

Design for Sustainability through a Life Cycle Assessment Conceptual Framework Integrated within Product Lifecycle Management

Ajay Kumar

Department of Mechanical Engineering, Monad University,
Hapur, U.P.

Assoc. Prof. Vikas Kumar Tyagi

Department of Mechanical Engineering, Monad University,
Hapur, U.P.

Abstract The need to incorporate sustainable structure standards during item acknowledgment represents a few difficulties needing research. The interest for greener items has expanded while rivalry has abbreviated item acknowledgment forms. Product Lifecycle Management (PLM) gives arrangements in quickening the improvement procedure and time to showcase by dealing with the data through a full life cycle of a product offering. Life Cycle Assessment (LCA) gives an approach to foresee the ecological effects that ought not out of the ordinary over the total life cycle of a given item, however LCA strategies are not appropriate to proficient examination of item choices during early plan stages. Clients and different partners request items that not just conform to guidelines and limit ecological effects, yet in addition limit costs and expand certain exhibition destinations of an item. Therefore, a methodology is expected to bring together approval of new items consistence with all encompassing thought of natural effects alongside different destinations over a total life cycle for the choice of the ideal plan idea in a productive way.

Keywords- *manufacturers, machines, Total Productive Maintenance, Overall Equipment Effectiveness, Lubrication.*

I. INTRODUCTION

With the expanding weight of natural guidelines, for example, RoHS, REACH, WEEE, the choice of plan and assembling forms which conform to these guidelines and furthermore have much lower ecological effects has turned out to be progressively confused. Numerous organizations understand that so as to remain aggressive in the present market, it is pivotal to present natural intuition during the structure of an item. These days, as an ever increasing number of individuals care about the earth, clients will in general incline toward greener items. Increasingly feasible items won't just form a decent notoriety of an organization's image, yet in addition increment their piece of the overall industry. Counting ecological reasoning and consenting to guidelines appears to be inescapable for each organization that needs to make due in their market.

II. PREVIOUS WORK

With the expanding request of greener items while creating time has diminished, LCA strategies are not appropriate to effective examination of item options during early plan. Items that not just agree to guidelines and have lower ecological effects yet in addition limit costs and expand other execution targets are normal by clients and partners. To this end, past distributed works in the exploration gathering acquaint approaches with location these issues.

A methodology was created to systematically represent LCA alongside vulnerability and item costs over a similar life cycle. The strategy presented the scientific meticulousness of a regularizing way to deal with select an ideal structure idea by the all encompassing thought of various targets [1].

Another methodology exhibits an ontological structure intended to speak to both the destinations that relate to manageable plan and the relevant maintainability guidelines and guidelines. This incorporated methodology not exclusively can facilitate the reception of the benchmarks and guidelines during a structure procedure yet can likewise

impact a plan toward maintainability contemplations. The outcomes demonstrate that both the guidelines and criteria might be considered at early structure stages. Besides, it tends to be utilized to catch, uncover, and proliferate the plan purpose straightforwardly to all structure members [2].

A Bill of Material (BOM)- based methodology was acquainted with select the most appropriate materials for multi-criteria basic leadership of the ideal item structure. Surrogate models are built which comprise the natural destinations with other conventional plan targets. At that point novel plausible guess approach are utilized to distinguish ideal ideas in the plan space past the first informational collection of the known structure options. This strategy can streamline LCA estimation for material determination of real parts in another BOM at the early structure stages[3].

III. PRODUCT LIFECYCLE MANAGEMENT (PLM)

As designers notice a growing volume of files generated by CAD system, engineers realize there is a need to keep track of them in one place. In the late 1980s,

Product Data Management System (PDM) has emerged. PDM is usually considered to be a subset of PLM. A PDM allow designers to standardize items, to store and control document files, to maintain BOM's, to control item, BOM and document revision levels, and immediately to see relationships

between parts and assemblies. This functionality allows them to quickly access standard items, BOM structures, and files for reuse and derivation, while reducing the risk of using incorrect design versions and increasing the reuse of existing product information [4].

