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INTEGRATING LIFE CYCLE COST ANALYSIS INTO THE DECISION MAKING PROCESS IN NEW PRODUCT DEVELOPMENT

A. P. Silva and A. A. Fernandes

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1. Introduction

Traditionally product design has been concentrated in the production phase only, aiming at optimizing manufacturing costs and short-term performance. The trend towards sustainable development is driving companies to adopt a broader life cycle perspective in produtct development [Krishnan and Ulrich, 2001]. This new emerging paradigm is imposing a profound change in the way the Design Process is approached. Within this context Life Cycle Cost Analysis models, when applied at the Concept Development Stage can be a decisive decision support tool to achieve the best value over the whole life of a product. In this way a definitive shift in emphasis from focus on the production costs to costs over the life cycle of the product is taking place. Costumers are demanding products that demonstrate value over the long-term, including its impact on the surrounding environment. LCCing is “the total cost of ownership of a system during its operational life”. It embraces all costs associated with the feasibility studies, research, development, production, maintenance, replacement and disposal as well as support training and operating costs generated by acquisition of the equipment” [Harvey 1976]. The life cycle and related cost of a product can be illustrated in general terms by the diagram of figure 1.

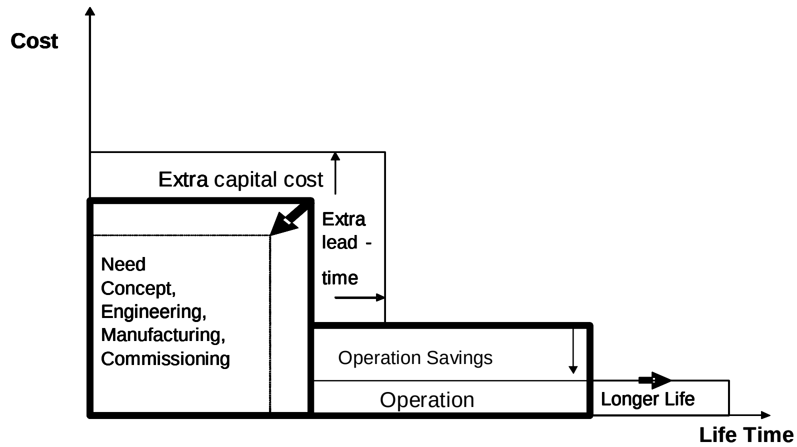

Figure 1. LCC taking into account production and operation at design stage. (Adapted from Tore Markeset and Uday Kumar, 2005)

In order to achieve the best economic LCC and increase the performance and attractiveness of a product an LCC analysis should be carried out early in the design stage of a product life cycle. The main goal is to identify and choose the alternatives that generate the lower LCC, assuming that the costs incurred by decisions changes taken at design stage are minor compared to changes taken at a later stage in the product development process,in particular in the operational phase. LCC analysis can be a powerful decision support tool specially if combined with risk analysis.

LCC modelling research, published in the last 15 years, focused on problems associated with data collection and interfaces of the model, but has failed to attract substantial support in decision-making activities [Adamany & Gonsalves, 1994]. Shields [1991] reports the reluctance of employees of nine US high-tech companies to use parametric models for product LCC evaluation. This was attributed to the fact that LCC models have failed to incorporate the decision making process in the development of the model, involving all employees in the implementation of the LCC analysis. Although Life Cycle Cost analysis is widely viewed as a valuable tool in the design process, two key factors have undermined its potential impact [Flanagan, Kendell, Norman and Robinson 1987, Bird 1987]:

- A suspicion that LCC estimates are in some sense inaccurate or based merely on guess-work
- The absence of sufficient and appropriate cost and performance data

The inaccuracy of LCC analysis is directly related to the absence of adequate cost data collection mechanisms. A number of cost models exist, to asses the economic consequences of design decisions, but all have in common a lack of appropriate information/data.

