The Research on Eco-design and Eco-efficiency of Life Cycle Analysis

Lizhe Wang¹, *, Jianbo Bai², * and Hejin Wang³, b

¹Jiangsu Urban and Rural Construction College, Changzhou, Jiangsu Province, China
²College of Mechanical and Electrical Engineering, Hohai University, Changzhou, Jiangsu Province, China
³Changzhou Open University, Changzhou, Jiangsu Province, China

*Corresponding author e-mail: 1245277904@qq.com, a573883995@qq.com, b1817547064@qq.com

Abstract. This paper focuses on utilizing the life cycle analysis and other assumptions. For the life cycle cost section, the market price of one set of front loading washing machine is considering the cost for each life cycle stage that could be acquired from the data sources. Additionally, the LCC analysis could compare the initial investment options of the current front loading washing machine which calculated by a series of formulas and identified the minimum cost in each life cycle stage. According to the LCA and LCC results during the entire life cycle stages of the front loading washing machine, the procedure of eco-design could improve the hotspots of ecological impacts and reduce the pending expenses through some radical measures. Therefore, reducing energy consumption and improving the recycling rate would immensely enhance the hotspots of the redesigned product.

1. Introduction

Due to the large consumption of industrial materials and energy, the Eco-design and Eco-efficiency project could fulfill the requirement of minimizing the expenses and the ecological impacts as well as improving the productive effectiveness during entire life cycle stage. This paper will provide an overview of available approaches and computed tools for comparison and analytical procedure such as the LCC methodology, Eco-design and Eco-efficiency analysis. The aim of the paper is to present the calculation of the entire life cycle cost (LCC) of the front loading washing machine and illustrate how to handle the price data sources and then make summative evaluation of Life Cycle Analysis (LCA) and LCC results, finally conduct an Eco-efficiency (E/E) analysis.

Life Cycle Costing (LCC) is regarded as a vital and effective economic analysis which utilized in the selection of alternatives that has a significant influence on the pending and inevitable expenses. The aim of Life Cycle Costing (LCC) is to compare the initial investment options of the current product and identifies the minimum cost for each life cycle stage which would be presented in the aspects of material, procedures, usage, end-of-life and transportation. Secondly, the utilization of the Eco-design analysis could discuss the identified hotspots from the LCA and LCC results. The purpose of this section is to design an approach with special consideration for the entire lifecycle of the environmental impacts on the current product. In this paper by comparing the SLCC points for the
current and the redesign products, the objective of eco-efficiency is to reduce the material and energy expenses as well as the ecological impacts of production during the whole life cycle stage. Moreover, this paper will make comparison between the current product and the redesign product in order to improve the hotspots of ecological impacts and expenses by analyzing LCA and LCC results for the entire life cycle stage of the front loading washing machine. Furthermore, it will conduct an Eco-efficiency (E/E) analysis of the primal product and the redesigned product which could be assumed in a graph.

2. Life Cycle Cost

For the life cycle analysis, a supplemental assumption is made: the average transporting distance for all the materials except metals from local suppliers to the assembly factory is 30km. And truck/road is chosen for transportation. For the life cycle cost, the current market price of one set of front loading washing machine is $150 – 230 [1], so we assume the price of the washing machine in this assignment is $200 and the overhead, which includes labour, transportation, maintenances and other expenses, is $50.

And some important assumptions and extra calculations are made as follow:

1) The cost unit of glass from the internet is $5/m2, and the density of glass is 2.3g/cm3. Assume the thickness of the glass used in the washing machine is 5mm. Then the price of glass for LCC is $0.43/kg x 1.3kg = $0.56.

2) The cost unit of wood board is $250/m3 and the density of wood is 600kg/m3. Then the price of wood for LCC is $250/600 x 0.4 = $0.17.

3) The cost of unit polyester is $1.3/unit and we assume the weight of one unit is 1kg.