PLM evolved from the PDM approach. While PDM focuses on management of product data within product design, PLM has a management focusing on data, processes and applications for the whole life cycle of a product. PLM is an integrated approach including not only items, documents and BOM, but also analysis results, specifications, engineering requirements, manufacturing processes, product performance information, suppliers and so forth. PLM is also a system. A modern PLM system has capabilities of design workflow, program management, and project control and speed up operations. The web-based system can not only address only one company but it also enables global collaborations between manufacturers, suppliers and customers. PLM is a collaborative backbone allowing people of different fields to work together effectively [5].

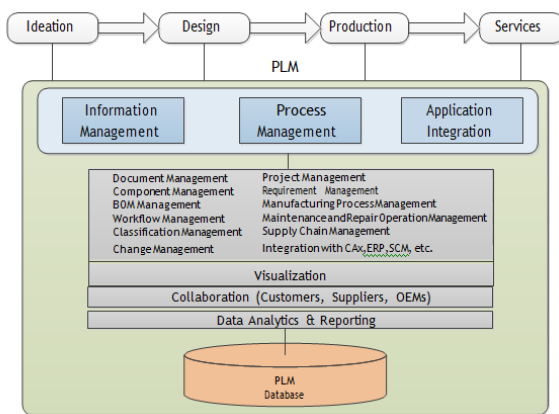


Figure: 1 PLM architecture

IV. LIFE CYCLE ASSESSMENT (LCA)

Seichi Nakajima, father of TPM and vice president of LCA is a “cradle to grave” approach for assessing industrial systems. “Cradle to grave” means resources firstly must be extracted from earth and converted into material or components from which the product is made, infrastructure must provide its function to the plant and employees. When the product enter its end of life stage, the materials are to be recycled or returned to earth. LCA includes five stages of: raw material extraction, manufacturing, distribution, use and end of life. LCA evaluates all stages of a product’s life cycle from the perspective that they are interdependent. It enables the estimation of cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not

considered in more tradition analyses. By evaluating the impacts throughout the life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of environmental trade-offs in product and process selection [6]. It is a tool for relative comparison, thereby it can be used by decision makers to compare all major environmental impacts in the choice of alternative courses of action [7].

The International Standards Organization (ISO) started a standardization process for LCA [8]. Four standards were developed for life cycle assessment and its main phases and issued in ISO 14000 series of standards for Environmental Management. The framework for LCA is shown in Figure 2.

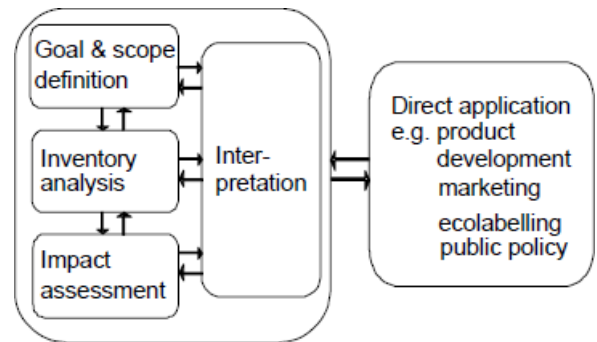


Figure 2: ISO 14040 Life cycle assessment framework.

