LIFE CYCLE COST EVALUATION FOR ENHANCING DESIGN FOR REUSE

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Abstract

Product recovery strategies such as reuse, remanufacture and recycling requires a cost analysis that covers the entire product life cycle, from the design concept to the recovery and disposal. Life cycle cost estimation provides a framework for identifying the best design alternatives that can satisfy both economics and environmental requirements. This paper presents a life cycle cost analysis (LCCA) on a locally manufactured car door with the aim of enhancing the reusability of the car door. The existing design of the car door was evaluated and some design modifications for ease of disassembly are proposed in view of enhancing reusability and cost. Significant improvements to the design of the car door that satisfy the disassembly and life cycle cost are presented and discussed in this paper.

Keywords: *design for reuse, life cycle cost analysis, disassembly*

Introduction

Environmental consciousness has led many developed countries such as European Union (EU) countries, Japan and Korea to deal with the end of life recovery of their products. Automotive industry is one of the leading industries in this sustainable production. Those countries established the end-of-life vehicles directives to enhance the end-of-life recovery of vehicles. As a result, for example, the average reuse and recycling rate of the end-of-life vehicles (ELVs) in EU in 2006 is 81.8% which is slightly higher than the European Union ELVs directive goal of 80 % for that year [1].Product recovery includes reuse, remanufacture and recycle. Reuse is the highest hierarchy in these product recovery strategies where the products or components at the end-of-life cycle can be directly reused or recovered as components for reassembly with savings in energy, possible emissions, costs related to the productions and in the volume of virgin materials [2]. In order to enable reuse, the product should be designed by taking into consideration the entire product life cycle.

One concept evaluation of the design is Life Cycle Cost Analysis (LCCA) that provides a framework for satisfying both economics and environmental requirements. Fabrycky and Blanchard [3] stated that Life Cycle Cost Analysis (LCCA) or Life Cycle Costing (LCC) is a methodology used to evaluate all the costs associated with a product over its entire life cycle including raw material extraction, processing, product assembly, distribution, use, end-of-life recovery and disposal.

This study aims to enhance reusability of a locally manufactured car door by evaluating life cycle cost of the car door. Some new designs of the car door were generated by taking into account ease of disassembly design. A proposed design concept is evaluated using LCCA approach to determine the best design of the car door for reuse.

Life Cycle Cost Analysis (Lcca)

Cost estimation and control during the design process is necessary in the development of an efficient product. In such case, life cycle cost analysis (LCCA) plays an important role due to the fact that not only production cost, but also all other costs incurred during use and disposal are greatly influenced by the initial design choices. The economic feasibility can only be achieved by evaluating all the cost over the entire life cycle of a product beginning from conception, production, use and retirement phase [2]. According to Giudice et al. [2], a product life cycle costs are decomposed into four categories:

a. Research and development costs, include the costs related to the initial planning of the project, development of the design and evaluation and improvement of the results.
b. Production and distribution costs, include all the costs of product engineering, production

planning, manufacturing, assembly, testing and quality control, and the distribution costs.

c. Operation and support costs, include the cost of utilization and operation on the part of buyer and after sales support (customer service, maintenance, updating).

d. Retirement and disposal costs, include the costs of retiring the product at the end-of-life cycle, recovery of parts, recycling of materials, disposal and waste management.

Methodology

In the first stage, the original design of a locally manufactured car door is evaluated for reusability. A new design concept for reuse is introduced based on the study using the Morphology Chart and Pugh Concept Selection Matrix. In the second stage, a life cycle cost analysis for reuse is introduced. Part of the life cycle cost of the proposed design concept of the car door is evaluated based on LCCA approach. Manufacturing costs of the new design of the car door were determined using DFM Concurrent Costing® software from Boothroyd and Dewhurst Inc.

Results And Discussion

Redesigning of the car door and disassembly time evaluation

The type of fasteners and joining used in the original design of the car door is not appropriate for reuse. In the original design, the door skin is crimped to the door frame at the three sides except the upper side. There are two spot welds on the front side. These crimping and spot welding cause difficulty in removing the door skin from the door frame and may cause damage during disassembly process.

Table 1
Life Cycle Cost Components

No.	Life Cycle Phases	Internal Costs		External Costs
		Producer	User	Society
1.	Research and Development	Market recognition Research Design & Development		
2.	Production and Distribution	Materials, energy, labor Facilities Processing Packaging Transport, storage		Resource depletion Waste Pollution Health damages
3.	Operation and Support	Warranty Service	Materials, energy Maintenance Breakdown	Pollution Health damages
4.	Retirement and Disposal	Disassembly Reprocessing, Recycling Disposal	Recycling or disposal dues	Waste Pollution Health Damages

Source : Giudice et al. [2]

The other part which is the outer window panel is connected to the door frame using both snap fit and screw, while the inner window panel is joined to the door frame using a clip. The choice of those fasteners leads to a longer disassembly time. Therefore, the car door needs to be redesigned to facilitate reuse.

