A Life Cycle Cost Calculation and Management System for Machine Tools

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Abstract

A life cycle cost calculation and management program for machine tools is presented here. Its aims are: to provide life cycle cost data prediction at the offer phase and to support design phase decisions by managing real machine tool behaviour data. The system is being tested in various types of machine tools such as machining centres, transfer lines and grinding machines. It comprises four main areas: cost model design, cost concept and basic data definition, product model design and instance cost calculation. It also allows for generating customer defined outputs in various formats and integration with commercial reliability analysis packages

Keywords

LCC, RAMS, machine tool, software program, design, quotation

1 INTRODUCTION

Life cycle concepts are increasingly being considered by industrial good manufacturers. The issue of the full cost of a product, i.e., not just the purchase cost but also the costs of using, keeping, repairing if necessary, and disposing of it, has been around for many years but it is now becoming a central worry for machine tool manufacturers [1]. Thus, machine tool customers and, among them, the big car manufacturers, are requesting their OEMs to provide life cycle cost data on the basis of the life cycle behaviour of their products, i.e., the machine tools they use to produce their cars' parts [2]. It is clear that in order to be able to deduce the cost that a machine tool is going to generate to its user, a deep knowledge of the real behaviour of the machines of the same or similar type is required. This knowledge can only be retrieved from historical data since machine tool testing basically guarantees only functionally rather than reliability. The continuous technology progress, products increasingly customised that multiply the number of variants, all this makes even more difficult to collect and manage the right data in order to make a realistic prediction of life cycle costs.

There are a number of cost models to represent product life cycle costs, proposed by international organisation or experts on this field [3] [4] [5] [6] [7].

As a general rule, the numerous cost concepts that can be assigned to the product can be grouped in the following three categories (from the point of view of the purchaser/user of the product) [8]:

1. Acquisition costs
2. Ownership costs
3. Disposal costs

Acquisition costs are composed of the product price plus all those costs associated to installing it and set it up running such as the various administration costs, installation costs, training costs and shipping costs. All these are quantities that derive from the cost estimation that the manufacturers should calculate for the activities they develop (concept and definition, design and development, manufacturing, assembly, installation). In these sense, they are visible costs and, so, fairly well known ones.

Ownership costs take place during the longest period of machine life, which is its use phase – operation and maintenance (Figure 1). In this case the machine is no longer controlled by the manufacturer and, specially, after the warranty period, more often than not the manufacturer does not have information on the actual behaviour of the machine.

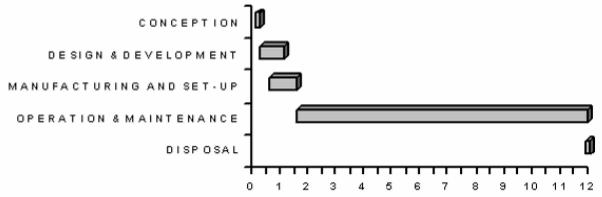

Figure 1: Machine life phases [9]

Ownership costs may be subdivided into operating costs or normal working costs and maintenance costs, if there is any. It may be that maintenance costs may not exist for certain products like lamp bulbs, which are disposed of as soon as they fail, but they are essential in the case of repairable systems like machine tools.

Within the group of maintenance costs a simple division may be carried out to separate programmed maintenance costs from unprogrammed maintenance costs. The first ones could also be called preventive maintenance costs and refer to all those costs of materials and personnel involved in maintenance operations that are executed according to a plan that consists of a list of operations to be carried out with certain frequency, usually (though not always) proposed by the machine tool manufacturer. These costs are easy to predict for the machine tool manufacturer, since it is him who proposes them. However, they are usually not properly justified and optimised in the view of real machine performance data.

For example, a machine tool manufacturer establishes a period of 30 days for checking the tension of certain belts connecting motors to headstock spindles following the belt supplier recommendations. This is an operation that takes 15 minutes, machine idle. According to real data of historic behaviour of these belts, they fail every 6 months. An increase of the checking period seems reasonable. This is not an unusual case.

Unprogrammed maintenance costs refer to all those expenses of materials and personnel derived from machine failures that produce stops in production.