V. OVERVIEW OF SUSTAINABILITY AND SUSTAINABLE DESIGN METHODOLOGIES

Sustainability is not only about environment. It simultaneously addresses the social impacts, the environmental impacts, and the economic impacts of the company’s activities as introduced in the concept of Triple Bottom Line (TBL) [9].
 Eco-efficiency

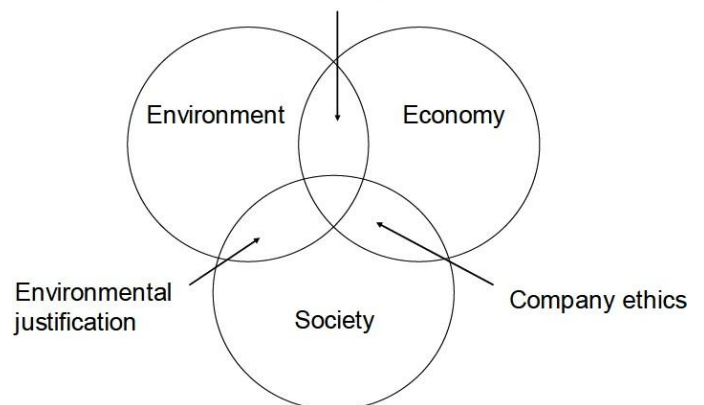


Figure 3: The dimensions of sustainability

As shown in Figure 3, the intersection of three spheres lies the most sustainable product that balance economic, social and ecological dimensions. Many organizations have adopted the TBL framework to evaluate their performance in a broader perspective to create greater business value [10]. Integrated sustainability triangle is one such tool that does not only provide a way to quantify sustainable performance of a product [11], but also introduces an appropriate instrument for the systemization and evaluation of the performance of a company regarding sustainability management [12].

VI. MULTI-CRITERIA DECISION MAKING (MCDM)

As mentioned above, a sustainable design should balance environmental, performance, cost, cultural and legal requirements. The integration of environmental considerations must find its place among many other priorities considered in

the development of a new product as shown in Figure 4. Usually, some of these criteria cannot be considered into a monetary value, because environmental concerns often involve ethical and moral principles that may not be related to any economic use of value. Selecting from many design alternatives often involves making trade-offs. Nevertheless, considerable research of MCDM has made available practical methods for applying scientific decision theoretical approaches to complex multi-criteria problems. MCDM method has been utilized to iteratively

solve engineering problems [13]. The application of MCDM in engineering design can be found in many literatures [14] [15] [16].

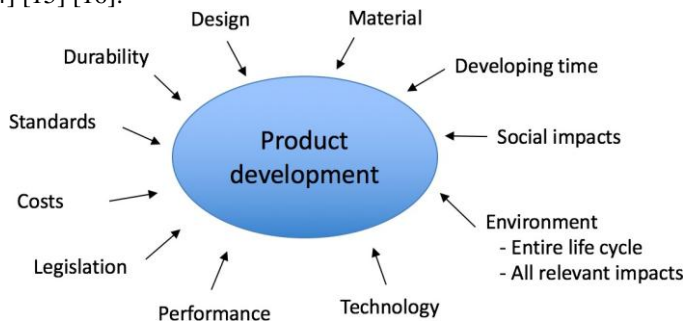


Figure 4: Design attributes considered in new product development

VII. OVERVIEW OF LCA INTEGRATED WITH PLM/CAD

Normally, integrating two systems is through interface approach or integration approach. The interface approach is most common. It usually involves two standalone system exchanging information between each other, such as PLM and CAD system. One can use CAD system to build model, drawings. Through interface, models or drawings can be opened and modified in PLM system. In terms of integrating LCA with PLM, there is some research done both on the interface and integration approach. However, existing research outcomes seem to focus more on the integration of LCA with CAD rather than PLM.

Interface approach

Mathieux et al. have proposed the “DEMONSTRATOR” [60]. It is a prototype of tool based on feature technology in extracting CAD/PDM data, from CATIAv5 (CAD) to EIME (LCA). The identified benefits of this interface are: time saving, more data collected, data keyed-in only once. However, the limitations are that all the environmental data required by the LCA tool cannot be located in the CAD and PLM system, most of the data are related to product structure (component tree, mass...) rather than product & corresponding processes in other life cycle phases:

manufacturing, transportation, use, end of life. This work has demonstrated that a direct connection between CAD and LCA tools provides less information than using PLM but most of the additional collected data are not located in the PLM with a direct link. The information is in attached Word documents or expert applications [17]. Consequently, the necessary data to carry out a LCA study is not easy to obtain.

