Life Cycle Costs Measurement of Complex Systems Manufactured by an Engineer-to-Order Company

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Abstract

Complex technical systems such as packaging lines, computer networks, material handling systems, are crucial for the operations at the companies (or institutions) where they are installed. Companies require high availability because their primary processes may halt when these systems are down. High availability implies a high level of support and service activities, and, thus high support and service costs in the exploitation phase. Together with acquisition costs, operational costs and maybe some others, support and service costs constitute the Life Cycle Costs (LCC) of a system. Then the question is what portion of LCC consists of support and service costs? If this portion is high, the companies should take into account these costs more carefully in their decisions.

In this work, we develop a Life Cycle Costs Measurement (LCCM) methodology by adapting a Life Cycle Costs Analysis (LCCA) approach. With this methodology, cost buckets that compose LCC of the systems are determined and costs are measured for each bucket. LCC is just the sum of those costs then. This methodology is used to measure the LCC of complex systems at two different sites. These systems are manufactured by an Engineer-To-Order (ETO) company that we have cooperated with. The company designs and engineers systems from existing building blocks such that the customer requirements are met. We mainly focus on the measurement of the cost buckets that stem from the exploitation phase of these systems. The cost figures show that the nominal support and service costs are more than the acquisition costs and account for a significant portion of LCC. This suggests that both the suppliers and the buyers of these systems should deal with support and service costs seriously, when investments in new systems are made.

1. Introduction

In this paper, we introduce a methodoly for the Life Cycle Costs Measurement (LCCM) of complex systems. We apply the methodology in cooperation with an Engineer-To-Order (ETO) company to identify the cost stucture of the systems it manufactures.

An ETO company typically manufactures capital goods that are used by their customers to execute their primary processes. The parts and components (building blocks) manufactured by an ETO company are normally not dedicated to one specific customer, whereas the complete system, the combination of building blocks, its interfaces and controls are specifically tailored and engineered for a single customer. Each customer has its own desires and prerequisites and each customer site may be different in terms of space, already existing equipment and degrees of freedom.

The primary process of an ETO company is run on a project management basis. Order sizes and requirements of each project may differ to a large extent. Winning or missing one or a few large orders can significantly affect financial performance and determine an ETO company's success.

In general, an ETO company executes a project through three main stages, which also embody its primary process:

i. the sales process,
ii. the operations process,

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iii. and the service process (if the ETO company provides service and a customer asks for it).

The sales process is initiated by a request of a customer for a system. A conceptual design with respect to the customer requirments is generated and a quotation is offered. After the customer order is obtained, basic design activities start. During the basic design, functional specifications and engineering layouts are defined. These layouts are then used as inputs for the detailed design process in the first stage of the operations process. Then, the operations process proceeds by production of the building blocks and their assembly (integration) and installation on site. If the ETO company also provides service (some ETO companies are also involved in service support, while others are not) and the customer demands it, the execution of the project continues with the service process.

Systems manufactured by ETO companies, which we will refer to as ETO systems, are very crucial for their customers. The primary processes of the customers depend heavily on the availability of these systems. Downtime costs are high and ETO cumpanies are expected to ensure that their systems are operating smoothly. Several internal and external developments force ETO companies not only to develop and sell technical systems, but also provide maintenance and support during the complete life cycle of these systems. In addition, the customer requirements with respect to costs and system reliability and availability are aggravated, which also puts more pressure on these companies to be responsible for the complete system life cycle.

In this work, we focus on the LCC measurement of existing systems and identification of factors which account for significant portions of these costs. Many definitions for LCC can be extracted from different publications which date back to the 1960's; see [1, 2, 3]. This work is based on the following definition given by the US Department of Energy in 1995; see [4]: "LCC are the total costs estimated to be incurred in the design/development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span."