4) The cost unit of cardboard is $0.1/m2. Based on the total weight, the size of a front loading washing machine is 600x600x850mm [2], so we assume the size of cardboard box is 700x700x1000mm. Then the surface area of the box is 3.78m2. So the price of cardboard in LCC is $0.378.

5) For one washing machine, only one paper packaging is needed so the price of paper packaging in LCC is $1.

6) Because we cannot find the current market price for material recycling, we assume the cost of recycling of all the materials in this assignment is -0.8$/kg.

Life Cycle Cost analysis of the current product, considering the cost for each life cycle stage (i.e. material, process, use, end-of-life and transportation). The following equations are the methods used for calculating LCC score in this assignment. The costs of landfill are based on Landfill Levy [3].

Price data (including data source and calculation)

\begin{align*}
P_{M,1} & \quad P_{P,1} \quad P_{U,1} \quad P_{T,1} \quad P_{EOL,1} \quad P_{EOL,2} \\
W_{M,1} \times P_{M,1} & = C_{M,1} \quad C_{P,1} \quad C_{U,1} \quad C_{T,1} \quad C_{EOL,1} \quad C_{EOL,2} \\
\end{align*}

\begin{align*}
\text{Life Cycle Cost (including analysis on contribution and uncertainty of the result)} \\
C_{Total} & = C_{M} + C_{P} + C_{U} + C_{T} + C_{EOL} \\
\Delta C_{Total} & = \Delta C_{M} + \Delta C_{P} + \Delta C_{U} + \Delta C_{T} + \Delta C_{EOL} \\
\Delta C_{M} & \approx \Delta C_{M} + \Delta C_{P} + \Delta C_{U} + \Delta C_{T} + \Delta C_{EOL} \\
\end{align*}

The table for LCC calculation can be found in the appendix. From the results we have:

Product market price ($200)

=36.9% of profit ($73.71)+63.1% of production cost ($126.29)

Production cost

=$74.52(Material cost)+$1.77(Manufacturing process cost)+$50(Overheads)

The manufacturing process cost is the cost of energy during the process. The rest are included in the overheads.
3. Eco-design Aim

3.1. Hot spots from LCA
The hot spots from assignment 1 are listed below:
(1) Material stage: steel, stainless steel, copper and aluminium. And material stage is one of the main hot spot of the whole life cycle of the washing machine.
(2) Manufacturing process stage: cold transforming steel and inject moulding.
(3) Usage stage: usage stage is another hot spot of the whole life cycle of the washing machine.
(4) End of life: there is no hot spot during this stage.
(5) Transportation: the shipping of products from Sydney to Darwin is the hot spot.

3.2. Hot spots from LCC
The calculations of LCC can be found in table in the appendix. The graphs below are the hot sport analysis from LCC. The red circles in the graph indicated the hot spots. The orders of figures are set to adjust the format.

The price of electricity is assumed to be 20c/kWh based on the data from AGL in this assignment [4].

![Figure 1. Cradle-to-Grave (the red columns are the SLCC scores of transportation).](image1)

![Figure 2. Transportation.](image2)

![Figure 3. Manufacturing process.](image3)
According to the results from LCA and LCC, the hot spots of the four stages are the material stage and the usage stage. Although the usage stage has higher SLCA and SLCC scores, it is difficult to choose
an alternative energy resource, thus we chose to change a material for eco-design. The hot spots in the material stage are steel, stainless steel, copper and aluminium. The reason steel and stainless are the hot spots is that both of them have a large amount in the machine (steel: 30.27kg; stainless steel: 8.33kg), but the SLCA and SLCC scores per unit are lower than the other two. Copper is mainly used for making electric wire because of its high electrical conductivity and relatively low cost thus it cannot be replaced by other metal.

As a result we chose to replace aluminium with steel. Compare to aluminium, steel is heavier but more environmental friendly. The total weight of aluminium (density = 2.7g/cm³) in the washing machine is 5.11kg and is replaced by steel (density = 7.85g/cm³) with the same volume. The weight of steel for replacement is 14.85kg.

The two tables below are data of current and redesigned product.