Integration approach

Currently, there is no LCA that is embedded within PLM. There are many researches on LCA integrated with CAD system. Otto et al. [18] introduced a framework for the integration of data from a product model and an LCI database. It allows efficient data retrieval of LCI relevant product information and provides a tool for practical evaluation of digital product models and process models.

Dassault Systèmes SolidWorks includes SolidWorks Sustainability and SolidWorks SustainabilityXpress to provide a complete dashboard of LCA information for determining the environmental impacts of part or assembly drawn. It allows LCA analyses in real time on parts or assembly and replacement of comparable materials in real time to see how they affect environmental impact [19].

Also, EcologiCAD [20] works as a standalone assessment system that in conjunction with CAD system for ecological assessment during development stages. The lack of this solution is his dependence to the CAD system used in this work.

The drawbacks of currently CAD integrated with LCA systems are that they use Simplified LCA (SLCA), which neglects the whole lifecycle (in particular use and end of life) and lack of detailed estimation on material used and manufacturing cycle impact. Literature shows that SLCA system based on integration of CAD tools with LCA databases are deeply inaccurate, compared with dedicated LCA tools.

VIII. OPENING PRODUCT MODEL FROM PLM TO LCA

The operations and representations in the two systems are different. In order to integrate them, firstly a common representation of product model must be used. However, the aggregated materials and processes in LCA do not clearly indicate which part is a “hot spot” and are difficult to change when another alternative is worked out. The main goal is to let LCA to receive structural items and use them to perform a LCA study.

product structure usually used in PLM is introduced. A product structure includes assembly, parts and features. Assembly consists of sub-assembly and parts. Parts consist of features. Each part or sub-assembly can be subordinate to only one other assembly to ensure a hierarchical tree rather than a network [20].

Entity	LCA phase	Type of processes
Root	Production Use End of life	Assembly Transportation Energy production
Node	Production End of life	Assembly Transportation
Leaf	Production End of life	Material Transformation Transportation
Feature	Manufacturing	Machining

Table 1: Entity, Life cycle and process type

Life Cycle	Requirements	Extraction places
Raw material Extraction (Transformation)	<ul style="list-style-type: none"> Material Geometry Volume 	CAD, PLM
Production	<ul style="list-style-type: none"> Manufacturing process Energy Machine selection 	CAM, CAPP, PLM
Transportation	<ul style="list-style-type: none"> Transportation modes Distance 	PLM
Product Use	<ul style="list-style-type: none"> Energy Resources Parts 	PLM
End of Life	<ul style="list-style-type: none"> End-of-life treatment scenarios 	PLM

Table 2: Required information for life cycle and extraction places

IX. DESIGN METHODOLOGY

A sustainable design methodology is proposed using the concept of proposed Sustainability Module integrated within PLM. The design methodology combined with LCAatPLM mainly tries to solve the challenges mentioned in Chapter 4. Some design steps use of capability provided by a PLM system. The main design process of the methodology is shown in Figure 5 followed by a detailed illustration of each process. We illustrate this methodology is used at early design stages, where potential design goals and alternatives are established for comparison.

