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Life Cycle Cost through Reliability

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Abstract. This work presents a novel approach using dependability of sub-assemblies to compute the life cycle cost of complex products (i.e. products that are technologically more complex than average or have a higher life expectancy) This work is composed of two parts, first a retrospective on life cycle cost and its challenges, then a description of the approach using reliability as the key element. This approach combines the usage of already well-known components or sub-assemblies alongside new, innovative ones in order to compute the life cycle cost of the system. This work is currently conducted as a PhD thesis and as industrial support.

1 Introduction

Many products and systems are more complex than others. That is mainly due to their technological complexity or life expectancy. These products therefore should have control over their availability, with maintainability taken into account. The use life phase is to generate huge costs in terms of maintenance, operation and energy consumption [1-2].

These products require a focused study of their design; this work presents a retrospective of life cycle cost analysis as well as the interactions of life cycle cost with the design phase. In a second part, we propose a novel approach based on life cycle cost estimation using reliability as a main factor. This approach allows the incorporation of innovative sub-assembly into a well-known system and focuses on the modification of the life cycle cost induced using the predicted reliability of the component. This work is currently conducted as a PhD thesis, with the support of industrial partners.

2 Life Cycle Cost Analysis

The first objective of life cycle cost analysis is to assess the monetary weight of each and every of the phases of the life of a product [3]. One of the many definitions of a product life phases is by Kriwet, Zussman & Seliger [4] on figure 1.

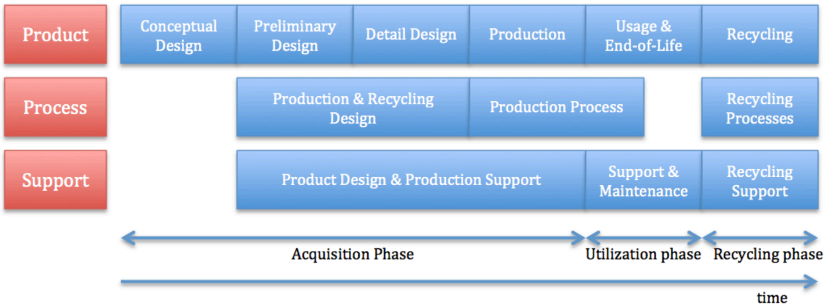

Fig. 1. Life Cycle Phases (adapted from [4])

The metaphases of the life of the product are well defined (Acquisition, Utilization & Recycling). Each of theses phases are then sub-divided into multiple subphases than covers the whole life of the product. This definition is interesting as it identifies not only the product itself but also the process and logistic support needed to the accomplishment of the product-centric phases.

2.1 Key Phase

In a global life cycle cost approach, the key phase is the early conception phase. This phase is the key point where most of the technical choices are committed, theses choices are of the same importance whether they are technological, components or materials. All theses choices have a major impact on the detailed design phase. Once committed, they are not to be questioned due to cost of changing already committed choices.

The preliminary design phase is the one where most of the costs are committed (see figure 2). Thereby this phase has a disproportionate influence on the downstream design, usage and end-of-life phases. At this stage, not all the necessary data for the assessment of the life cycle cost. That is even more evident in the case of a project containing many breakthrough innovations on which there is not yet any capitalization in terms of life cycle cost.

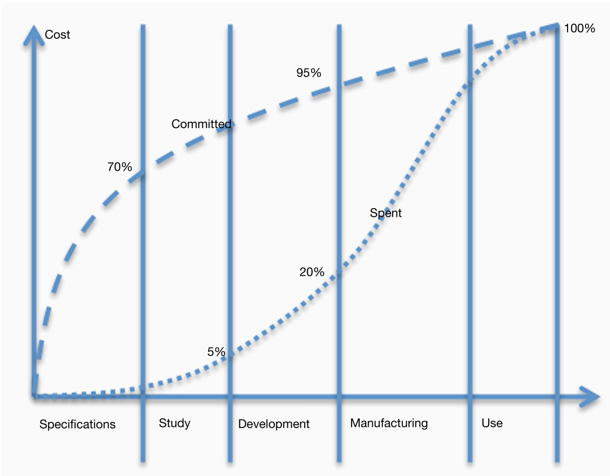

Fig. 2. Cost Phases (adapted from [])

2.2 Over-costing & under-costing

As previously shown, costs are incurred at a very early stage before being spent as the result of the project. There is therefore several risks that can be discerned for the rest of the life of the project.