Recent work on LCC methodologies and metrics has begun to deliver effective solutions to the problems of uncertainty. However, the methodological aspects of LCC are still open to wide interpretation and criticism. One example is the management of the complexity of the product development decision-making process. The design of a product can require a huge number of decisions [Krishnan and Ulrich 2001], depending on the complexity of the product. In general few design decisions are supported by decision support tools [Ullman and D'Ambrosio, 1995] and even less by validated decision support methodologies [Olewnik and Lewis, 2003].

Knowledge of the decisions made and the information contained in the decision making effort is considered an important element for the successful management of the design process. When a product design is complex and of sufficiently large magnitude, handling the data and results from the design process can be a difficult task.

LCC is now becoming a standard practice to help designers to improve design products, reduce design changes and reduce cost and time to market. Some LCC models provide an approach for quantifying the uncertainty to achieve better forecasts and estimates. Generally the models developed are restricted to specific processes, simple operations or one phase of the life cycle. However in order to facilitate the implementation of such metrics within a complex product development in a holistic manner a methodology which promotes the logical and iterative application of the LCC model is required.

The current LCC models are generally used retrospectively and not as part of an iterative decision-making process at the concept development stage.

In the present paper an innovative approach to combine a stochastic LCC model and a decision support tool to assist in the optimisation of the design process is described. The model is combined with a probabilistic LCC model, described elsewhere by Silva and Fernandes [2005], in order to enable the product development team to establish and maintain a Logbook or Register of the design decisions taken during the whole process development. The adoption of this approach enables design changes to be assessed in relation to the consequential capital and/or Life Cycle Costs, thus providing a design rationale for the interaction between the design team and company management during the product development process. The work being reports preliminary findings. The full managerial implications of the model being developed are still being investigated.

2. Re-engineering the Life Cycle Cost Analysis

A number of design process models have been developed for manufacturing engineering (in automotive, aerospace industries in particular). These are often referred to as new product introduction process models as they attempt to involve activities in the supply chain outside the strict design activity and may also comprise other strategic issues. The approach in all cases is to assume that

design is effectively a linear process. In general the issues of design iteration are not usually a central feature of these models.
The need to estimate Whole Life Costs will arise at various stages within a project. The LCC analysis can be carried out at 3 levels of detail,which can represent LCC decision stage gates:

- Strategic level (corporate strategy,planning, technology developments and market objectives)
- System level (definition of product architecture and decomposition into subsystems)
- Detailed level (complete specification of the geometry ,materials, tolerances of a product)

The process map, illustrated in Figure 2 considers design (from product planning through to completed design) as a linear, sequential process along the ime axis, indicating the issues/stages where decisions are made (and the relevant data and information needed) in relation to LCC performance. This map is not intended for the purpose of project monitoring and control, but should enable the correct LCC data and information to be available at the appropriate point in the design process.
The map proposed was designed with 3 levels, instead of 5 or 6 as proposed in other product design models, in order to preserve its generic nature and allow a sufficient degree of design detail.