In our previous study [4], five design concepts for reuse were generated and evaluated using the Morphology Chart and Pugh Concept Selection Matrix [5]. From the study, one best design concept for reuse was proposed, whereby the attachment of the door skin to the door frame uses the "tongue and groove" principle. This concept was first proposed by Amezquita et al. [6] and is modified by sliding the door skin from the front side. There are two grooves and two tongues to guide the door skin direction into the door frame (Fig. 1). Bolts and nuts are used to hold the door skin. Three bolts are used to fix the position of the door skin to the door frame. One bolt is used to fasten the door skin to the door sash. This new design will lead to an easier disassembly of the door skin and the door frame and prevent damages during disassembly process as compared to the original design.

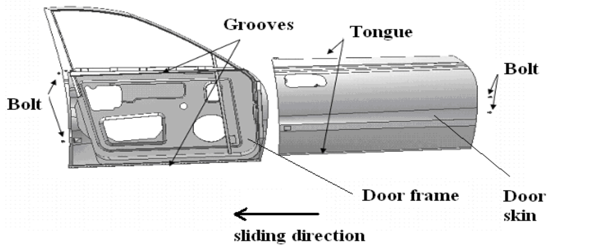

Fig. 1. Tongue and Groove Principle in The New Design

The connection between the door sash and main door panel is maintained using spot welding as in the original design. The door sash is proposed to have a circular edge groove as the circular edge groove does not trap dirt and is easier to be cleaned than a sharp edge groove (Fig. 2).

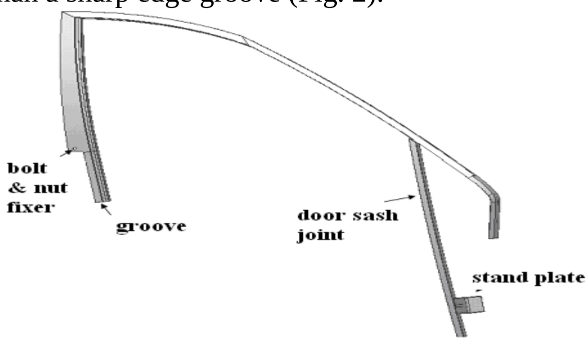

Fig. 2. Door Sash

In the new design, the outer window panel uses snap fits to replace the use of both snap fit and screw in the original design (Fig. 3). It is also proposed that the inner window panel uses snap fits instead of clips. Even though clips are able to hold strongly, it is not easy to disassemble (Fig. 4). Snap fits are easier to disassemble and reassemble than clips.

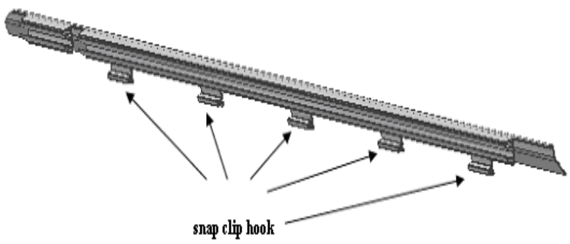

Fig. 3. Outer Window Panel

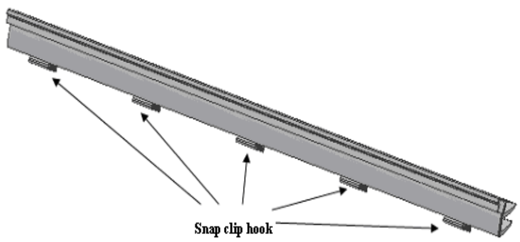

Fig. 4. Inner Window Panel

Life Cycle Cost Evaluation of the New Design

Based on the life cycle concept, the estimated life cycle cost (C_{LC}) incurred by manufacturers includes design and development cost (C_{dev}), manufacturing costs (C_{mfg}), assembly cost (C_{ass}), maintenance cost (C_{maint}) and end-of-life costs (C_{EOL}). Manufacturing cost (C_{mfg}) consists of cost of material and processingcost. Maintenance cost (C_{maint}) includes after sales support costs during warranty period. End-of-life cost (C_{EOL}) consists of cost of recovery (C_{rec}) if the product or component is recovered (reuse, remanufacture or recycle) in the end-of-life cycle and cost of disposal (C_{disp}) such as waste treatment. Equation 1a and 1b presents the life cycle cost and end-of-life cost (C_{EOL}) to the manufacturers as follow:

$$C_{LC} = C_{dev} + C_{mfg} + C_{ass} + C_{maint} + C_{EOL} \quad \text{(1a)}$$

$$C_{EOL} = C_{rec} + C_{disp} \quad \text{(1b)}$$

Due to time limitation, only a part of life cycle cost is analysed and discussed in the current study as such manufacturing cost (C_{mfg}) and end-of-life cost (C_{EOL}). Manufacturing cost (C_{mfg}) of the new design of the car door is estimated using DFM Concurrent Costing software® from Boothroyd & Dewhurst Inc. The estimation of manufacturing cost is based on the new design of the car door for reuse that has been discussed in previous chapter.

