Sustainable Manufacturing based Decision Support model for Product Design and Development Process

A.K. Kulasundara*, N. Karunatilakeb, N. Weerasinghec, R. K. Ihalawattad

aDepartment of Production Engineering, University of Peradeniya, Sri Lanka.
bComputing Centre, Faculty of Engineering, University of Peradeniya, Sri Lanka.

d* Corresponding author. Tel.: +94812393658; fax:+94812393655 .E-mail address: aselakk@pdn.ac.lk

Abstract

Sustainable manufacturing is creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety. In order to adapt sustainable Manufacturing concepts, it is essential to plan and decide from a product design and development stage as it has been revealed that 80% of sustainability impacts from the product are decided in the product design and development stage. In modern day Products Design and manufacturing it is always advantageous to have complete knowledge of the Life Cycle of the Product. If Life cycle information is available for the designers, it will be easy for them to take many decisions related to specially the environmental performance or eco efficiency which is one of the emerging marketing tools. Further, with the full knowledge of the product life cycle, new/existing products can be designed/redesigned based on eco-design principals or environmentally friendly manner, thereby to improve the material and energy efficiency during the manufacturing and user phases and finally will have better environmental performances. The product life cycle and Eco design are two key techniques used in Sustainable Manufacturing specially these will enable to convert any existing product or process to be competitive in the market by better environmental performances and quality while minimizing manufacturing cost beside with better environmental performances. These issues prevail mainly since there is no such systematic approach towards Product Design and Development among the many manufacturers. Since Sustainable Manufacturing Concept applicable for all major phases of the product Life cycle, it is essential to co-relate life cycle assessment outcomes with product design and development process. However, there are numerous decisions needed to take into account at different stages of product design and development process. Therefore, in this research, a decision support model is developed based on LCA and Eco Design concepts. The developed model has been validated with few existing product design and development processes. The results shows that significant number of issues and potential improvements to the existing design and development processes can be taken from the proposed model and that will leads to many sustainability options to the whole product life cycle than what is persist presently.

Keywords: Sustainable Manufacturing; Decision Support System; Eco Design; Life Cycle Assessment; Analytic Hierarchy Process

1. Introduction

In order to fulfill the basic requirements of sustainable development, the new products entering to the market should be more environmentally sound. The desired product output can be obtained by a good product design and development stage. The concept called Eco-designing is one of the strategic approaches which use for the purpose of new product development with environmental consideration. Every day many new products or the modified versions of the existing products come in to market. These products ultimately lead to economic, social and environmental impacts to the world when consider them as a whole.
Product Design and Development (PD&D) phase embraces a leading step in new product manufacturing process. The purpose of product manufacturing is the profit gaining through proper marketing. Demand for the products is basically depend on the customer requirement. Considerable percentage of individuals in current society are more environmentally friendly, who can be considered as green customers or green consumers and they basically prefer green products when they purchasing. Further, due to various economic reasons, environmentally friendly or eco designed products which have better energy efficiency, material efficiency etc. get the preference over the others. Therefore, incorporating sustainability concepts in PD&D is need of hour, not only by concerning consumer preferences but due to the various global issues such as global warming, climate change, ozone layer depletion, raising the sea level, soil, water and air pollution, and natural resource depletion etc. since many of the reasons link with PD&D somehow or another. For example, material select for the packaging of consumer products finally creates an environmental pollution or energy efficiency of a consumer product during the user phase leads to climate change. Therefore, some enterprises even consider eco design as their innovation edge [1].

Already there is a concept called Design for Sustainability (D4S) [2] which up to certain percentage accommodate sustainability concepts in PD&D. However, it is evident from the previous examples [3,4] that, it is essential to consider whole Life Cycle (LC) of the product during the PD&D phase to eradicate or to minimize social and environmental impacts of a product.

There is some similar kind of researches in this domain in the recent past. S. Waage (2006) [5], gives pathways for designers and business decision makers and present the effectiveness of the world production with the key elements of sustainability. Jayal et.al.,[6] presents four influencing factors in the product life cycle stages under three sustainability components (Environmental, Economic and social). S. R. Lim et.al., (2013) [7] presents system optimization techniques for eco design process. This method can generate a single design solution by developing mathematical optimization models with a single-objective function for environmental impacts and economic cost. In order to formulate the single-objective function, environmental impacts are monetized to external cost by using the environmental priority strategies. Further, eco design and LCA techniques have been used in predicting the evolution patterns of the surrounding environments at the concepts design stage [8]. There, a simple life cycle assessment is carried out to determine whether if the solution is better for the environment than the currently available ones. This enables the trade-offs between environmental impacts and economic cost in the same unit.