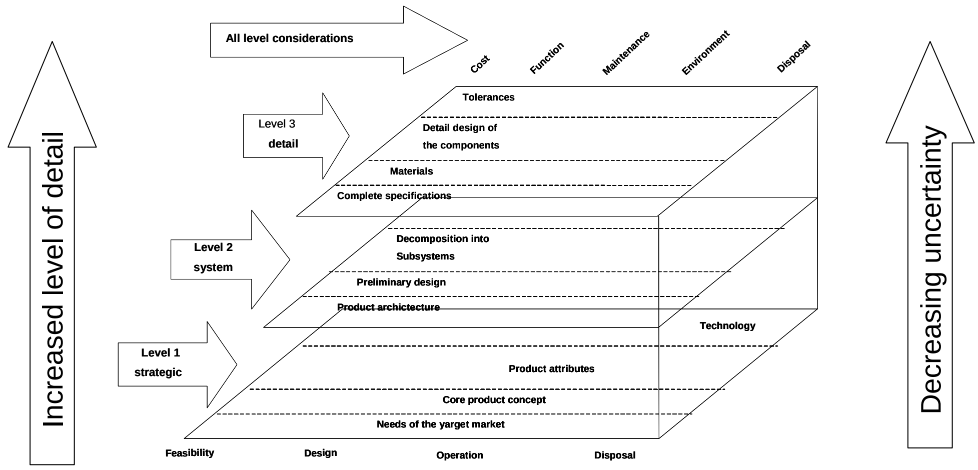

Figure 2. Design process map

By having different levels, it should be possible to take into account various kinds of performance and cost data with a degree of precision and detail fit for the purpose of that level analysis: in fact the data needed at the strategic level 1 for example is more general than that needed at detail level 3 ,where the analysis is carried out at component level. As the design proceeds, the cost, performance and environmental data can become progressively more precise and can then be entered into the lower levels of the design map. Another advantage of this multi-level approach is the possibility of taking into account design interactions and tradeoffs . In this way, the methodology proposed allows an interactive dynamic design process to take place, supported by a quantitative LCC analysis, as illustrated in figure 3.
The strategic level stage involves LCC modelling in the broadest sense, looking at the product design in its entirety, focusing on specific details considering the product life cycle services and after-sale supplies. At this planning stage, most of the research work is focused on setting the product's attributes or costumer requirements and does not explicitly consider design and production costs or overall profitability [Krishnan and Ulrich, 2001]. The decisions that emerge from the conceptual phase are, according to the traditional approach, frozen due to the large amount of resources needed to change. Thus it is important to take into account LCC analyses to assess the various alternative design solutions that are presented to company management at the product planning stage. The results from this analysis and any subsequent data extrapolation form the basis to Stage 2 - System Design - where a more detailed Systems analysis can be performed on the solution(s) identified in Stage 1- Strategic

Product Planning. The product is broken down in subsystems or chunks that allow a more detailed analysis, as illustrated in figure 4.