### Table 1. Current product.

| Life cycle stage | Material/Assemblies       | Unit | Input: Design value |
|------------------|---------------------------|------|---------------------|
| Material         | Aluminium                 | kg   | 5.11                |
| Manufacturing process | Machining aluminium  | kg   | 5.11                |
| Usage            | Electricity in Australia  | MJ   | 0.56                |
| Transportation   | Ship is used from NZ to SYD and From SYD to Darwin, truck is used from storage to household, recycling and landfill | kg | 5.11 |
| End of life      | 50% recycling             | kg   | 2.555               |
|                  | 50% landfill              | kg   | 2.555               |

### Table 2. Redesigned product.

| Life cycle stage | Material/Assemblies       | Unit | Input: Design value |
|------------------|---------------------------|------|---------------------|
| Material         | Steel                     | kg   | 14.85               |
| Manufacturing process | Cold transforming steel | kg   | 14.85               |
| Usage            | Electricity in Australia  | MJ   | 0.48                |
| Transportation   | Ship is used from NZ to SYD and From SYD to Darwin, truck is used from storage to household, recycling and landfill | kg | 14.85 |
| End of life      | 50% recycling             | kg   | 7.43                |
|                  | 50% landfill              | kg   | 7.43                |

### 5. Eco-efficiency Analysis

The following figure is plotted based on integrated chart of Data input, Environmental Weight and Price for current product.

The following figure is plotted based on the integrated chart of Data input, Environmental Weight and Price for redesigned product.

From the appendix, the total LCA score of aluminium is 1.19822953 and total LCC score is 9.592065. And the total LCA score of steel which is used to replace aluminium is 0.820737 and total LCC score is 8.563095. Thus, we have the total LCA and LCC of current product is 34.0570727 points and 595.0193485 dollars; while the redesigned product is 33.67958004 points and 593.9903785 dollars (Table A7&A8 in the appendix are the total LCA and LCC scores of redesigned washing machine). Then the eco-efficiency can be calculated as follow:

Eco-efficiency of the current product=\frac{\text{LCC}}{\text{LCA}}=\frac{595.0193485}{34.0570727}=17.47$/points

Eco-efficiency of the redesigned product=\frac{\text{LCC}}{\text{LCA}}=\frac{593.9903785}{33.67958004}=18.13$/points

The data used in the calculation above can be found in the appendix.
According to the eco-efficiency analysis above, for the current product, the environmental impact in the material stage is higher but in the other stages is lower than the redesigned one. The cost of the current product during the material stage is slightly lower than the redesigned product as well as in the other stages except the end of life stage.

Both of the LCA and LCC scores of the redesigned product are lower than the current product. And the eco-efficiency of the redesigned product is also higher than the current product.

6. Conclusion

The analysis above shows that both of the environmental impact and the cost of the redesigned are lower than the current one. This is mainly contributed by the material stage in LCA analysis and the end of life stage in LCC analysis. Though in some stages the redesigned product has a higher environmental impact or higher cost than the current product, the overall results of the redesigned product is better.

However, this result is only valid when the overhead cost remains the same. In real world, the labor cost of the redesigned product may increase because by replacing the aluminum with steel makes the washing machine 9.74kg heavier than before. Besides, the cost of maintenance may also change for the redesigned product. The overheads of the redesigned may also increase after changing the material. On the other hand, the cost of material recycling in this assignment is based on assumption. So in real life, the total cost of the redesigned product may be even higher than the current one.

References
[1] http://www.alibaba.com/product-gs/431411071/front_loading_washing_machine.html <accessed on 16/09/2012>.
[2] http://www.alibaba.com/product-gs/431411071/front_loading_washing_machine.html <accessed on 16/09/2012>.
[3] Landfill Levy, Background paper, WALGA, prepared by the Municipal Waste Advisory Council, February 2012.

[4] http://www.agl.com.au/home/pricing-and-tariffs/Pages/Price-and-Product-Information-Statements.aspx <accessed on 17/09/2012>.