The foremost influent factors in the case of complex products are, between others, inflation, financial costs and technological risks. This risks lead to two meta-risks: conservative calculation (over-costing) and liberal estimations (under-costing).

Over-costing can jeopardize the first phases of go/no-go without representing the true costs, therefore threatening commercial projections (or tender response). This is most often the case when there is over-estimation of costs from energy, personal, formation and/or maintenance.

Under-costing has the same effect, in a somewhat different view. Under-costing has a tendency to appear on projects where the risk involved with the industrialization phase is not well assessed and create huge costs, for instance when specific tooling is necessary but was not thought of.

3 Evolution of costing

Life cycle cost analysis started to be used in the late 60s, early 70s by the US Department of Defense (US DoD) [5]. The DoD started to completely reorganize its procurement strategies using the deterministic factor of global costs instead of just using acquisition costs. Global costs included, but not limited to, support, fabrication, technological developments and formation costs. This started a *Design-to-X* [6] procedures that are used to minimize life cycle costs for system development and usage.

3.1 A transition from programs to projects

Life cycle cost analysis slowly evolved from the DoD and large-scale procurement programs toward other US Army department at smaller scales. The DoD authored many notes concerning the *Design-to-Cost* processes and *Integrated Logistic Support* [7-8-9].

Integrated Logistic Support (ILS), also contributed by the US Army, ensures the supportability (maintenance, repair & operations) is taken into account within the design & development of a product/equipment.

This methodology has a major influence on design processes, especially that there is a tendency to search and identify as soon as possible reliability problems. This rend tends to initiate a dialogue on the drawing of parts thought for reliability improvement, maintainability, testability and/or availability [10-11-12-13].

ILS also has a huge part for the support in staff training, documentation and spare parts supply. All these considerations allow, and facilitate, specification steps, design steps and support phases, with a major focus through the whole process on maintainability.

The transition between calculating a global supply cost and seeking the minimal life cycle cost using maintenance also helped the usage transition of these methods from multiple large-scale systems to smaller scale products. Notes authored by the US Army [11-12-13] were published in the mid-80s; and, by late 80s, these concepts started to diffuse into civil design [14] first to avionic industries, electrical power production, oil & gas and railway industries [15-16-17-18].

This techniques diffusion coincides with a modification into the ILS approach; global life cycle (cf. figure 1) is more and more used for design, alongside with maintainability in complex and/or large-scale systems.

3.2 *The concept*

Integration of these techniques in more and more industries also allows the refinement of the different methodologies that are used.

In fact, it is difficult whenever there is innovation into a project to estimate a life cycle cost (regardless of the complexity). This difficulty mostly arise from the fact that it is not possible to have concrete results that fits into the global life cycle cost model of the product from testing.

3.2.1 Innovative difficulty

This difficulty, inherent to the conception of the innovative system, can jeopardize a life cycle cost model analysis conducted too early in the project. Also, difficulty arising from downstream design phase, and/or production, can lead to review the first estimators of life cycle cost.

The innovative part can cause huge repercussions on life cycle cost without changing the product a lot. One example of that is automotive paint with the transition from solvent based to oil based [19]. The two techniques have very small difference in costs regarding research, manufacturing and deposit onto the vehicle. However, aging is totally different, thus creating a modification on the usage phase of life cycle cost without changing upstream phases; this is also true for disposal procedures that are way heavier for solvent based paints.

The difficulties introduced by innovation can therefore deeply intervene into one phase of the life cycle cost, and have little or no impact on the other phases. However, it is extremely difficult to quantify this impact without having experts and trusting their judgment while waiting for field-tests that will confirm (or deny) their projections.

3.2.2 Estimators

The problem of estimating life cycle cost is not only present with innovations. It is also extremely difficult to assess during the evolution of a (well) known product in order to make the necessary adjustments to life cycle cost projections.

Several life cycle cost estimation techniques exists, however they all have advantages and disadvantages. Theses techniques are also linked to the fact that most of the design methods used in Western countries put forward the costs factors [20].