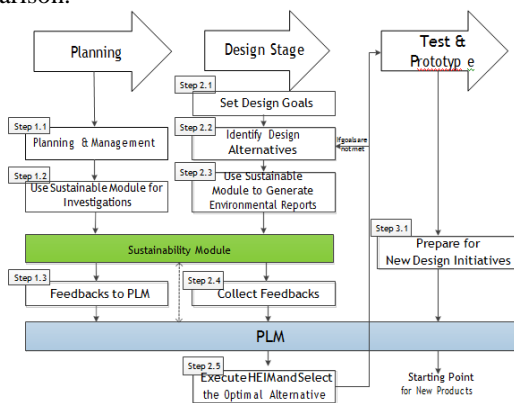


Figure 5: Proposed design methodology

X. CASE STUDY: CHARCOAL GRILL REDESIGN

A case study of redesigning a charcoal grill is performed to illustrate the design methodology and system. Since there is currently no LCA and PLM integration system, a simulation of the proposed concept is introduced using LCA and PLM separately. Two commercial LCA and PLM software are introduced and showed how they will be integrated to simulate the proposed LCAatPLM. After the simulation, it is applied to a Weber charcoal grill that used by Choi [21] [22]. In their paper, the product lifecycle scenario for a baseline charcoal grill is defined based on realistic scenarios and assumptions.

Simulation of the Proposed System Concept

Since currently, there is no LCA software integrated with PLM. Two stand- alone software are used in combination to simulate the proposed system. GaBi 6 from Thinkstep is used for evaluating environmental impact and Teamcenter 10 from Siemens is used as PLM system. A spreadsheet is uploaded

into Teamcenter to collect design attributes and helps the decision-making process.

The use of GaBi 6 requires remodeling process of an entire life cycle of a product by creating customized blocks. In each of these blocks, inputs and outputs that remodel the life cycle of the product will be defined. These inputs usually include material type, weight, energies and processes. The outputs are the final outcome, usually finished assembly or part, within that block. The last block's output serves as the input of the next block. Then they are all connected together to complete the whole life cycle. Overall, the remodeling process enabled by LCA software is rather open as long as the users follow certain rules.

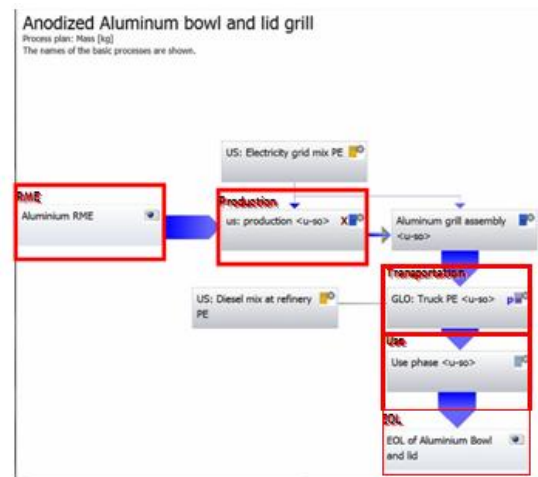


Figure 6: Simulation of LCAatPLM

XI. CASE STUDY: DESIGN STAGE

Step 1: Set Design Goals

Firstly, the general design goals are mentioned above:

1. Minimize the cost and keep it below \$ 100
2. Minimize time to heat up the cooking zone to ideal cooking temperature
3. Minimize cooking time

Then, based on the environmental profile obtained above, use stage and raw material extraction stage are identified to be the phases that contribute most to the environmental. Thus, two strategy of new alternatives are worked out shown in Table 3.

Strategy number	Description of Strategy	Design Goal
#1	Components from renewable resources	50% more recycling and half greenhouse gas impact
#2	Efficient during use	1/3 less energy during use and 2% more materials and manufacturing impacts

Table 3: Strategies of new alternatives and goals

Step 2: Identify Design Alternatives

Regarding the environmental “hot spots” identified early and largest impacts from them, they will be redesigned towards the design goals. For strategy one, more recyclable materials will be chosen for components. Aluminum is a more recyclable material but has a higher thermal conductivity, which means it

cannot maintain heat within the grill. Aluminum oxide on the other hand seems a perfect material to keep heat. Thus, surface treatment of anodic oxidation is applied on the aluminum bowl and lid to increase heat insulation. For the second strategy, material with much lower thermal conductivity is selected for maintain heat. Thus, to achieve the same performance of the baseline design, less charcoal is used. Several potential materials are stainless steel, cast iron, ceramic, etc. Considering the design goals, stainless steel is selected as the second alternative.

