LIFE CYCLE ANALYSIS

A tool for environmental conscious

Product Design and Development

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Abstract:

The present work aims to provide an overview of a procedure which is getting increasingly important throughout the design / manufacture / disposal chain, known as Life Cycle Analysis (LCA). A literature review was made, the overall frame of the methodology was traced and the focus was to show how LCA and all its environmental implications relate to the design process. The objective is to show the importance of LCA for developing new environmentally friendly products (usually labelled as "green" products) or re-designing old ones. A brief discussion was handled regarding the practical cases in the automotive industry. Some importance was also given to a broader approach regarding Sustainable Development, and the particular experience of a professor and environment consultant of the Engineering Department of the University of Portsmouth (UK).

Contents:

Keywords:

Life Cycle Analysis; environmental friendly products; Life Cycle Assessment; LCA; Life Cycle Engineering; environmental assessment of products; sustainable development;
product design and development

The Context

Humankind seems to has finally got aware of its huge responsibility of managing its planet in a non-deploring way, as a significant number of new techniques and philosophies arise attempting to put together both the businessmen and environmentalists. According to the World Business Council for Sustainable Development, "an increasing number of business leaders realise that to achieve market success they must honour a changing array of environmental and social responsibilities". With conditions so very different around the World, and nations at such different development stages, it is hard to make a meaningful list of policies that are necessary to help business to better support sustainable development. Nevertheless, it seems clear that such policies must be based on an integrated view of the economy, society and the environment, reinforcing the urgent need for deeper studies that point out good practices regarding the Environmental Engineering field.

Environmental activities

There is a significant number of acronyms representing relevant Environmental Engineering activities, although all of them frequently refer to the same issues, or at least are concerned with the same problems. Since this is a fair new research field, this is a natural and expectable process, until the present findings and works lead the way to universal therminologies and standards. Thus, it is not hard to find in the current publications: LCE (Life cycle Engineering), LCI (Life cycle Inventory), LCM (Life cycle Management), LCVA (Life cycle Value Analysis) and LCA (Life cycle Analysis or Life cycle Assessment). In spite of the fact that all of them present their own particularities, they all somehow consider the inputs and outputs of the processes, as well as the energy balances involved. Some variations, however, are already being developed, showing the real dynamics of such issue. A new streamlined method for LCA has been advanced, as an example to illustrate this situation, called MLCA (Modified LCA). It is said to be able to provide holistic environmental assessment of a product, improving its performance over and above compliance with regulation, but lack of evidence and quite a low number of practical experiences contradict this assumption.

Life Cycle Analysis

In a broader way, LCE (Life cycle Engineering) can be understood as a philosophy for the investigation of environmental parameters regarding technical and economical aspects. LCA (Life cycle Analysis) can be understood as a part of the whole life cycle engineering approach, though more responsible for specific aspects such as environmental inventory or impact assessment.

The World is facing a huge hall of environmental problems, among others, that arise from production activities. The most significant ones can be enumerated as depletion of the ozone layer; summer smog; winter smog; soil acidification; toxins in the air; water and soil; waste disposal and energy wastes; each of them having a very specific effect on the environment. Generally speaking, products and services cause different impacts along the various stages of their life cycles. Improving the environmental performance of these require that industries implement engineering, process and material changes. However, positive changes in one environmental aspect of a product can influence others aspects negatively on the other hand. Life cycle Analysis or Life cycle Assessments is being widely used as a method to evaluate benefits and pitfalls incurred in making such changes.

Life cycle Analysis aims to provide a statistical inventory of the total impacts during the complete life of the product, from the acquisition of the needed raw materials to the final disposal – many times being known as ‘ cradle to grave’ approach. It is being used as an important tool to help designers to minimise the environmental impacts of the products they develop. Like all tools, yet, LCA requires awareness of the context and intelligent approaches to bring up good quantifiable results. For a design team, particularly speaking, it can: “indicate the most likely routes for improvement, facilitate materials selection, provide quantitative information on the differences between design alternatives and it can also identify the major points of concern” (Burall,1996) such as possible toxic emission processes. Determining the environmental soundness of a product is a very hard activity, but increasingly necessary as, for instance, the BS 7000: part 2 determines the general good practices for managing the design of manufactured products including *disposal* in the hall of responsibilities and concerns of the design team.