The users and suppliers of the systems can use LCC for various purposes (see [4]). The motivation for LCC measurement in our case can be summarized as below:

- Once there are some measures on the LCC of existing systems, prediction of the LCC of new systems through the gained insight will be possible. LCC can be the unique selling point then. Customers can be convinced to choose a system with low LCC while its acquisition costs are higher.
- As the most important cost factors are identified, an ETO company can organize and plan its processes in order to have more efficient operations and lower LCC accordingly.
- The profit margins on service are higher than the sales of a system, in general. The LCC perspective would provide advantages in service offering for a company which wishes to be more active in service.

There are different terms used in the literature to refer to life cycle issues. Life Cycle Assessment (LCA) is one of them. LCA is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle; see [5]. It enables a manufacturer to quantify how much energy and raw materials are used, and how much solid, liquid and gaseous waste is generated, at each stage of the product's life. Sometimes, the same concept can be referred to as Life Cycle Analysis.

The terms Life Cycle Costs Analysis (LCCA) and Life Cycle Costing (LCC) are frequently used to describe an analysis supporting engineers to select equipments and processes based on total costs rather than the initial purchase price; see [4]. (LCC is used for both Life Cycle Costs and Life Cycle Costing. One can understand for which it stands from the context.) The objective of LCCA and/or LCC is to choose the most cost efficient option among a series of alternatives.

LCCA can be executed from two different perspectives: The manufacturer's perspective or the customer's perspective. The costs to be included into the analysis depend on the perspective. For example: A manufacturer distinguishes the design/development and production costs for LCCA while these costs are merged into acquisition costs for a customer. The LCC of a system from a customer perspective is also termed as Total Cost of Ownership (TCO); see [6].

The methodolgy we introduce here is adapted from an LCCA methodolgy, indeed. However, since we just measure LCC of existing systems but do not compare any alternatives for a decision, we refer to our work by Life Cycle Costs Measurement.

The organization of the paper is as follows. In Section 2, the details of the LCCM methodology will be given. In Section 3, the execution of the methodolgy will be examplified by its application on two ETO systems. In Section 4, we conclude and give directions for further research.

2. THE LIFE CYCLE COSTS MEASUREMENT METHODOLOGY

The LCCM methodology is based on the LCCA methodology, which has been presented in Barringer and Weber [4] and stems from the results of Blanchard and Fabrycky [7]. In this LCCA methodology, there are several steps that are meant to compare two or more competing alternatives among each other, so they are not relevant for LCCM. Some of the remaining steps are modified for their conformation to measurement. The methodolgy is visualized in Figure 1. Each step is detailed in the remainder of this section.

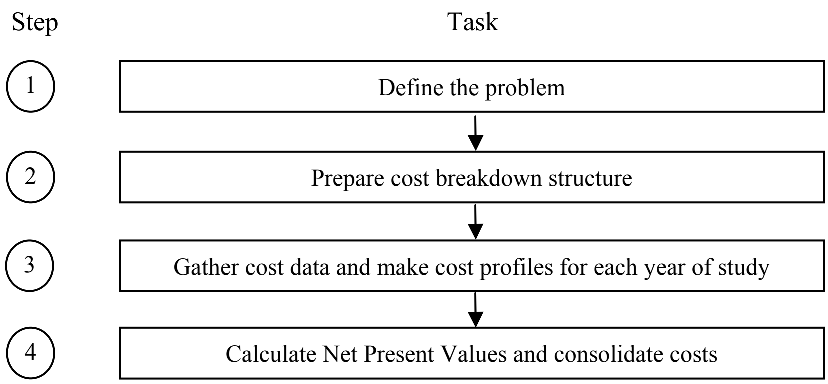

Figure 1: LCCM Methodology

STEP 1: DEFINE THE PROBLEM

The object (system/product or the class of systems/products) under investigation is defined first. We will refer to the object as "the system" from now on.

STEP 2: PREPARE COST BREAKDOWN STRUCTURE

LCC of the system are decomposed into subcollections called *cost buckets* level by level. A Cost Breakdown Structure (CBS) is a tree which shows this decomposition. The CBS depends to a great extent on the perspective (manufacturer perspective or customer perspective), the characteristics of the system under consideration and common sense. We measure LCC from the customer perspective. What is prevalent in every CBS from the customer perspective is the breakdown between acquisition and maintenance (or sustaining) costs in the first level (see [4]). For an ETO system, operating costs also constitute a large cost bucket since these systems are the backbones for primary processes. Due to system unavailability, a customer might experience substantial downtime costs as well. These costs might be considered as a part of the operating costs, but due to their different nature they are treated as a separate entity. One ultimate cost bucket which might need attention is the one for disposal. ETO systems might be quite large and decomposition/conversion costs might be considerably high due to materials used.