Car door components are processed through sheet metal stamping process using progressive die. The material of the car door is similar to the original design which is low carbon steel. There are six components of the car door that have been improved for reuse including door skin, door panel, door sash, door sash connection, inner window panel and outer window panel.

Cost estimation is based on the type of material, dimension, form of design and type of stamping machine. Stamping process cost requires the identification of the area and perimeter of blank, number and area of holes, number of bends and length of bends, number and perimeter of form features. As an example, the new design of the door skin has a length of approximately of 1024.4 mm (40.33 in), width 721.1 mm (28.39 in) and thickness 1 mm (0.039 in). There are five holes with the total area of holes 19832.2 mm^2 (30.74 in^2) and perimeter of holes 751.1 mm (29.57 in). Number of bends is eleven with the length of bends is 5064.76 mm (199.4 in) (Figure 5). The other input data for manufacturing cost estimation includes machine rate, operator rate, operation time, set up rate, set up time, die life, tooling cost and design and manufacture time. Based on interview with the local manufacturer car door, the operator rate is $3/hour, machine rate is $ 61.8/hour, progressive die operation time per door skin part is around 60 s, batch size 500 units, reject 5 % and low carbon steel sheet price is around 0.3 $/lb or $ 0.64/kg. Some design parameters that influence the manufacturing cost of the car door can be seen in Table 2.

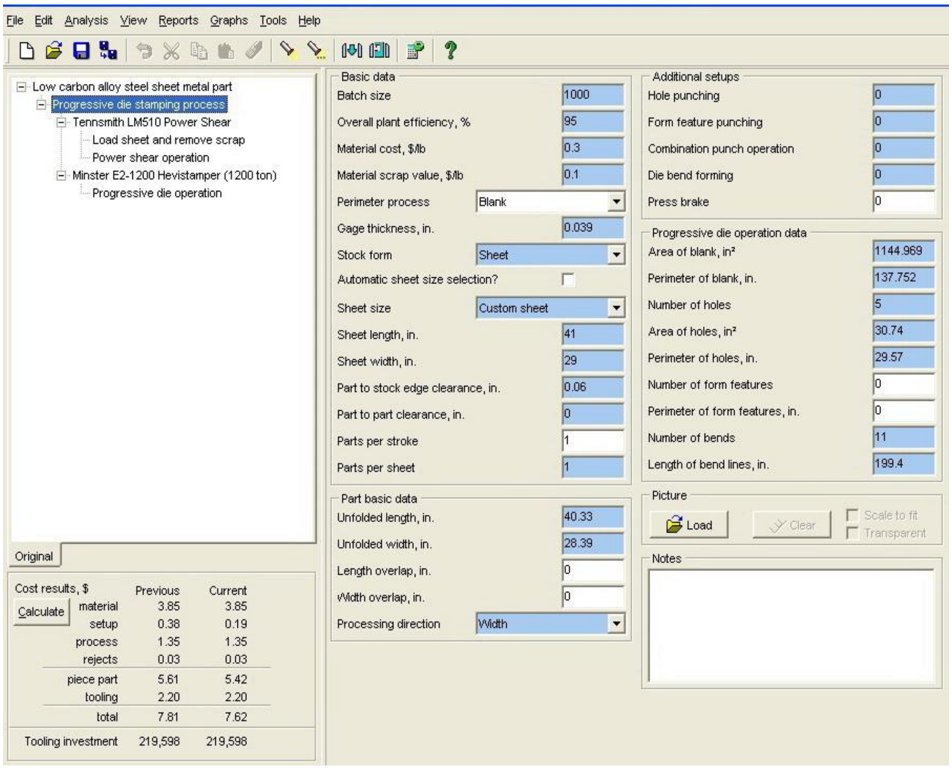

Fig. 5. DFM Concurrent Costing Input Data for Door Dkin

Table 2
Design Form Parameters of Car Door Components for Reuse

No	Part	Material	Dimension (mm)			Blank		Bends		Form features	Holes	
			Length	Width	Thick-ness	Area (sq mm)	Peri-meter (mm)	∑	Length	peri-meter (mm)	Area (sq mm)	Peri-meter (mm)
1.	Door skin	Low carbon steel	1024.4	721.1	1	7.39 x 1e5	3500.1	11	5064.8	-	19832.2	751.1
2.	Door panel	Low carbon steel	1033.8	889.0	1	9.19 x 1e5	3853.2	7	6159.5	4175.8	92386.9	2568
3.	Door sash	Low carbon steel	2115.8	45.7	1	95211.9	4330.7	8	3914.1	-	-	-
4.	Door sash connection	Low carbon steel	659.9	25.4	0.5	16761.3	1374.6	6	3324.9	-	-	-
5.	Inner window panel	Low carbon steel	922.0	86.4	1	79625.6	2024.4	6	2164.1	-	-	-
6.	Outer window panel	Low carbon steel	970.3	58.9	0.5	57174.1	2062.5	14	3975.1	-	4051.6	1171

