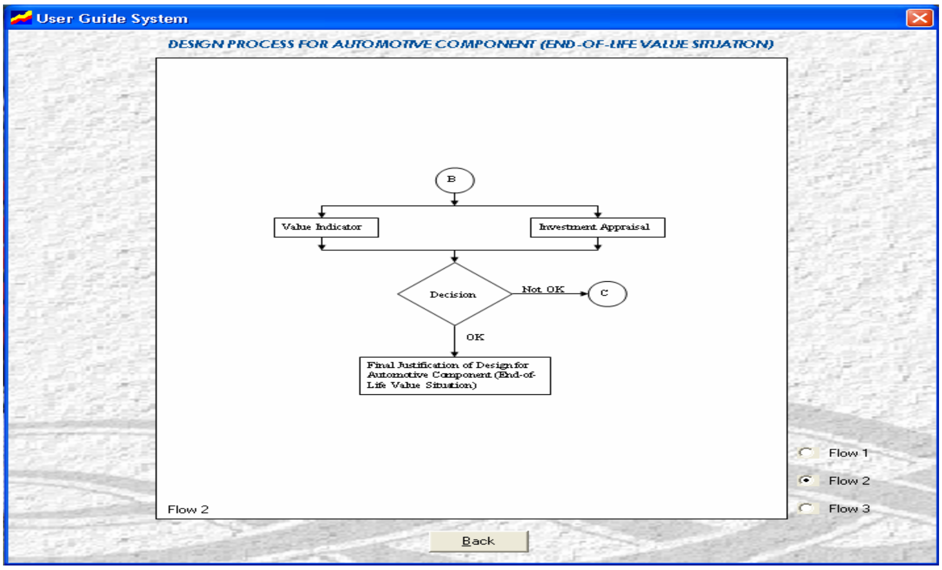


Figure 3b: Software prototype flow chart (continued below)