When PD&D is concerned, many decisions have to be taken at different phases. For most of the phases, often product LCA information is required to come up with innovative eco designs. However, current methods are generally still not adapted to designers, who often lack the time and expertise to make use of LCA results in their day-to-day activities [9]. Decision Support Systems (DSS) which closely use information of the LCA can be developed in order to overcome this problem. In [9], this has been implemented up to a certain degree. Business Process Reengineering methodology has been used to develop the DSS (DSS).

This has enhanced the use of LCA results in early design phases. Further, development of this tool illustrates how it is aligned with the current designer expectations and constraints. However, there are some inherent limitations in here specially to compare the alternatives in a quantitative manner in the different phases of eco design. Therefore, this research proposes a DSS based on Sustainable Manufacturing concepts with quantitative comparison capabilities. Rest of the paper is organized as follows; section 2 presents the methodology of the proposed decision support system. This is followed by a case study to test and validate the proposed methodology. The conclusion remarks including future directions are given in last section.

2. Methodology

Proposed decision support system for Eco design consists of 8 steps. This methodology was developed based on ISO 14062 guidelines, which covers wide array of considerations staring from project planning stage to the final stage of market launch. The rest of the stages include, product
analysis, defining and developing of Eco design strategies, development of new product concept, product detailing, and production market launch, evaluation of the project and Follow up Activities. The schematic representation of the decision support system for eco design (DSS4Ecod) is given in Fig 1. Each of these stages comprises of multiple sub-factors which are necessary to be considered in order to identifying potential sustainability decisions which can be taken. In some stages where many comparisons to be carried out, a pair-wise decision making tool is adopted based on Analytic Hierarchical Process (AHP) [10]. When user wanted to compare the different options available for example type of raw material or manufacturing processes, different options could be evaluated in pair-wise: that is taking two options at a time and decide the best out of two and continue with the comparison and represent the outcomes numerically in the matrix form. Later, with some matrix operations best combinations can be decided.

The first stage is dedicated to project planning, which has the capability to incorporate or chooses and marks each of the sub functions required / necessary to consider under eco design guidelines. Depend on the relevancy and importance, the user can click select box out of the all points comes under each of the sub factors. Figure 4 shows the GUI of the project planning stage sub functions required / necessary to consider under eco design guidelines. Depend on the relevancy and importance the user can click select box out of the all points comes under each of the sub factors. Fig 4 shows the GUI of the project planning stage.

2.1 Decision Support System for Eco-design (DSS4Ecod)

When developing the DSS4Ecod, seven stages of the Eco design methodology was incorporated as separate pages in the software environment. The home page (Fig 3) of the DSS4Ecod has the facility to define new project along with project description.

Fig 2: AHP based pair wise comparison matrix

Fig 3: Main interface showing the eight stages of eco design
Next page is for the definition of eco design strategies of the product. There are seven main strategies given in the main flow and these criteria further divided into sub components. There are nine main criteria to be considered in selecting lower impact materials, four criteria to be considered in reducing the use of materials and another five in reducing the environmental impact of production. Promoting environmentally friendly packaging and logistics has nine sub categories to be considered, reducing the environmental impact in use phase has six, increasing product durability has another eight criterion and finally there are nine sub categories in optimizing the end of life system. All those information are available in the third stage of the process which is given in Figure 6. When comparison to be done where necessary there is a link incorporate to MS excel environment where AHP based calculations can be done.

When developing a new product concept, it is needed to move various creative thinking strategies prior to the concept development. There are two main ways to creativethinking. They are the scheduled thinking and lateral thinking. Under lateral thinking, the steps of proper brainstorming are given. Development of new concepts is the next step to be followed after creative thinking process. Figure 7 gives the summery of this stage. One editable worksheet was linked to the section of brainstorming for further details.

Final phase of DSS4Ecod is the evaluation phase. This GUI consists of evaluation against the benchmark product and the ecodesign project against the factors considered in the project planning phase of the DSS4Ecod.
Fig 10 : GUI of Project evaluation phase

Fig 10 shows the evaluation stage of the eco design process. It has two main aspects as the evaluation of the eco design process and the evaluation of the eco design product. This stage supports to measure the effectiveness of both project and the product. This stage is very important as it gives an overall result.

2.1 Case Study

Two case studies were carried out to validate the capabilities and adaptability options of the DSS4Ecod. The first one was on alternative to the existing roofing materials. The new tile was developed based on renewable material and industrial waste. The material selection related aspects were evaluated and designers selection based reasoning is highlighted in Table 1. Here the order to the sub categories given in Table 1 was based on pair wise comparisons based on AHP method.