Estimating the costs of future breakdowns of machines currently being manufactured is not a trivial task and can only be made, in a reasonable manner, based on probabilistic grounds and historical data. Within these unprogrammed costs it is also possible to include what are called Consequential Costs related to the damage to image and reputation due to the breakdown and others such as the loss of revenue, as a result of machine unavailability during repair.

Finally, disposal costs or retrofitting costs (if the machine is recovered rather than disposed of) may greatly vary according to the laws in force in each country relative to the obligation of the user or the manufacturer to manage the end of life phase of the product. There are some sectors like the chemical and nuclear where the disposal of products may become a significant cost factor. Closer to the machine tool industry, the automotive sector is forced to reuse or recycle a significant part of the automobile [10]. A similar directive for machine tools cannot be disregarded in the near future.

The automotive sector has been demanding machine availability data to their original equipment suppliers for some time now. In the last few years it is also requesting life cycle cost data. Ford, for example, not only provides a cost model to be worked out by its machinery suppliers but enforces a methodology of Reliability and Maintenance to be implemented at the manufacturers' enterprise [11]. DaimlerChrysler identifies the Total Cost of Ownership (TCO) as, basically, composed of the maintenance costs (both scheduled and unscheduled) of a machine tree of Functional Subassemblies and their respective Constructive groups according to a predefined structure.

2 NEED FOR A LCC PACKAGE FOR MACHINE TOOLS

As mentioned, although the notion of the Life Cycle Costs is not a new one, the application to machine tools is largely a topic for research. Research projects specifically dealing with this topic in Europe are only a few. A German national project, LoeWe [12], aims at reducing machine tool life cycle costs and includes a LCC navigator. Considering that, as said, important car manufacturers are requesting life cycle costs, one of the main reasons for the lack of specific applications for machine tools may be the fact that objective data acquisition, i.e., data about the real performance of machine tools is not easy to obtain. Project TOPFIT [13] was specifically set up to cater for this problem. Recently, another project, PROMISE [14], although addressing the issues of any type of product, aims at using PEIDs (Product Embedded Information Devices) for enabling proper data acquisition and, therefore, an analysis not only based on estimations and predictions but on real data.

An LCC tool applied to machine tools has to consider the specific cost structure of machine tools with its particular cost concepts. Clearly, there are a large number of machine types within the definition of machine tool and so the number of different cost items could be considerable. Certainly, the specifics would appear as one navigates deeper on the cost breakdown structure (CBS). Therefore, common layers can be identified in the larger cost groupings, although different authors would propose different classifications, as was mentioned earlier. A LCC software tool should provide these diverse cost concepts as well as the possibility of defining new user defined ones.

The management of different cost models for the various types of products of a machine tool manufacturer has also to take into account the cost models imposed by the customers, such as Ford or DaimlerChrysler mentioned before. So, some kind of mapping is required between the manufacturers' own models and the customers' ones.

The question of managing different cost structures is further complicated by the need for combining them with the product structure and the several branches of subassemblies it is composed of. A flexible tool has to be able to combine product structure with cost structure, so that the whole set of cost concepts can be applied to each of the product subassemblies. The life cycle cost models proposed by Ford and DaimlerChrysler lack this flexibility and include a fixed combination of cost and product. In Ford all costs are assigned to the entire machine and in DaimlerChrysler maintenance costs, which are the only ones being assessed, are evaluated at the level of constructive subassemblies.

A basic feature of a LCC tool for machine tools is the evaluation of Maintenance costs which are based on the RAM (Reliability, Availability and Maintainability) parameters of the machines. Obtaining, evaluating, and managing data related to these parameters is an essential task to be incorporated into the LCC tool. Several commercial packages exist to perform the task of calculating failure and repair distributions and their corresponding parameters.

As mentioned above, most commercial packages developed to calculate life cycle cost come from companies related to RAM management. Historically these programmes were focused on electronic systems, originating most of the actual standards and parts data libraries [15].

The LCC modules were introduced later to create different cost structures and to evaluate them looking for the best one. Relex [16], for example, has a module integrated in its package which is very helpful to create a CBS based on a cost tree structure and cost mathematical functions created with global or local variables. In the same line, Isograph [17] has developed a program called LCCWare which include these utilities in addition to a frequently used parts costs manager.