LCA cannot be seen as a *Panacea,* and surely still presents its amount of difficulties. Some general drawbacks of this assessment are: the complexity of the issue (that can lead the amount of information gathered to rapidly get out of hand); the time and labour extremely high consumption; and last, but not the least, the management difficulties in dealing with numerical objective and subjective sources of data at the same time. Acquisition of data from the companies that reveal interest in applying this approach is by far the worst problem to manage, according to environmental consultants.

The common practical and methodological problems that arise from the LCA methods are: definition of the system *boundaries*; allocation of *limits* for processes that generate *more than one product*; definition of *impacts* or avoided impacts; determination of the *geographical features* of the product site (as well as its proposed disposal) and, finally, the choice of *technology*.

Besides being a complete philosophy, LCA can also be applied in a narrower way, acting like a tool. As a need for reducing the actual environmental impacts is getting stronger day-by day, product development professionals are looking for a new mentality. The kind of product and the related process might play a more or less important role, regarding environmental consequences. The key considerations that will show the way are quantity, energy expended, risk (especially if the product involves hazardous substances) and finally environmental sensitivity concerning that specific product. A careful evaluation is required after the completion of this analysis in order to show a path for non-damaging or less damaging choices along a product manufacturing process. For the product design team it seems to provide some immediate uses: identification of the environmentally important stages in the product life cycle and the main impacts which the designers need to concentrate on, as well as helping to decide which approach to use. As an example, a life cycle assessment of the environmental impacts of washing machines, considering production, distribution, use and disposal showed that the vast majority of the impacts occur during the USE stage of the machines’ life. There was nothing that the design team could do regarding the technical features of the product (i.e. materials). The problem lies mainly on the soap and dirty water that come as an output of this process.

LCA methodology

LCA is usually divided in some steps. This is the typical general framework, as discussed by the Society of Environmental Toxicology And Chemistry (an “euro-american” agency which runs a branch in Brussels), easily understood by the following diagram:

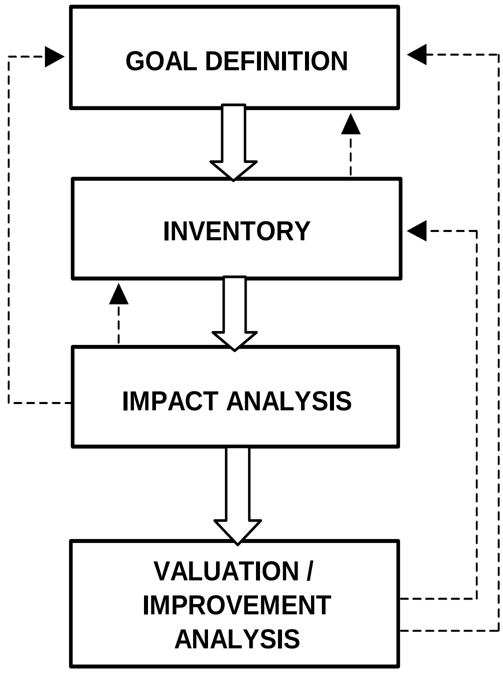

Figure 1: The different sections of an LCA according to SETAC. The large arrows show the main route of the analysis, and the dashed arrows show the interactions that may be necessary.

The goal definition phase is the most important to bear in mind, because it will show the way of LCA application, precisely defining what the designer/manufacturer are looking for. It can be either an ecological justification for a more expensive material choice or a communication to the authorities showing that it can be more useful to concentrate in certain aspects rather that others (for example, concentrate in solid waste and energy rather than ozone layer depletion). The inventory step will describe which emissions will occur and which raw materials are used during the life of a product. Then these emissions will undergo an impact analysis. Finally, the evaluation step will assess the impacts, feeding back some preceding steps.