The three main types of life cycle cost estimators are:

- Analogue models from a similar system, extended over the current product using experts interventions to model the transformation of the life cycle cost between the old and new products;

- Analytical models involving a set of experts modeling each and every components and/or sub-assemblies and then generating an overall life cycle cost model;
- Predictive analysis based on field-collected statistical data and/or probabilities related to the various components.

The first two types of estimators have the huge drawback of relying on the expertise of a small number of people and on the previously collected data [21]. These methods are generally deployed late in the design process, i.e. when the product is already undergoing production and not in an upstream design phase.

As shown by Baguley & al [22], the biggest challenge in cost modeling methods is identifying and collecting the necessary data for the construction of the model. At an upstream stage of the design process, there is little to no available data and information to identify the correct model.

In addition, another problem arises from highly innovative products. These products suffer from a lack of historical data linked to the innovative attributes; therefore it cannot be extrapolated into an already existing life cycle cost model [23]. This lack of data requires projection tools that can rely on data other than those usually harvested during the use phase.

An interesting development is to use behavioral model of the product life cycle modeling (in terms of cost) and its failure. From this model, it is possible to create alternative models of the life cycle cost in terms of maintenance, and then go back to the overall life cycle cost.

4 Reliability approach

The use of reliability to calculate life cycle cost is possible at an early design stage. This approach is based on the fact that each component or sub-assembly of a product as a reliability (function of charge, desired dependability, expected lifetime) that can be associated with it. Most often than not, most of the component used in a product are well described and only a handful are real innovation.

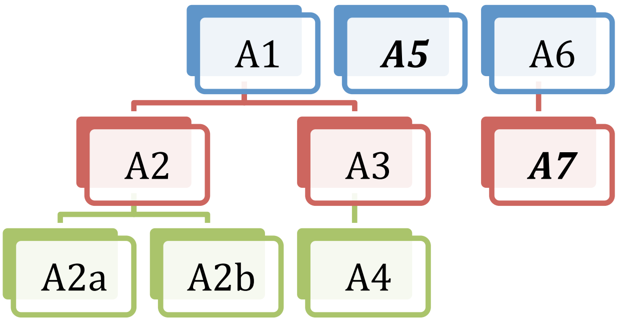

Fig. 3. Product functional nesting diagram

Figure 3 presents a product that uses nested sub-assemblies and top assembly, where italic represents innovations (A5 innovative assembly & A7 innovative sub-assembly). Each assembly and sub-assembly has its specific costs for engineering, manufacturing, support and disposal. Non-innovative sub-assemblies are perfectly defined using the collected data on already existing products. A7, the innovative sub-assembly is also likely to change the comportment of A6 its top assembly.

It is then possible, using simulation and expected data from design, to calculate the associated costs of the innovative assemblies. It is also necessary to introduce uncertainty into the calculation for the innovative components; hence not having a straight curve output but a region for life cycle cost estimation (see figure 4).

Another uncertainty source is the addition of the different project component life cycle cost, as discussed in 3.2.2. This will introduce an error area alongside the running charge and the follow through with the manufacturer/designer support programs.

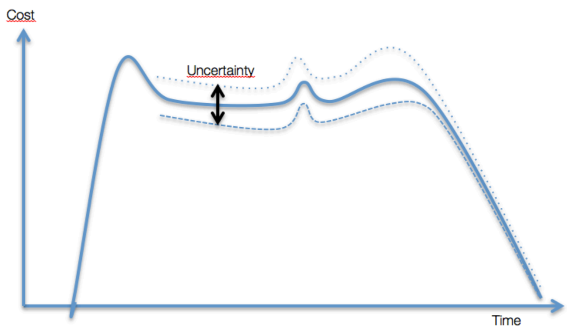

Fig. 4. Uncertainty in Life Cycle Cost with mid-life overhaul

Using all this data, it becomes possible to have a projection of the life cycle cost for each component and extrapolate it to the whole system. This is a crucial data at early design stages. It allows to focus on strategic sub-assemblies and/or design to a specific factor (maintenance, energy, …) using 80/20 rule and life cycle cost.