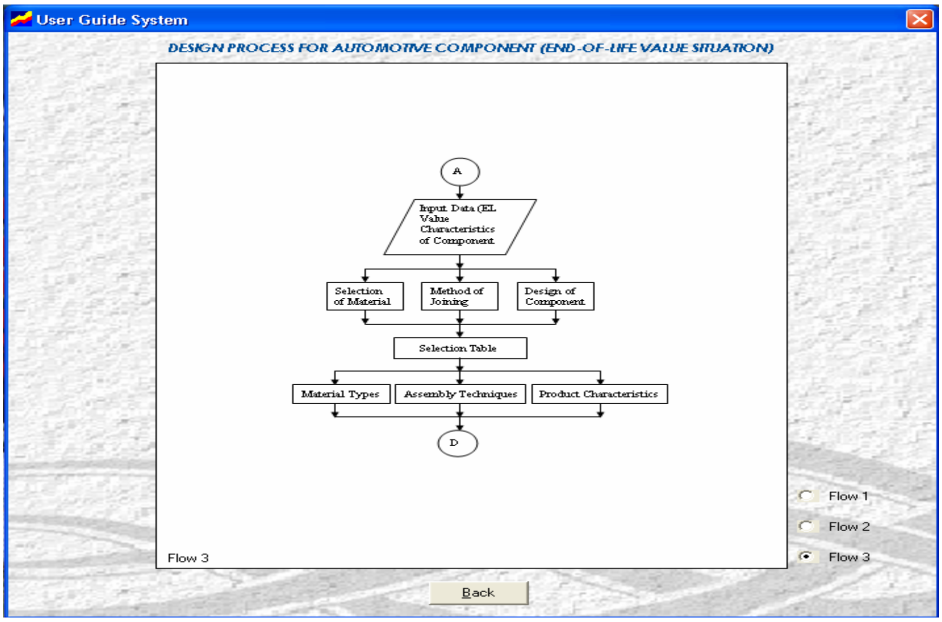


Figure 3c: Software prototype flow chart

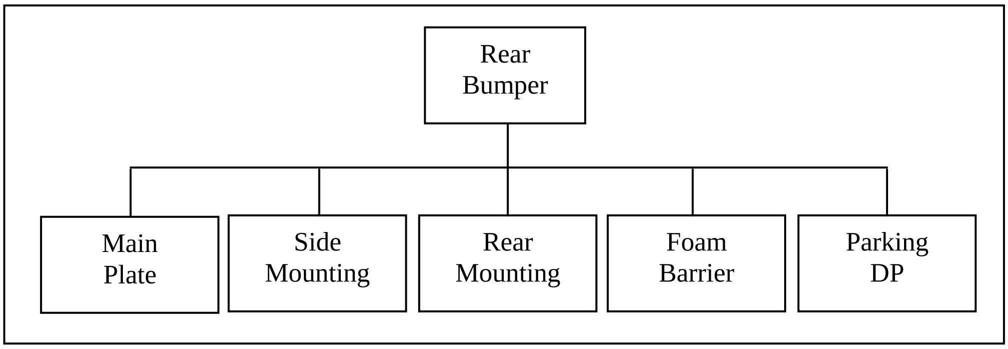


Figure 4: Product structure for rear bumper

Table 1: Proportion of materials for rear bumper

Category of Materials	Weight (kg)
Ferrous	0.507
Plastic	6.495
Low value	0.670
Total weight	7.672

5.0 RESULTS

5.1 Evaluation Study for Design Performance

The evaluation study for design performance is based on the RFD analysis. Based on this analysis, the first study is a revenue determination. The results showed that the income from part or component sales is about 82.0% and income from material sale contributes about 18.0% impact to the current design. These values will be transferred into Level 2 for further analysis.

The components that contribute the highest revenue are the parking distance panel (46.8%) and the main plate (40.4%), followed by side mounting and rear mounting (6.4%) and lastly foam barrier (0%). The parking distance panel can be categorised as a high value component whereas the foam barrier material contributes nothing to the value at EOL.

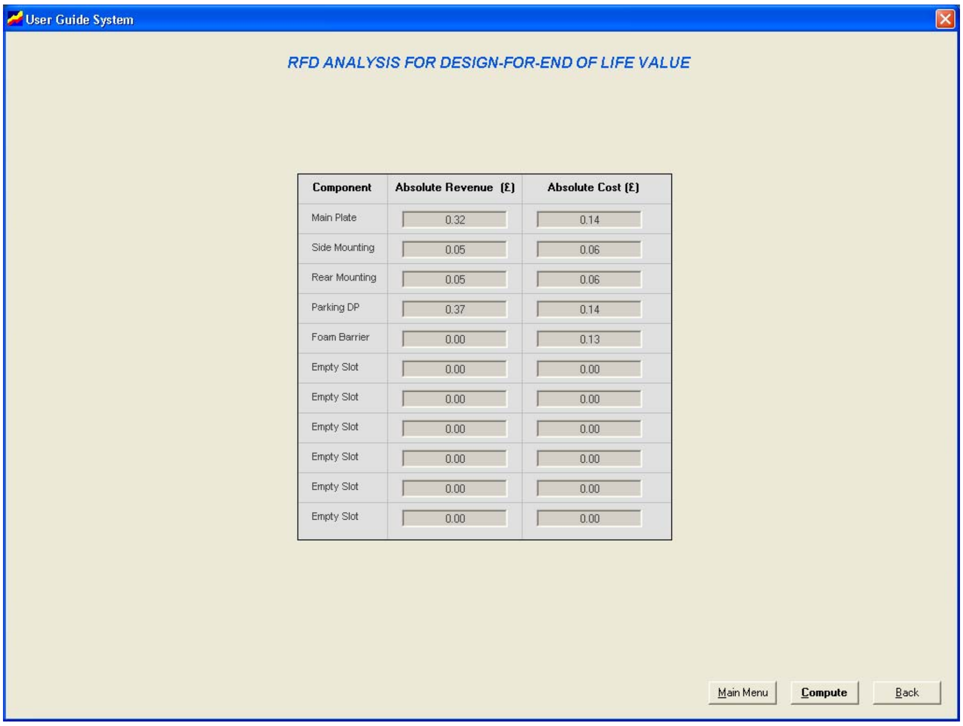
After that the cost determination is performed. The results showed that the disassembly method and handling contribute the highest impact to the cost for recycling process (55.0%). Meanwhile, cost of material reprocessing is about 39.0% and facility is about 6.0%.