SETAC also suggests more specific step-by step methodology that can be applied in these assessments, in five stages. Planning; screening; data collection and data treatment; evaluation; and improvement assessment - highlighting again that the first stage is extremely important as it states the depth and relevance of the environmental issues of the product under research. The heart of this activity is the inventory of industrial processes. The inputs are raw materials and energy; the outputs are emissions, energy and waste, and the method allows the creation of a table impacts that require further interpretation for the impacts calculation.

The impact assessment can be done in many different ways; from a complete evaluation of the cause-effect chain providing a unit-human impact to another method known as "Ecopoint " - method that is based in a reference target value that is reasonable to expect. The distance from the target represents the seriousness of the impact.

Different approaches

Some methods indicate that the process is grouped by classes of impact, applying weighting factors so that the different effects and substances are considered. The drawback of this particular approach is that the materials can only be compared by effect, leading interpretation to be dependent on two factors: the relative size of the effect compared to the size of the other effects and the relative importance attached to the various environmental effects. Therefore it is easy to understand the growing need for a reference table or standard to eliminate the subjectivity of the analysis. This normalisation, when achieved, would considerably improve the insight into the results. They ought to be carefully broken into practical cost/time estimated measures in order to provide procedures, instead of philosophy.

Different experiences showed that quite unexpected factors might arise from using LCA techniques in an overall process. As another example, the transportation energy and its strict relation to a truck's load once showed that re-arranging the interior layout inside the delivering truck would enable a more cost-effective delivering policy regarding energy!

Although LCA seems self-contained to a certain extent, the European Environmental Agency, in its publication "Life cycle Assessment" (1998) recommends that LCA be used together with other techniques, such as environmental impact assessment and environmental risk assessment. These approaches deal with the same issue, but they complement each other and there are no means for substituting or interchanging them.

LCA throughout the Design Process

In order to conceive environmentally friendly products, the tasks of the designer fall within four main general categories: focusing, specification, synthesis and verification.

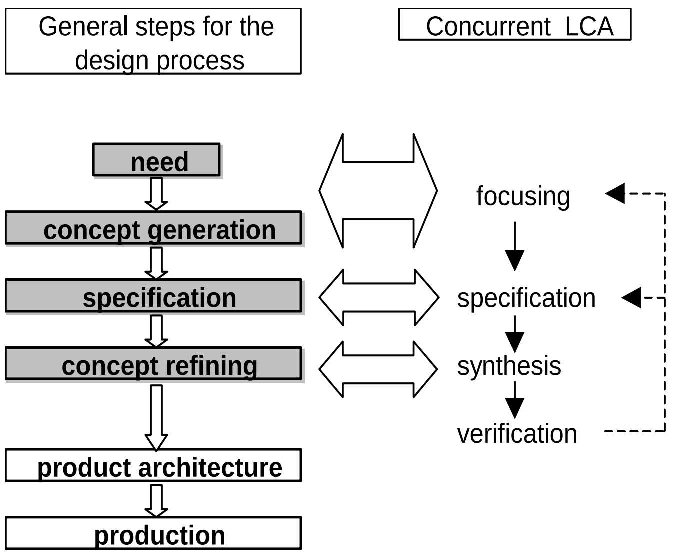

Figure 2:

Proposition of how the LCA approach should be used along the **conception phase** of the design process.

During the focusing stage the designer should make a balance of the situation, add common sense and be aware of its constrains – usually beyond his control. Then, he should make an effort to point out the most important categories of impacts, also indicating *when* along the design/manufacture process these should be expected to arise.

The specification is considered the heart of any design process, many times being responsible for the failure or success in the launching of a new product. At this stage, besides all the concerns, the designer should also define ' environmental targets', establishing then a method to achieve them, or at least to come as close as possible. All the commercial issues should be considered in this approach.

During the synthesis phase the concepts will be developed, considering all the systems that the product will interact with and aiming to create an attractive product life cycle. Many new business opportunities may arise at this stage, revealing unexpected or unusual practices for making profits - intelligent recycling policies are a good example. In generic terms four main systems ought to be considered along this phase: materials, energy, chemicals and others. Some authors (Wenzel, Hauschild and Alting, 1997) call this approach the MECO principle, useful either for conceiving a new product from the sketch or for assessing an already existing one.