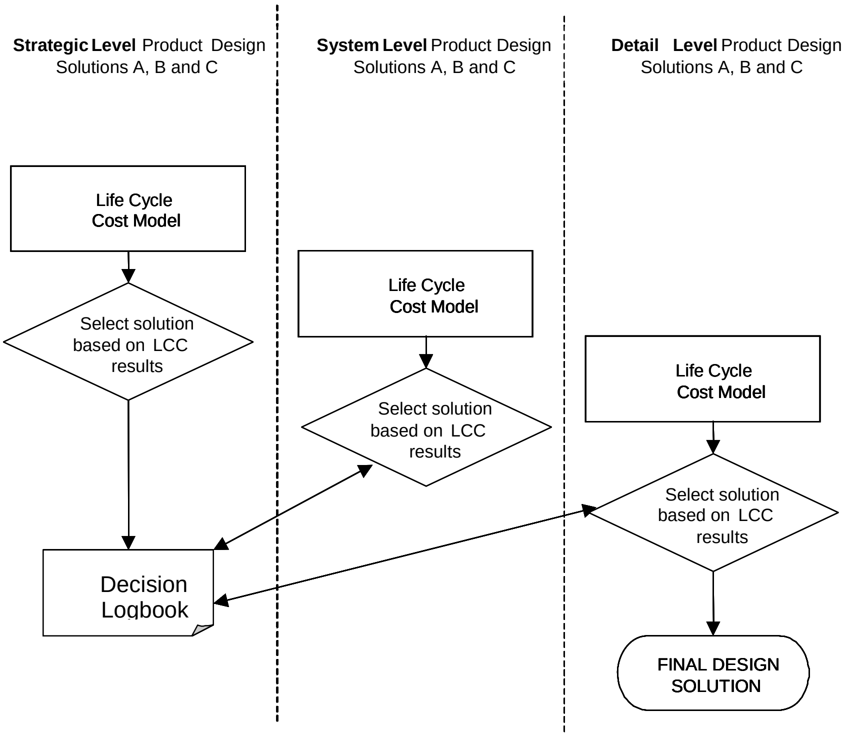

Figure 3. The 3 stage iterative LCC modelling process

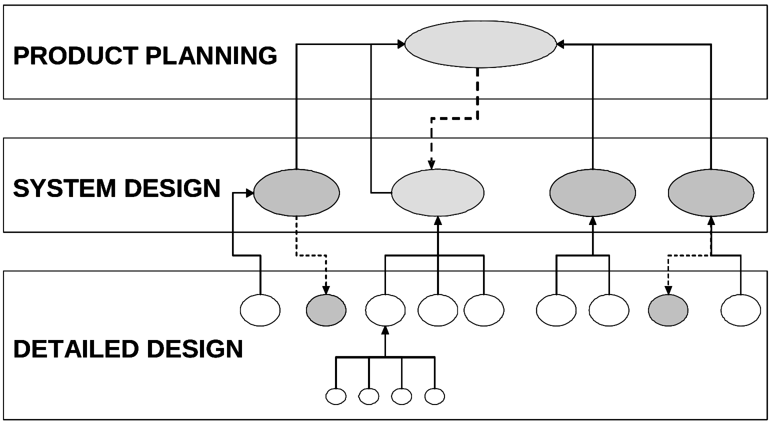

Figure 4. Breakdown of product into chunks or blocks

The subsystems or chunks are defined on the basis of product architecture: each chunk can materialize a specific function, in a modular architecture, or perform several functions if an integral architecture is adopted. The LCC analysis may be used to compare the costs associated to different types of architecture and also support decisions as to whether to outsource or make specific chunks or blocks. A risk analysis can also be carried out , assessing the likelihood and impact in economical terms of potential risks and devising the contingency management plans. The data elicited should provide the design team with the key information necessary to develop the detail design at stage 3 – Detail Design - where component specific LCC analyses are to be performed. At this stage, the LCC model allows an Activity Based Costing (ABC) to be undertaken since it is based on cost drivers or resource drivers consumed. The identification of the resource drivers will depend on the product being analysed. It is unlikely that a Life Cycle Analysis needs to be done for all components;generally the most critical ones will be analysed: conducting a Sensitivity Analyses can help to identify the most critical cost drivers and the most cost sensitive items.

Rethinking Life Cycle Cost Analysis in this way should ensure that the process is used logically and systematically, as opposed to the ad-hoc retrospective procedure applied traditionally.

In order to implement this methodology in the context of a design process, there is a need for some kind of supporting tool, that records the decisions taken at each stage, thus integrating, in a dynamic way, the Design Team work with company management.

3. The Decision Support Tool

The decision support tool was devised as to function as an user interface. The tool will be the point of entry for the data input and also the source of information of company historical data related to similar product design projects, as illustrated in figure 5. The design of the tool architecture is generic and applicable to any type of product design. The process shown in figure 5 could be considered as a "query";design solutions are selected within the core product concept, using the tool to record the selection of various components.