Other commercial packages, like Reliasoft's Blocksim [18], focus the LCC evaluation on the simulation of events associated to a block diagram. Each event has predefined some costs, for example spares, logistic or personnel cost. The sum of all these costs originated during the simulation gives a value for the LCC of the simulated system.

However, the use of these packages to evaluate the feasibility of a new design during the conception and definition phase is very complicated. These software programmes are not prepared to manage mechanical parts and all the data related to their manufacturing and performance.

In the case of machine tools, there is only a small number of cost models, most of them defined by standards or by certain customers. The OEM's real need is a software package that allows an easy application of a given cost model to a particular product. A quick product structure definition together with a flexible data management and storage are other features required by this software.

Therefore the objective of this package would be to assist the supplier at two phases: first, during the conception of new equipment, evaluating all the possible configurations by means of existing and tested parts data to obtain the best one; and second, during the offer phase supporting the quotation process by means of the use of real performance data of the equipment.

3 LCC TOOL FEATURES

A software tool to support the management and storage of data related to costs (LCC) and performance (RAM) along the product life cycle for machine tools is being developed as the result of some preliminary work carried out in TEKNIKER and IDEKO, together with early work in the PROLIMA project [19], which is a running Collective Research project directed to the machine tool sector, where both the environmental and economic impacts of machine tools along their entire life are being studied.

The package addresses the requirements of such a tool as described in the previous chapter. It can be both used for offer making and as a decision support system at the design phase. In both cases, the calculation of the LCC is required either applied to the whole machine or to a particular subassembly.

It comprises four main areas: Cost Model Design, Concept and Basic Data Definition, Product Model design and the Instance Area.

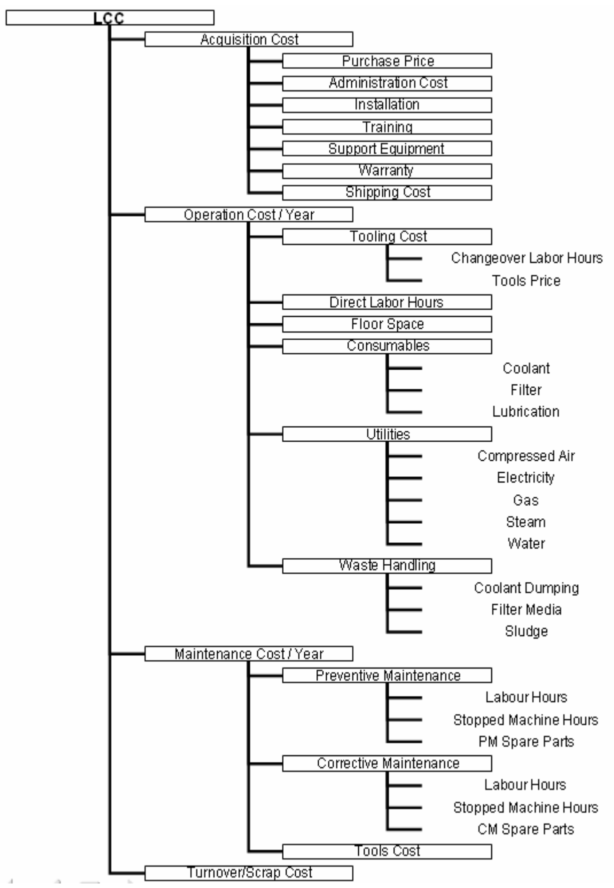

Figure 2: Predefined Cost Breakdown Structure

Within the cost model design area, the tool developed allows the user to define all the cost concepts related to foreseeable activities of the equipment along its life cycle, grouping and classifying the costs concepts according to customer's needs or its own criteria. The software has a predefined LCC calculation model adapted to machine tool manufacturers' needs, but it is possible to define a user designed model.

The LCC predefined CBS is as shown in Figure 2.