Our first level LCC decomposition for ETO systems looks like the one proporposed by the Society of Automotive Engineers (SAE) (see [4]) and is depicted in Figure 2.

The decompositions of cost buckets at the first level into the second level of CBS are more case specific. This dependence gets heavier as we proceed in constructing further levels. Thus, we intermit the explanation of CBS here. You will find a full description of the CBS for a case in the next section.

STEP 3: GATHER COST DATA AND MAKE COST PROFILES FOR EACH YEAR OF STUDY

Once the CBS of the system is constructed, the cost data for each cost bucket represented by a leaf node of the CBS tree are gathered. Cost data are spread over the life span of the system. Since the life span of ETO systems is typically in terms of (several) years, for each cost bucket, cost profiles are prepared for each year. For systems having relatively short life spans, shorter time units such as quarters or months can be used.

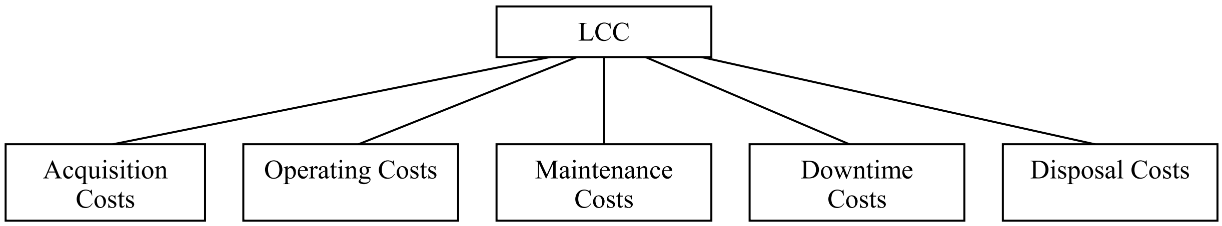

Figure 2: First level cost buckets for the CBS

STEP 4: CALCULATE NET PRESENT VALUES AND CONSOLIDATE COSTS

To make the cost buckets comparable, net present values (NPVs) of costs for each cost buket at leaf nodes are calculated. For the calculations, a discounting rate and an inflation rate are identified first. Discounting rates vary widely across industries and per business segment, so there is no unique correct rate. As LCCM intends to display costs from the customer perspective, it should incorporate the customer's preferred discount rate.

After having NPVs of the cost buckets at leaf nodes, those of cost buckets in the upstream levels of the CBS tree can be obtained simply by adding up the NPVs of their child nodes recursively. The final step of this recursion results in the LCC of the system.

3. APPLICATION

We have cooperated with an ETO company to measure LCC of a class of systems manufactured by this company. The company is also active in service business and its primary process may be briefed as the one described in the first section. The company offers service activities such as preventive maintenance, corrective maintenance, helpdesk support, call-out service, training, and revision, modification and retrofits (RMR). These activities are provided through service contracts which include spare parts management. Although there are no two identical systems, we seek for generalizations which hold for the majority of the systems. To find these generalizations, two systems were selected and their cost structure has been analysed. The company provides service for both of the systems. Here, let us mention that, we measure the LCC from the customer perspective, however we use cost data available in the manufacturer's information system. That is, the cost data used are the records of the prices charged for equipment and activities by the manufacturer.

These systems are still in use. Since their lives are not over yet, a reasonable life span is set and the costs that belong to their remaining life duration are estimated by extrapolation.

The execution of the LCCM methodology for the two systems is detailed step by step below. Our objective is not to report the exact LCC of the systems but rather

- to demonstrate an application of the methodology
- and to clarify the cost structure of the class of systems by revealing what portion of its LCC is accounted for by each cost bucket.