Finally the verification step shall ensure compliance with the objectives established before, feeding back some assumptions and making the necessary changes before going on to the definition of the product architecture and detailing.

Although the designer is not expected to be an environmental specialist (it seems that he is already expected to be holistic enough), he is being increasingly required to include routines in the process that were not so common 10 years ago. He is becoming thus also responsible for including environmental considerations throughout the way.

The automotive industry case

The automotive industry seems to be the industry segment that has achieved best results concerning applications for LCA, many of them providing quantifiable and practical data. The intensity of research in this field is certainly a consequence of international agencies pressures upon vehicles manufacturers, since the annual production volume is enormous and the consequent waste generated during car's use and disposal is evidently harmful to the environment as a whole. Research is intense in enterprises like General Motors, Chrysler Corporation, Ford Motor Company, Volvo Car Corporation and Mercedes-Benz, among others.

Case studies of LCA were undertaken by the vehicles industries comparing, for instance, conventional gasoline and reformulated gasoline as produced from energy resources in Alberta, Canada, and this assessment concluded that the whole life cycle of the fuels presented no significant differences between them. In the light of this discovery, it was stated that reducing vehicle fuel consumption would reduce environmental impact more than comparable improvements in emission rates at the various steps of the process. However, this statement surely goes against the interests of the big oil companies, as it requires alternatives methods for energy generation.

Another study proposed a comparison between instrument panels, in order to investigate the damage caused by the materials involved in this production chain.

And research goes beyond: investigations comparing magnesium and aluminium in order to create lighter weight vehicles (and therefore increasing fuel economy); the rise of new data collection tools using EPS (Environmental Priority Strategies in Design), investigations to point out less harmful painting processes – and many more examples.

From all the research that is currently under development all it can be said is that car manufacturers surely are more conscious than never before, although the true concerns or reasons cannot be precisely determined. Nevertheless, beyond any shadow of doubt, environmental matters have really migrated to being integral part of business, and foreshadowed the inclusion of design for the environment as a cost - but moreover, they brought about a competitive advantage in conducting business.

A means for minimising waste

Professor M.R.I. Purvis, a recognised character in the environmental research and consultancy field, and also a lecturer in the University of Portsmouth, made use of the traditional methodology for LCA, incorporating though some more procedures aiming at reducing or minimising waste from industrial processes. He developed a model that presented two more steps beside the LCA itself, and was followed by an *expert system* development and the formulation of measurable decision tools, such as mathematical algorithms.

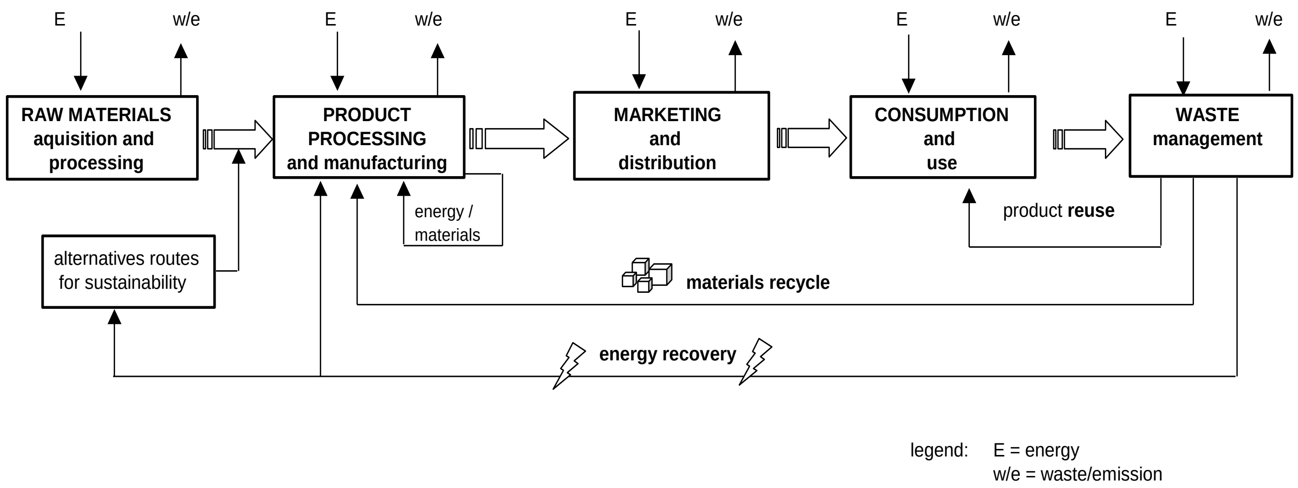

Figure 3: example of process loops identifying sustainability functions
(Adapted: Culaba and Purvis, 1995) – reproduced with permission