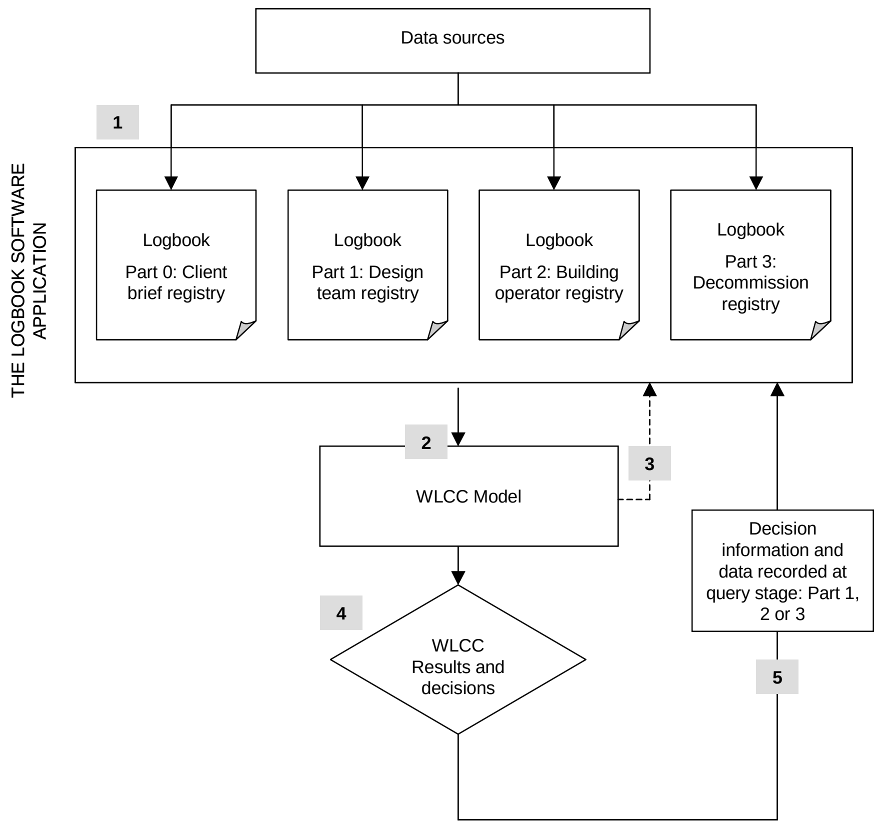

Figure 5. Decision support process

The data is then assessed in the LCC model, resulting in outputs that can then be used to make decisions. The decisions made are then recorded in the tool (the outcome of the query). In essence, the model is used to query if a set of selections are acceptable. The steps of the process are thus:

- Step 1: Specific project information is recorded in the tool (i.e. name, function, product description, etc). Selection of components is also recorded with the rational behind the decision
- Step 2: Using a variety of data sources, cost and performance data is obtained; this is fed directly into the LCC model
- Step 3: The LCC model computes the whole life cycle cost and a probabilistic analysis can be performed.
- Step 4: The results are presented in a variety of methods: Probability Density Functions, Sensitivity Charts, Cost Profiles and Performance Analysis. These results can then be used to make decisions
- Step 5: The decisions made are recorded in the tool logbook

This process is carried out through the 3-stage design process described earlier. By using this approach, the design team can create an audit track of all decisions taken and the evidence that supported them. This approach helps focus all the stakeholders on LCC. The tool comprises 5 parts each one dealing with a specific aspect of the development process:

- **Part 0 Strategic Planning**. Information is stored taking into account the mission statement and any other information related to the concept development. At this stage information on the needs and wants of the costumer and also on the opportunities to add value both to costumers and to the company is stored. By recording these decisions in the Strategic Level registry, a greater understanding can be achieved of how and why certain decisions have been made on a project.
- **Part 1 System and Detail Design**. The ability to influence Life Cycle Cost is greatest during the design phase as the types of material specified, the quality of the design and the contracting method chosen impact directly upon long-term operation and maintenance costs. This information is therefore essential and should be recorded. Part 1 records the final materials and components selected by the design team, being also a registry of the elemental details of the final design. More specifically, Part 1 consists of two distinct sections. The first section provides the designer with the ability to review any previous decisions that have been made on the project. This section will also include the ability for the user to define a new scenario analysis.

Once the user has reviewed previous decisions and specified a new scenario analysis, the second part of the tab (Section 2) is then activated. Section 2 considers each design scenario analysis that is produced within the LCC model. Once all simulations have been completed, the designer is then able to select the simulation that represents the optimal LCC. When making the decision, the analyst is presented with a form to enter a textual description of why the decision was made, which is then recorded with the file in the database.