Hence the analysis for Level 2, it shows that the highest cost for reprocessing were main plate and parking distance panel (26.2% each) because they require manual disassembly process which is costly. Meanwhile, the foam barrier contributes 24.1% and side mounting and rear mounting, 11.7% each.

Lastly the overall performance results for the recyclability assessment of rear bumper can be determined as shown in Figure 5 and Figure 6. Referring to both figures, there are three components that have ratios lower than one; side mounting, rear mounting and foam barrier. These components need possible improvement in order to improve the recyclability performance. In order to improve these components, the proposed methodology provides the facility to check the weaknesses of the current design and also design advice mechanism.

5.2 Evaluation Study for Financial Appraisal

The rear bumper will be dismantled and categorised into different types of material. It will then be measured based on the weight as shown in Table 1. In this case, the total weight of rear bumper is 7.672 kg i.e. about 0.49% compared to the total weight of the vehicle, 1576 kg.



Component	Absolute Revenue (£)	Absolute Cost (£)
Main Plate	0.32	0.14
Side Mounting	0.05	0.06
Rear Mounting	0.05	0.06
Parking DP	0.37	0.14
Foam Barrier	0.00	0.13
Empty Slot	0.00	0.00
Empty Slot	0.00	0.00
Empty Slot	0.00	0.00
Empty Slot	0.00	0.00
Empty Slot	0.00	0.00
Empty Slot	0.00	0.00

Figure 5: The absolute results for rear bumper

All the basic data and analysis are same with the analysis for front bumper but for this component, there is a dismantling process involved. This is because some of the components can be sold as spare parts. The analysis shows that the return from the dismantling process is £0.41 and also the return for the shredding process gives a loss to the company; -£0.05. This is because of some of the materials are foam and go to landfill as waste. The total return for the whole process is £0.24.