At the lowest levels of the CBS, there are the basic cost concepts which depend, through formulas, on a series of input data [20], which can be of the following types depending on the source of the information:

a. Machine User Data
b. Machine Manufacturer Data
c. General Data

These data are defined in the Concept and Basic Data Definition area. They mostly refer to general machine characteristics like the number of operators required to work with it or the floor space it occupies. Other data depend rather on the processes the machine is to carry out. If these are known then the machine supplier can easily obtain the production rate of the machine, the various consumptions like electricity, air, gas, steam, etc.

Certainly, in general purpose machines, one can only assume a certain use of the machine and derive consumption data from there.

There are finally certain costs that depend on data that is readily available but that has to be worked out from sources like work order sheets, machine stop records or the technical service reports from breakdown assistances or programmed interventions. These are the data required to obtain the parameters that define machine performance in terms of Reliability (MTBF), Maintainability (MTTR) and Availability, which is a combination of the previously mentioned two. These data is usually associated to failure modes of components that are included in subassemblies of the machine. Thus, it is possible to derive the global machine RAM parameters from the failure modes, provided that a product model is defined to link the machine to the failure modes. So, in much the same way as CBS definition, the product model has to be defined in the LCC tool and then RAM data can be assigned to each block of the product structure.

Among the data sources for calculating RAM parameters cited above, machine stop records give the most objective information to derive them. The LCC tool is able to read raw data from the files containing the stop records, filter them and using commercial packages obtain the product structure associated to the RAM parameters and integrate the results within the LCC tool database.

Filtering data is necessary because:

1. Raw data from the monitoring of the machine performance can be dirty data as a consequence of lost information or wrongly classified data. These entries may cause bad software performance or bad RAM results. Consequently a manual filtering is required. Nevertheless, taking into account the huge size of data commonly handled, to use a software that assists performing this task greatly eases an otherwise tedious work.

2. Commercial packages for calculating RAM parameters work with times between failures, while data acquisition (monitoring) programs usually get the start time and end time (dates and moment). It's necessary to calculate the intervals between failures with a same root cause considering the work calendar of the equipment.

3. By filtering, all the other available sources of information (for example work order sheets, technical service reports or shop floor control data) can be combined with the monitored data to do a better classification of the root causes of each failure.

Data originated in different phases of the life of a particular machine can be recorded and, so, the LCC tool is also a machine performance data management system, which allows studying the evolution of machine behaviour along its entire life cycle.

The software is able to generate graphical reports to show the evolution of the costs and to infer a certain tendency or average value in a period of time.

As mentioned, product models are defined in the product model design area. Previously, a list of subassemblies must have been introduced and the software allows organising them into a hierarchical tree. Product models can also be imported from other programs, where the product structure has already been defined like, for example, in system reliability assessment tools where reliability and maintainability, together with availability, are derived for a set of subassemblies of the product from bottom to top. The current software prototype can accept BlockSim hierarchical trees (Figure 3).

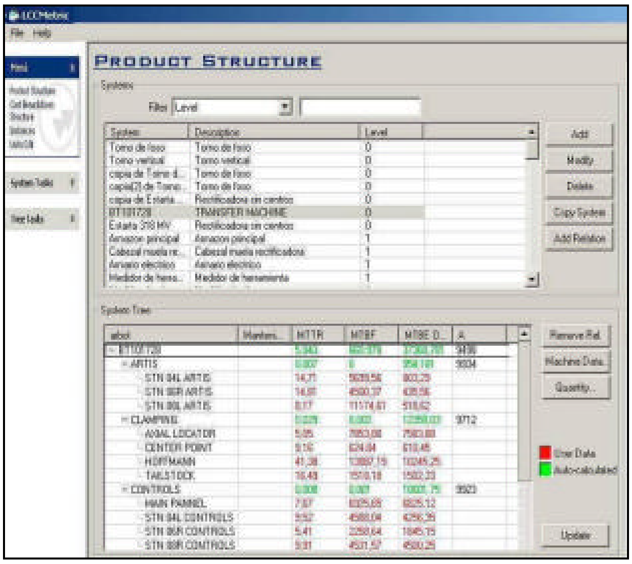

Figure 3: Imported Product Structure in LCCMETRIC

The LCC calculation is carried out in the instance area (Figure 4), where the cost model and the product model (or rather a subassembly of the product model) for a given customer are selected and input data is introduced. The result is the LCC for the subassembly chosen.