Thus, the numerical results are given as percentages at the end of the section.

STEP 1: DEFINE THE PROBLEM

The cost structure of a class of systems manufactured by the ETO company will be identified. (We will refer to the class of systems as "the class" from now on.) Two systems from this class are selected for the LCCM. These systems will be referred as System I and System II.

STEP 2: PREPARE COST BREAKDOWN STRUCTURE

You can see the entire CBS that is generated for the class together with the results in percentages in Figure 3. The explanations for each cost bucket of the CBS except the ones in the final level are given level by level below:

Level 0

LCC: Total costs incurred over the life span of a system from a customer perspective. This means that costs to operate the system and to keep it running are included in the total figure.

Level 1

Acquisition costs: The price the customer has to pay to acquşre the system. This includes materials, installation, commissioning, initial training and an initial set of spare parts.

Maintenance costs: All necessary costs to keep or restore the system in a functioning state; this comprises costs like preventive and corrective maintenance, inspections and spare parts.

Operating costs: Costs to keep the system running in normal operation. It includes direct and indirect labour, energy costs, facility costs and other operating costs.

Downtime costs: This represents costs incurred for system unavailability. System standstill will cause operational losses. Consequences are expensive subsequent deliveries and customer dissatisfaction.

Disposal costs: The disposal costs are neglected, as the experts in the company indicate that they are expected to be negligible compared to other cost buckets in their sector.

Level 2

Acquisition costs

During a project, the track of the costs are kept by so-called "project pricing sheets", in which project management costs, engineering costs and material supplies can be differentiated. If these are available for all projects, these breakdowns can be used. The project-specific costs furthermore consist of site costs, being installation and commissioning costs. Additionally, the costs of initial spare parts, the costs of capital (interest costs) and sales charges are tracked and should be added to complement the acquisition costs. We thus distinguish the following cost buckets:

Project costs: All costs which are booked directly on a project. These are the hours spent on drawing / engineering / simulating a system, all the materials required, the management and supervision costs, all the work executed on site like installation, commissioning and initial operator training.

Sales charges: All costs allocated to a project by the Sales Department.

Initial spare parts costs: Cost of the package of spare parts for the first period of operations. The exact composition of the package is determined in congruence with the customer.

Costs of capital: Costs necessary to finance the investment.

Maintenance costs

There are many possible classifications for the maintenance costs. One can discriminate between direct and indirect labour, between mechanical maintenance, electrotechnical maintenance and controls (software) maintenance. It can be either corrective or preventive, and, then there still are spare parts. There is even a further complicating issue: Each customer has its own cost accounting system and it may be hard to present all maintenance data in the same format. Fortunately, in general, the distinction among labour costs, spare parts costs, helpdesk costs and RMR (revisions, modifications and retrofits) costs is possible. The costs which originate from different sources/activities for different systems are gathered in a cost bucket named "Miscellaneous".

Labour costs: All personnel costs occupied with maintaining the system. Labour costs can be divided into direct labour (the service engineers actually concerned with keeping the system running) costs and indirect labour (concerned with work planning / preparation and process improvements) costs. The direct costs can be further divided into preventive maintenance and corrective maintenance costs.

RMR costs: Costs related to small system extensions, system adjustments or other additional work.

Helpdesk costs: Costs of support services which are primarily for controls-related problems.

Spare parts: Costs of spare parts usage and costs of handling, administering and stock keeping of spare parts.

Miscellaneous: Costs which cannot be located in any of the cost buckets above.

Operating costs

The operating costs are difficult for the company to measure, as they are not responsible for these activities. So things like number of operations and management employees and facility costs can only be approximated coarsely and are therefore not included in this LCCM. The only operational costs included are energy consumption costs since they can be more or less measured.

Downtime costs

The operational losses are not clearly defined, as they include both tangible and intangible costs. Some generally accepted assumptions, such as each unit of downtime costs a fixed amount of money, can be made to determine these costs. No further subdivision is made regarding this cost bucket.