- **Part 2 System Operation**. This is essential to provide the product owner with the information necessary to make decisions over the operational life of the product. It will allow the user to record, monthly and annualised cost data and also to record capital investment decisions and maintenance overhaul. This part of the tool is dynamic in that it should be updated on a yearly basis so that LCC forecasts can be recalculated and updated based on the latest cost information.
- **Part 3 Decommissioning registry**. This part of the tool will only be completed when a query is made as to whether the product is still economically viable to run. Other factors may also be included in this assessment such as environmental factors. The results of the analysis are again locked into the project archive. Figure 6 shows examples of the tool layout and composition for part 0 and part 1.
- **Part 4 Ecodesign**. This part of the tool provides the interface to assess the environmental and societal issues related to manufacturing ,use and disposal of the product

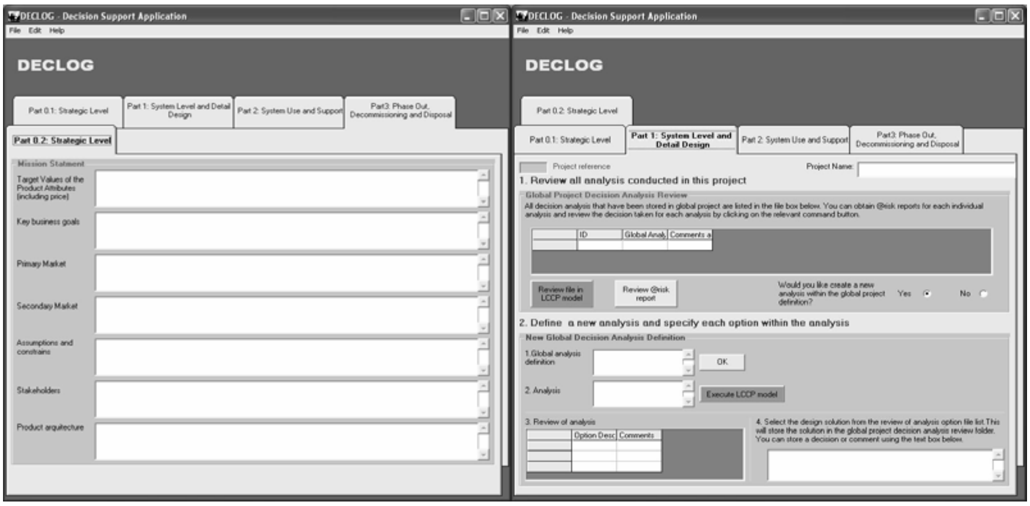

Figure 6. Screen shots of the tool

4. Conclusions

This paper reports work in progress to develop a methodological framework to integrate LCC concepts in New Product Development processes. The aim is to develop a decision support tool that facilitates the logical recording of whole life costs throughout the product development process, enabling the user to quickly identify the assumptions made and evaluate the impact that these hypotheses have on subsequent phases of the product development process. Additionally the tool will allow the traceability of decision making and work as a register of *when* quantitative decisions, based on LCC, have been made and the reasons *why*. The tool will also provide a history of the project, which could provide invaluable information for similar projects in the future. An innovative feature of the tool is the possibility of interaction with the LCC calculation tool, thus converting a static LCC model into a dynamic one, that can be used not only at Design Stage but throughout the life cycle of the product. Adopting this approach enables design changes to be assessed in relation to their Life Cycle Cost, as well as the capital cost, providing quantitative information that makes the dialog between the design team and company management easier, during the development process and makes for better informed decisions. Without this interaction, decisions may be taken to save on capital cost, which may have a detrimental effect on cost during use, making the product less attractive from a sustainable point of view.

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Antonio Augusto Fernandes
Professor
Faculty of Engineering,University of Porto
Rua Dr Roberto Frias,4200-465 Porto,Portugal
Tel.: +351 225081491
Fax.: +351225082201
Email: aaf@fe.up.pt
URL: http:// www.fe.up.pt