In Prof. Purvis' particular proposal, the industrial processes were arranged in the form of process trees. Using the output of one process stream as an input to the following one the materials and energy flows were closely monitored and quantified. The usage of the *expert system shell* named *Crystal* helped to "grow algorithms for material usage and forecasting elements for future environmental impacts and resource sustainability"

(Purvis, 1995), but further on it was identified that improvements in terms of flexibility of the system were required.

The above explained is a proof of practical and intelligent ways to provide data for the non-experts in such terms that businessmen can easily understand and make decisions upon. Materials balance and energy balance could be evaluated, bringing a significant increase in LCA credibility as a method. Professor Purvis successfully applied his work in a practical case regarding a pulp and paper manufacture process, building reference for future improvements in environmental policies.

Tools to make LCA easier

Nowadays there is some software already available to help determining LCA. Usually the software requires inputs of information such as quantities of materials, energy consumption and manufacturing processes. As the environmental performance of materials, processes and energy sources can rapidly change, it is very important to guarantee that current data is being used. Three reasonably well established software are described by Paul Burral in 'Product Design and the Environment', 1996. The first software of this kind to be developed was PEMS, from PIRA International, as a joint effort of the UK government and the packaging industry. After a while the same enterprise launched a cut down version called ECO Assessor. Besides PEMS, Chalmers Industritenik, a Swedish Company, developed the LCA Inventory Tool, which is especially relevant for process design, and is provided already with some databases. The third software is SIMAPRO, developed by PRe Consultants, a Dutch Company, which seems to be the most complete one, presenting a more graphic interface. Other research sources have already identified 35 software, produced by European, American and Scandinavian countries, showing how fast the release of new tools can happen. The important conclusion is that this large software usage could finally prove that the problems of using LCA as a design tool in a meaningful way have probably been overcome.

Conclusions and Future Trends

Summing up, as important as it may seem, it is still a long way to effectively implement techniques like LCA to build up a more environment friendly production chain, although some improvements are definitely being achieved. Many current existing companies still do not take any kind of life cycle approach and many industry segments do not comprehend the effects of their products in terms of depletion the natural resources, use or ultimate disposal. The attention is primarily focused on the manufacturing environment, which is easier to quantify and control, but this is certainly not enough yet.

Another interesting conclusion from this literature review is that the state of the art regarding environmental issues and research is situated mainly in the Scandinavian countries, where studies are often undertaken to find out what the demands and expectations on LCA are. Than it comes Canada, than Europe as a whole with the European Community, followed by America (showing an evident concern with the automotive industries). In Australia, especially in the Royal Melbourne Institute of Technology, LCA is appearing as a valuable tool in the Eco redesign projects, but a shorter version, adaptable only to this particular activity locating the key issues of the product's life cycle at the beginning of the project.

All in all, there seems to be a trend that states that environmental policies need to be adopted in a short period of time, leading to a more sustainable development. Life-Cycle Analysis is getting mature whilst it is increasingly used, and more accurate in its context as well as in its possible applications. Passive communication is turning into multi-way active dialogue, the process and assessment will soon be turning into mandatory reporting and standards, verification and the actual management systems will turn into more precise strategies and procedures in the design context. Altogether will enable LCA to join the whole business mainstream and therefore play a more important role, contributing more and more to achieve sustainable development and generate effective green policies. " In the UK, LCA has grown surprisingly fast. Ten years ago there was only one main practitioner, Ian Boustead. In 1998 there were many more academies, consultancies and companies with an *in-house* capability" (David Cockburn, from PIRA).

It seems that we are walking on the right track.

3235 words

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