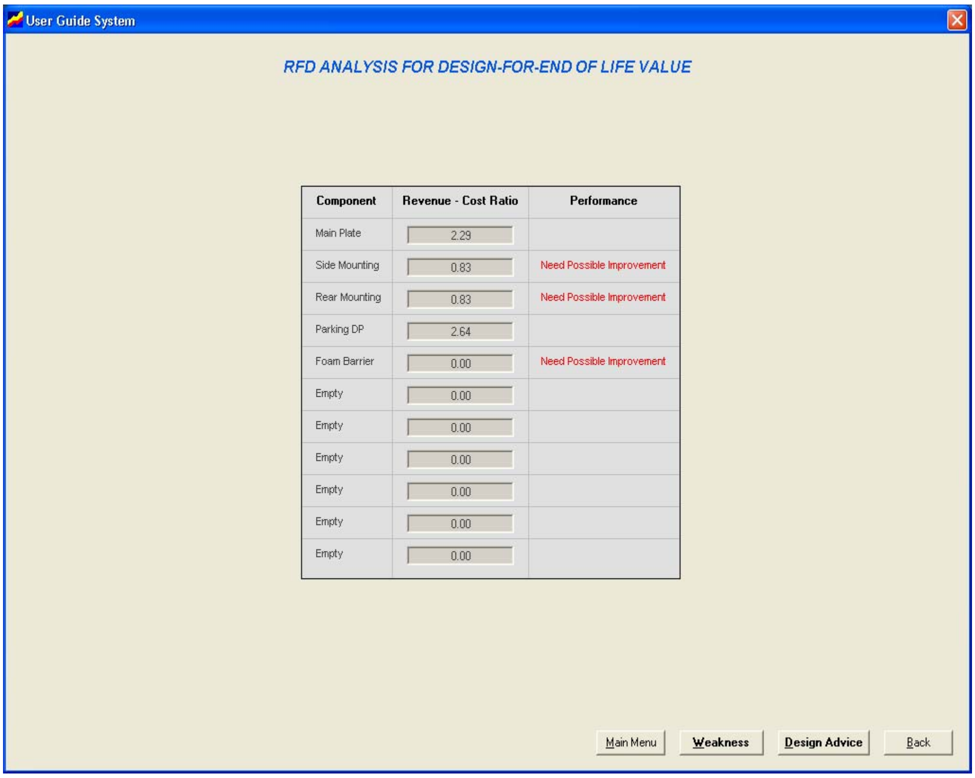


Figure 6: The revenue-cost ratios for recycling of rear bumper

The waste performance in this case is 18.51% which is below standard. This is because of most of the components used, especially plastic and foam, cannot be recycled and most of it becomes waste.

The results from the Value Analysis will then be transferred into the Investment Appraisal. This calculation was based on the quantity of processing 2,054,224 units of rear bumper per year. The return of investment for this case is 6.89 years. It is still out of control because the standard acceptable return of investment is 5 years. But this value can be improved because the system will provide guidance on how the rear bumper should be developed.

6.0 DISCUSSION

The main objective of this paper is to describe the development of methodology of DFEL Value in automotive engineering. The developed methodology focuses on several elements of DFEL Value requirements in order to complete the analysis of ELVs at the early design stage. These elements are design tools, materials, legislative implications, economic parameters and recycling techniques.

This is mainly focused on the methodology for coping with EU Directive on ELVs especially in the areas of environmental issues, disassembly operation and recycling targets. To meet this Directive more successfully, these three factors have to be considered during the designing stage of product development process.

The strength of the proposed design tool is that it will assist vehicle designers to analyse any design more efficiently. It can also provide guidance and justification on how the vehicle components should be developed in order to improve the design with the target to increase the value at end of life. Generally, the proposed design tool will,

a. become a guidance for vehicle designers in the decision making process in order to design the vehicle to fulfil the end of life value requirements.
b. provide a guidance and justification on how the vehicle components should be developed with respect to the component's potential improvement.
c. give an indication of the performance of the current and proposed design of the vehicle in relation to the revenue and cost of recycling processes.
d. provide information to the automotive recycling companies to determine the performance of the financial appraisal of any necessary capital purchase.

In general, a variety of data with the different scenarios is required for the DFEL Value analysis. It is necessary that the data encompasses all aspects for materials types, joining techniques and characteristics of product structure. The fluctuation of quantity of ELVs per year also will affect the overall analysis. So, DFEL Value methodology must incorporate all of these factors in the initial design stage. The designers must gather all this information before starting the design process. The vehicle designers must be aware how sensitive the value at end of life is to these factors. To produce a better design, vehicle designers can evaluate the sensitivity of each factor in terms of revenue and cost. The result of this analysis can give a clear view about the level of influence each factor has on the end of life situation.

Based on the analysis, two important values can be generated. These are value at EOL and also waste generated from the recycling process. Value at EOL is an indicator for the vehicle designers to identify the performance of that particular design and also it can be used as a reference for the improvement in the future. This value also can be used to determine the expected design life. In order to determine this value, the most important factor is the reliance on, and accuracy of, prediction of numbers of ELVs in several years time. It is suggested that this quantity can be successfully predicted by considering the numbers of vehicle based on the first registration. Meanwhile, the waste generated shows in unit weight and then can be converted into percentages. This percentage can be compared with the Directive requirements on percentages of waste in order to identify the area of improvement needed in proposing a new design. Automotive designers can use both values as a judgement of the current design and also for the future improvement.