STEP 3: GATHER COST DATA AND MAKE COST PROFILES FOR EACH YEAR OF STUDY

The acquisition costs have been taken completely from the company's financial system. The historical service costs are taken from this system as well. As mentioned earlier, the systems examined are still in use. Grounding on previous systems which have completed their lives and expert opinion, a life span of 20 years is assumed for both of the systems. Maintenance data of 5 years and 8 years are available for System 1 and System 2, respectively. To determine the future service costs, extrapolations have been conducted using existing failure data and values in the current service contracts for the two systems. For System II, the energy costs and the downtime costs could not be measured.

STEP 4: CALCULATE NET PRESENT VALUES AND CONSOLIDATE COSTS

Normally, a discounting rate is identified and the NPV of the cost buckets at the leaf nodes are calculated first. Then these values are aggregated in the upstream direction of the CBS tree to have the NPVs of all cost buckets. However, since there is no unique actual discounting rate, we consolidate the costs without discounting in this application. The percentages of nominal cost values are given in Figure 3. Two percentages are reported for System I. As noted before, the operating costs and the downtime costs could not be measured for System II. The first percentage for System I in each cost bucket shows the portion of the cost bucket in LCC when the downtime costs and operations costs are included, while the second percentage is the portion when these costs are excluded. A dash ("-") instead of a percentage at a particular position means that the corresponding costs were not measured.

For System I, both the maintenance costs and the downtime costs together account for 74% of the LCC. Maintenance is needed because the system is disrupted by failures and downtime costs are the net result of failures. Furthermore, the maintenance costs are higher than the acquisition costs in both cases. These results suggests that, if the company targets at lower LCC, it should take actions on processes and activities which affects the cost buckets relevant to maintenance and downtime.

The labour costs occupy a large portion of the maintenance costs. This is due to the locations of the systems. Both systems are installed in western Europe and it is well known that labour costs are quite high in this part of the world. Thus, by this figure it can be confirmed that the LCC of a system and its cost structure significantly depend on its location. LCC and the cost structure of similar systems at different sites might differ considerably.

Several NPV calculations can be conducted by having some reasonable assumptions on the cost figures given in Figure 3. You can see the percentages with respect to NPVs in Table 1 when the discounting rate is supposed to be 0.05 for both of the systems. The results indicate that the discounting rate affects the percentages, as expected. Yet, the maintenance costs and the downtime costs are still high in comparison to the acquisition costs.

4. CONCLUSIONS AND FUTURE RESEARCH

We have introduced an LCCM methodology which is adapted from an LCCA one. Our starting point was the need for the measurement of LCC for complex systems manufactured by an ETO company. The cost structure of two ETO systems have been revealed by using this methodology. The maintenance costs and the downtime costs appear