Alternatives	Main Components
Alternative #1	Anodized aluminum bowl and lid with cast iron grates
Alternative #2	Stainless steel bowl and lid with cast iron grates
Alternative #3	Anodized aluminum bowl and lid with stainless steel grates
Alternative #4	Stainless steel bowl, lid and grates.

Table 4: Main components of new alternatives

Step 3: Use Sustainability Module to Generate Environmental Reports

After the design is finished, these alternatives will be sent to Sustainability Module instantly to get real-time environmental reports. Same as the process of performing an environmental study on the reference product using Sustainability Module, LCA models of the new alternatives are created with the same rule which uses five main life cycle processes to simulate the five life cycle blocks proposed. Two LCA models are shown here in Figure 7 and 8.

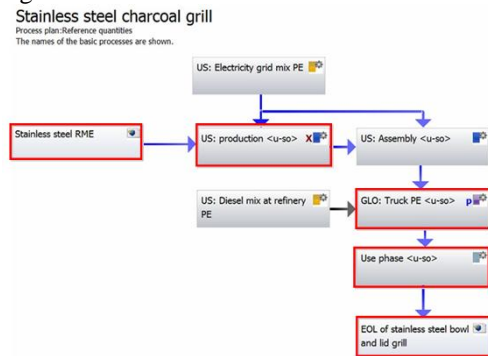


Figure 7: Simulation of LCA framework on alternative #2



Figure 8: Simulation of LCA framework on alternative #3

Step 4: Collect Feedbacks

Then, the environmental reports are fed back to PLM, same as the process of reference model sending reports back to PLM. Comprehensive environmental reports are stored in specific folder as well as other design attributes. Then the environmental index of each alternative is filled into the

decision-making module. These quantitative numbers are apparent to designers and can be used directly in the decision-making process. The production cost attributes are acquired using BOM report in PLM. The heating performance is evaluated using comparisons against the baseline design. It is calculated based on a normal direct cooking process which means placing the meat on the grate after the internal temperature reaches ideal temperature with lid closed at first. For simplification, the exact cooking time is not calculated. Instead, the cooking time is set to T second. The other alternative's cooking time is calculated accordingly. Finally, the performance attributes of four alternatives are 0.74T, 0.58T, 2.294T and 1.798T respectively. Then all these quantitative numbers are collected by decision-making module, as shown in Table 5.

	LCA	Production cost (\$)	Performance (s)
Reference	0.7282	76.15	T
Alternative #1	0.6061	83.46	0.74T
Alternative #2	0.5060	92.35	0.58T
Alternative #3	0.5681	80.65	2.294T
Alternative #4	0.5058	89.545	1.798T

Table 5: Design attributes in decision-making module

Step 5: Execute HEIM and Select the Optimal Alternative

At first glance, in terms of environmental impacts, all these alternatives have lower impacts compared with baseline. Due to better materials are used and its manufacturing process, the production cost have increased and the performance varies, too. In summary, all alternatives have their trade-offs. Since most of the information are already in detail and reflect the true aspects of the product, the execution of the methodology is best accomplished by an accurate and computationally efficient decision model. HEIM (Hypothetical Equivalents and Inequivalents Methods) was used on in this case that involve selection from multiple attributes having various advantages and disadvantages. However, the selection of the optimal alternative largely depends on the preferences of the decision maker. An under constraint optimization problem is firstly formulated to compare the winning alternatives under different preference. Then, more constraints are introduced based on the author's preference, a single robust alternative is found. The process of modeling preferences resulting in different optimal alternatives will increase the product knowledge so that they will be used for future development, which will be illustrated in the final design step.

XII. CONCLUSION

This exploration essentially uncovers that the natural effects can be considered alongside other plan qualities at early structure organizes by endorsing an approach to coordinate LCA into PLM. Other than that, the new idea likewise presented numerous advantages. These advantages make it altogether helpful during configuration stages, particularly at early structure arrange for creators.

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