In additional to this, integration of environmental management strategies gains more and more importance for companies. In order to achieve this, the Strategic Guidance model has been developed as discussed in previous section. This assists vehicle designers to identify the performance of the investment in the recycling areas. Besides that, the Strategic Guidance model also can become an advisory support to the recycling company in order to determine a defined return. The Strategic Guidance model has been developed with a clear flow of what is being considered, together with the specification of all assumptions made and combined with the rationale behind all assumptions. The estimations of all expected costs such as direct and indirect associated with the recycling process are clearly identified. These assumptions and estimations must be regularly reviewed in order to maintain their validity. To establish the Strategic Guidance model, an Investment Appraisal analysis has been formulated. In this process, Payback Period (PP) method has been used as a logical way of making decisions based upon the probable outcome of various scenarios of action. Uncertainty and choice are attributes of every decision made, with the best option aimed at reducing risks and evaluating the cost and revenue implications of a new investment. In calculating the investment appraisal, it assumes that there is 100% utilisation of each facility for the products being analysed. This must be adapted; for instance it is unlikely that a recycling plant will be dedicated to handling just parts or components only from a manufactures specific model.

The ability to assess ‘what if’ situations is a particular strength of the developed methodology. It is integrated with the current practice of design and is dynamic to be able to handle changes in legislation, cost and technology. In this case, the user can key-in any changes of data in order to suit the new requirements.

Generally in the context of a real design situation, the Design for End of Life Value tool is planned for use at the engineering conceptual stage before proceeding to the detail design. It is at the stage where basic design concept is at its final stage and engineering decisions are being made. As mentioned earlier, it is still economical to correct any mistakes at this stage. In other words, it will be applied during the conceptual design stage with consideration of all the aspects at the end of life such as the disassembly system, the material reprocessing system and also the reuse infrastructure system. In relation to that, environment, recycling and disassembly aspects must be considered more rigorously in the early design process. That means all the vehicle components can be assessed at the conceptual design stage. The vehicle designers can identify the performance of any part of the design early in the design process.

In the current situation, the vehicle designers really required a Design for End of Life Value methodology because it can guide them in making decisions in design the vehicle in the context of end of life situation. Besides that, they can explore all design possibilities in the design tool in order to determine the level of influence. The proposed design tool not only provides design decisions to the vehicle designers but also can be exploring to the financial justification that influence these design decisions. It also provides a guidance and advice on how the vehicle should be developed in order to produce a competitive vehicle in the context of end of life value situation.

The proposed DFEL Value methodology is believed to be a useful Design Tool for vehicle designers in achieving a long term vision and also to explore ‘what if’ scenarios that could possibly have an impact on the design that is being developed in order to fulfil the end of life value requirements.

7.0 CONCLUSIONS

This paper has provided the detail outline of the development of a methodology for Design for End of Life Value in automotive engineering. Two main methodologies have been proposed; Recycling Function Deployment (RFD) and Value Analysis. RFD is a method for mapping recycling needs into the product design and development process. Meanwhile, Value Analysis is a method for measurement of design performance in terms of recycling target. Besides that, it provides a tool for measurement of the business performance for investment in the recycling area.

This methodology can provide an organised process that allows designers to identify and understand the recycling needs, how to measure recyclability in the design process and to use it as a design target in the product development process. Based on these two main methodologies, the Design Tool has been developed in the form of a software prototype to assist automotive designers in designing the vehicle for end of life value, checking conformance with legislation and vehicle recyclers in appraising any planned investment in processing facilities. This is the strength of the proposed methodology. It can assist vehicle designers in designing a vehicle and also at the same time it can help automotive company in analysing an investment in recycling facilities if they are interested in this area or maybe for company development in the future to facilitate the concept of 'free of charge take back' as stated in the Directive.

The Design Tool is proposed specifically for use at the primary design stage before proceeding to the detail design. It is shown that there are a lot of potential benefits in introducing the proposed Design Tool especially to overcome the problem in assessing the recyclability aspects.

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