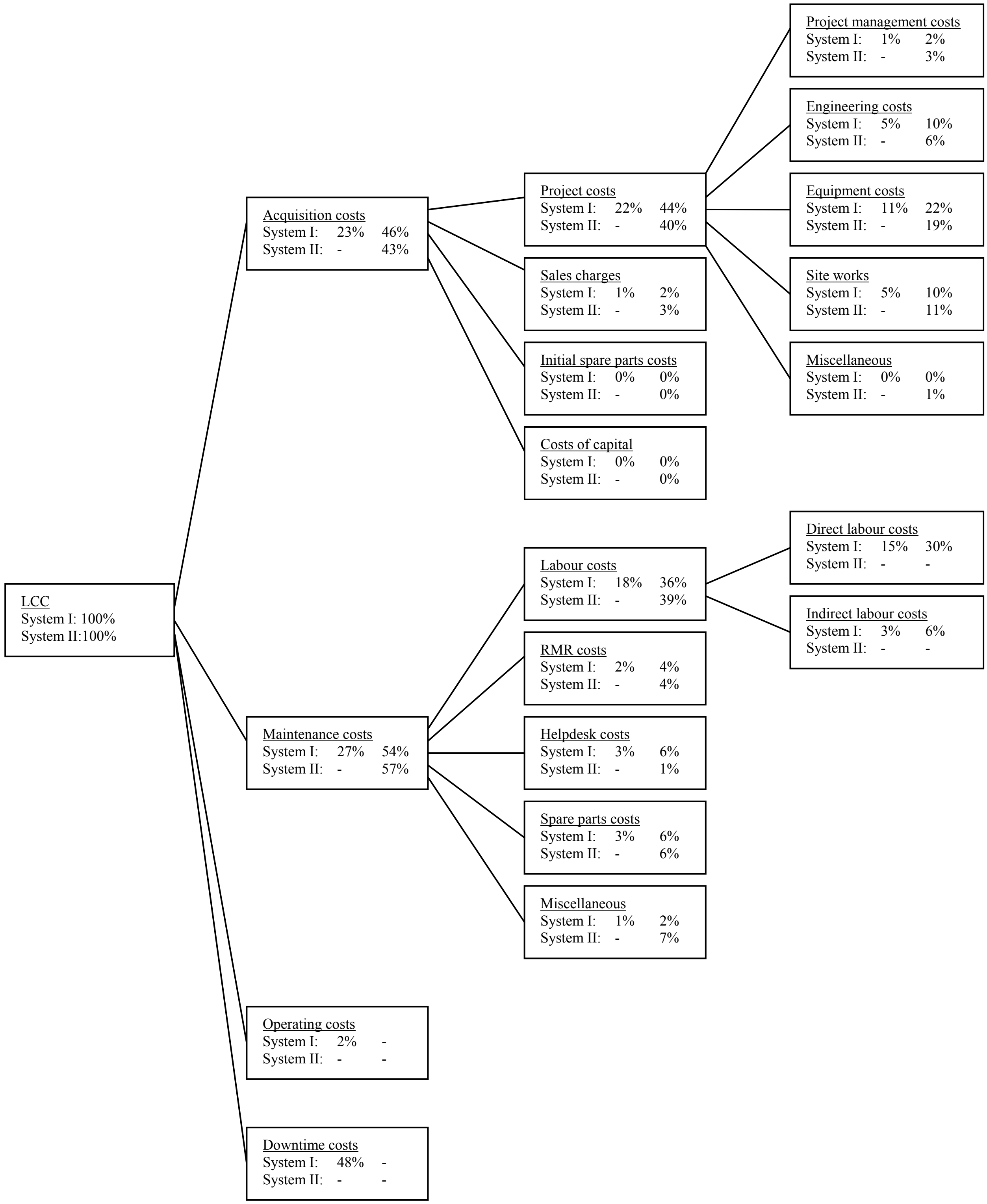

Figure 3: The CBS for System I and System II

Table 1: Percentages of the cost buckets in the first level of the CBS tree after discounting (discount rate = 0.05)

	Including the operations costs and the downtime costs		Excluding the operations costs and the downtime costs	
	System I	System II	System I	System II
Acquisition costs	33%	-	58%	55%
Maintenance costs	24%	-	42%	45%
Operations costs	2%	-	-	-
Downtime costs	41%	-	-	-

to occupy a significant portion of the LCC of these systems. Thus, the manufacturers of such systems should take actions in service and support activities to lower LCC.

Service activities are driven by failures in a system. Failures in the system mostly depend on its structure which is almost fully set during the initial phases of its project, namely the design phase. Thus, reliability and serviceability of a system should be taken into account concretely in the early phases of its project.

Having a life cycle perspective for purchasing decisions would be adventagous for the users of ETO systems in the long run. A system might have large LCC while its acquisition costs are relatively low. Besides, their activities and processes might have significant impacts on LCC. Many problems may occur due to the uncleanness, operators' faults, etc. Hiring adequate employees, their training, arrangement of adequate working conditions, keeping equipments clean and so on play roles in the life cycle of a system.

We have been working on LCC prediction models for new systems as well. These predictions are based on (the results of) our measurements. With such models, different design alternatives can be compared and the most cost-efficient options can be selected in the early phases of a project. The results obtained by such models can also be used to convince a customer to choose a system with high acquisition costs but low service costs and low LCC in the end.

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