Table 1: Material Selection sub categories and relevant criteria and justifications of Roof tile design

| Sub Category                  | Relevant Criteria                | Justification                                                                 |
|-------------------------------|----------------------------------|-------------------------------------------------------------------------------|
| Select Lower Impact Materials | Avoid hazardous materials        | No any involvement of hazardous materials                                      |
|                               | Use of sufficiently available materials | Can be grown in most of the parts in the island                               |
|                               | Use of renewable materials       | Plant materials are renewable materials                                        |
|                               | Use of low energy containing materials | less energy is required than competitors                                       |
| Reduce the use of materials   | Optimizing product shape, size and weight | Proper grading is done, so that same size parts will be selected for same sheet |
| Reduce environmental impact of production | Reducing Energy consumption of production process | Processing is optimized by doing the process manually, comparatively less when processing, and even in growing stage, only rain water required, remain waste is degradable and can be used as a sink to GHG |
|                               | Reduce water consumption         |                                                                              |
|                               | Waste prevention                 |                                                                              |
|                               | Reduce air emission              |                                                                              |
| Increase product durability   | Environmental friendly           | Can be grown highly in dry zone and most of the parts in the island            |
| Optimize end of life system   | Environmental friendly dispose   | Can be grown highly in dry zone and most of the parts in the island            |

Table 2: Material Selection sub categories and relevant criteria and justifications of Flower pot design

| Sub Category                  | Relevant Criteria                | Justification                                                                 |
|-------------------------------|----------------------------------|-------------------------------------------------------------------------------|
| Select Lower Impact Materials | Avoid hazardous materials        | No any involvement of hazardous materials                                      |
|                               | Use of sufficiently available materials | Can be grown in most of the parts in the island                               |
|                               | Use of renewable materials       | Plant materials are renewable materials                                        |
|                               | Use of low energy containing materials | less energy is required than competitors                                       |
| Reduce the use of materials   | Optimizing product shape, size and weight | Proper grading is done, so that same size parts will be selected for same sheet |
| Reduce environmental impact of production | Reducing Energy consumption of production process | Processing is optimized by doing the process manually, comparatively less when processing, and even in growing stage, only rain water required, remain waste is degradable and can be used as a sink to GHG |
|                               | Reduce water consumption         |                                                                              |
|                               | Waste prevention                 |                                                                              |
|                               | Reduce air emission              |                                                                              |
| Reduce the impact in use phase | Proper use of product            | Provide good water retention capacity to the soil around the plant where it going to degrade |
| Increase product durability   | Environmental friendly           | Good binding agent needed to be applied to bind coir together for use for six month duration |
| Optimize end of life system   | Environmental friendly dispose   | Can be used soil water retention system                                         |

Conclusion

The major output through this research can be described as the environmentally friendly decision support system for product design and development. The proposed DSS4Ecod is developed based on seven stage methodology given in ISO 14062 guidelines. In addition, when there are several alternatives or options to be evaluated or pair-wise comparisons to be carried out, a capability has been incorporated in DSS4Ecod software based on AHP based matrices. Each of the seven stages sub functions also established in the software so that user can easily create a project and he or she has the flexibility to use either all seven steps or selected steps and to move further with the required analysis either to select the most important eco design strategy, best material, best alternative design etc. Currently further evaluations are being carried out to validate the DSS4Ecod and in future a point scale also will be incorporated in to the software so that eco efficiency of the new design can be calculated too with respected to the defined point scale.
Reference

1. M. Santolaria, J. Oliver-Solà, C. M. Gasol, T. Morales-Pinzón, J. Rieradevall, “Eco-design in innovation driven companies: perception, predictions and the main drivers of integration. The Spanish example”, Journal of Cleaner Production 19 (2011) 1315-1323

2. Design for Sustainability, A Step by Step Approach UNEP, SCP Branch, ISBN: 92-807-2711-7

3. C. Yuan, Q. Zhai, D. Dornfeld, “A three dimensional system approach for environmentally sustainable manufacturing”, CIRP Annals - Manufacturing Technology 61 (2012) 39–42

4. J. Zufia, L. Arana, “Life cycle assessment to eco-design food products: industrial cooked dish case study”, Journal of Cleaner Production 16 (2008) 1915-1921

5. Sissel A. Waage, (2006), Reconsidering product design: a partial “road-map” for integration of sustainability issues, Journal of cleaner production, 638-649

6. C. J. Yang and J. L. Chen, “Forecasting the design of eco-products by integrating TRIZ evolution patterns with CBR and Simple LCA methods”, Expert Systems with Applications 39 (2012) 2884–2892

7. S.R. Lim, Y. R. Kim, S. H. Woo, D. Park, J. M. Park, “System optimization for eco-design by using monetization of environmental impacts: a strategy to convert bi-objective to single-objective problems, Journal of Cleaner Production 39 (2013) 303-311

8. V. Poudelet, J. A. Chayer, M. Margni, R. Pellerin, R. Samson, “A process-based approach to operationalize life cycle assessment through the development of an eco-design decision-support system”, Journal of Cleaner Production 33 (2012) 192-201

9. Karl T. Ulrich, Steven D. Eppinger, (1995), “Product design and development”, MacGraw- Hill Book Co.

10. Kamal M. Al-Subhi Al-Harbi, Application of the AHP in project management, pp 19-27, 2001