5 Conclusion

This work presents a novel approach using projected life cycle cost profiles estimation for complex products (products having a prominent support cost and requires high availability) design process. This method is based on the usage of reliability for estimating life cycle costs.

The current modeling using only reliability, charge and expected lifespan is lacking the obsolescence and technological maturity that will impact life cycle cost. Macroeconomics factors in the region of installation (and support) also need to be taken into account.

This approach is expected to reduce operation costs by allowing better prediction of the operation costs, as well as manufacturing and disposal.

This work is currently being tested and should be finished mid-2013.

References

[1] Clark, K. B., Fujimoto, T. (1991), *Product development performance: strategy, organization, and management in the world auto industry*, Boston, MA, Harvard Business School Press

[2] Davies, A., Hodbay, M. (2011), *Business of projects: managing innovation in complex products and systems*, Cambridge, Cambridge University Press

[3] Keys, L. K. (1990), 'System life cycle engineering and DF`X'', *Components, Hybrids, and Manufacturing Technology, IEEE Transactions on*, vol. 13, no. 1, pp. 83-93

[4] Kriwet, A., Zussman, E., Seliger, G. (1995), 'Systematic integration of design-for-recycling into product design', *International Journal of Production Economics*, vol. 38, no. 1, pp. 15-22

[5] Garin, T. A. (1991), *A Preferred Spare Decision Support System Incorporating a Life Cycle Cost Model*, Air University

[6] Blanchard, B.S., Fabrycky, W.J. (2010), *Systems Engineering and Analysis*, Prentice Hall International Series in Industrial & Systems Engineering

[7] DoD 4100.35, (1964), *Development of integrated logistic support for systems and equipment*, U.S. Department of Defense

[8] DoD 4245.3, (1983), *Design to Cost*, U.S. Department of Defense

[9] Dangel, R. (1969), 'Integrated Logistic Support (ILS) Implementation in the Naval Ship System Command', *ASE 6th annual technical symposium*, pp. 1-25

[10] Army Regulation 700–127 (2007), *Integrated Logistics Support*, Washington DC, Headquarters Department of the Army
[11] Mil Std 785, *Reliability Programs for Systems and Equipment, Development and Production, National Technical Information Services*, Springfield, Va.
[12] MIL-STD-1338-1A, *Logistics Support Analysis*
[13] MIL-STD-1338-2B, DoD Requirements for a Logistic Support Analysis Record
[14] Carrubba, E.R., et al. (1992), 'Intergrating Life-Cycle Cost and Cost-of-Ownership in the Commercial Sector', *Annual Reliability and Maintenability Symposium*, IEEE
[15] Dougan, K. W., Reilly, M. C. (1993), 'Quantitative reliability methods improve plant uptime', *Hydrocarbon processing*, pp.131-141
[16] Hokstad, P., et al. (1998), 'Life Cycle Cost Analysis in Railway Systems', *SINTEF Safety and Reliability*
[17] Rose, J., Phelps, E. (1979), 'Cost of Ownership Application to Airplane Design', *IEEE Annual Reliability and Maintainbility Symposium*, IEEE, pp. 47-50
[18] Vega, F.F. de la, et al. (1995), 'Plant Reliability Analysis in LNG Plants', *Proceedings of 11th International Conference on LNG*, paper#2.11
[19] Leitz, C. W. (2007), *Life cycle cost modeling of automotive paint systems*, Massachusetts Institute of Technology
[20] Grabowski, H., Geiger, K. (1991), *Neue Wege zur Produktentwicklung*, Karlsruhe, Karlsruhe Univ. (T.H.) (Germany). Inst. fuer Rechneranwendung in Planung und Konstruktion
[21] Niazi, A., Dai, J. S., et al. (2006), 'Product cost estimation: Technique classification and methodology review', *Journal of manufacturing science and engineering*, vol. 128, no. 2, pp. 563-575
[22] Baguley, P., Maropoulos, P. G., Pease, R. (2008) 'A roadmap for cost engineering in the automotive supplier sector', *International Journal of Manufacturing Technology and Management*, vol. 15, no. 3 pp. 265-283
[23] Newnes, L. B., Mileham, A. R., et al. (2006), 'Predicting the whole-life cost of a product at the conceptual design stage', *Journal of Engineering Design*, vol. 19, no. 2