The estimation results of manufacturing cost (C_{mfg}) of the new car door design are presented in Table 3. Stamping cost consists of material, set up, processing, reject and tooling cost. With the new design for reuse, the total cost of car door stamping is estimated around $ 27.82 for each car door. Door panel stamping cost is the highest which is $ 10.39/part, while stamping cost for door skin is around $ 7.81/part. The other components such as door sash, door sash connection, outer window panel and inner window cost $ 3.28, $ 1.64, $ 2.70 and $ 2.00 each respectively. Set up cost is influenced by batch volume. Processing cost depends on the geometrical design of the car door such as perimeter and area of blank, length of bends, number of holes, area and perimeter of holes and others.

Table 3
DFM Concurrent costing results

No.	Part	Cost per part ($)					
		Material	Set up	Process	Reject	Tooling	Total
1.	Door skin	3.85	0.38	1.35	0.03	2.20	7.81
2.	Door panel	4.67	0.38	1.36	0.04	3.94	10.39
3.	Door sash	0.54	0.19	0.84	0.01	1.71	3.28
4.	Door sash connection	0.06	0.07	0.44	0	1.06	1.64
5.	Outer window panel	0.15	0.19	0.01	0.01	1.60	2.70
6.	Inner window panel	0.42	0.12	0.54	0.01	0.92	2.00
				Total cost ($)			27.82

These stamping costs are manufacturing cost in the first stage of life cycle in which the product is manufactured from virgin materials. Life cycle cost (C_{LC}) in the first stage of life cycle includes manufacturing cost (C_{mfg}), assembly cost (C_{ass}) and end-of-life cost (C_{EOL}) as presented in equation 2.

$C_{LC} = C_{mfg} + C_{ass} + C_{EOL}$ …………..(2)

In the second stage of life cycle, if some components of the car door can be reused, the manufacturing costs of the car door components can be eliminated. Hence, in the second stage of life cycle, the life cycle cost (C_{LC}) is equal to the sum of assembly cost (C_{ass}) and end-of-life cost (equation 3).

$C_{LC} = C_{ass} + C_{EOL}$ …………………(3)

As the car door is redesigned for reuse, in the end of life cycle it will be disassembled after the car door was recollected from the users. Therefore, end-of-life cost (C_{EOL}) is equal to the sum of collection cost ($C_{collect}$) and cost of disassembly (C_{diss}).

$C_{EOL} = C_{rec} = C_{collect} + C_{diss}$ …………(4)

Life cycle cost (C_{LC}) for reuse product become as follow:

$C_{LC} = C_{ass} + C_{EOL}$

$= C_{ass} + C_{collect} + C_{diss}$ …………..(5)

Disassembly cost (C_{diss}) is equal to total disassembly time (t_{diss}) multiplied by labour cost per unit time (c_{labour}). In our previous study [4], it is found that the disassembly time of the new design of the car door for reuse is around 269.3 second or 4.5 minutes using MaxiMOST measurement system. If we assume the cost of skilled labour is around $ 3/hour, the disassembly cost of the car door is equal to :

C_{diss} = 4.5/60 * $3/hour = $ 0.225/car door

This disassembly cost of the new design is also lower than the disassembly cost of the original design. In the original design, the disassembly time is around 10.2 minutes [4] that leads to disassembly cost to be equal to $0.51 for each car door.

As it is found that the disassembly cost estimation is quite low and assuming that the collection cost of used car door is lower than new car door manufacturing cost, the life cycle cost for reuse product is lower than the life cycle cost of a new manufacturing product. Moreover, if the product is to be reused, cost to the environment and manufacturer in the form of disposal cost can also be eliminated. Hence, reuse can increase the economic benefit to the manufacturer by reducing manufacturing cost and disposal cost.

Conclusion

Design for reuse leads to the enhancement of reusability of products at the end of their life cycle. The main contribution of this study is a new design of a car door for reuse and economic evaluation of the design using life cycle cost analysis. Some design modifications to a locally manufactured car door have been proposed leading to a significant reduction in disassembly time, and hence disassembly cost. The manufacturing cost estimation of the new design of the car door for reuse is around $ 27.82. Reuse also leads to the reduction in manufacturing cost as compared to the new product.

Acknowledgement

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