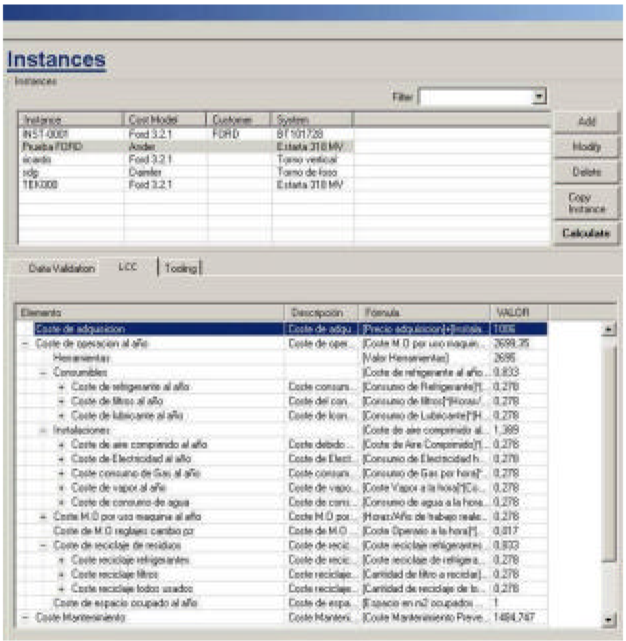

Figure 4: Instance Area

The software also has the possibility of working with different unit and monetary systems and a conversion facility is also provided. Similarly, several languages can be managed when the user language is different from the customer's one.

As mentioned, this package is aimed at supporting the decision making process at the design phase of a new product. The LCC of different design alternatives can be calculated previously to decide which the best one is or to identify principal costs drivers.

The program also allows us to generate customer defined outputs in various formats requested by the clients (FRED-Ford, DAIMLER).

4 EXAMPLES

The developed software has been evaluated in two test cases, each of them for different machine types and for different customers. A brief summary of each experience as well as some conclusions are shown below.

4.1 Transfer machines

In this first case, the manufacturer is the special machine tool builder ETXE-TAR and the machine selected for the test is a transfer machine designed for crankshaft machining. The customer was an automotive supplier that requested LCC data to be included in the offer of the transfer machine. A similar machine had been acquired in the past by the same client.

A RAM parameter analysis was carried out beforehand from machine stop record files of that already delivered machine. The analysis was carried out using the commercial packages Weibull++ and BlockSim. The result of this study was a hierarchical block diagram tree where the RAM parameters had been obtained per each of the blocks representing different subassemblies up to the complete machine in the root. The imported product structure and corresponding RAM parameters are partially shown in Figure 3.

The customer imposed a given cost structure very similar to the one shown in Figure 2, the predefined LCC model.

The results obtained for the machine being studied can be summarised as follows:

Acquisition Costs:	50%
Operation Costs:	22%
Maintenance Costs:	28%

Turnover/scrap costs were negligible compared to the costs of the other groups.

Further itemizing the operation costs (22% of the total) the results per each type of cost were as follows:

Tooling costs:	50%
Consumables:	10%
Energy:	35%
Floor Space:	3%
Inventory Costs (Spare parts):	2%

Finally, Maintenance costs (28% of the LCC) can be distributed among the following concepts:

Preventive Labour:	13%
Corrective Labour:	85%
Spares:	2%

Improving machine reliability and maintenability, namely, availability requires acting on the corrective maintenance cost figure, with the aim of minimising the number of breakdowns and the time required to set the machine back in operation, bearing in mind that corrective maintenance tasks amount for 23,8% of the total life cycle costs.

Therefore, the LCC cost breakdown provided the information required for acting on reducing costs on those concepts that had greater influence on the total costs and, at the same time, could be easily handled.

A systematic improvement process started from those types of breakdowns that caused greater unavailability. Thus, several design solutions were proposed for preventing machine stops due to uncontrolled chip removal, which was the main cause of unavailability of the machine. The implementation of these design solutions lowered the corrective maintenance task costs by a factor of 2.

Similarly, although it did not have the impact of corrective maintenance, preventive or scheduled maintenance task frequencies were reviewed and adjusted to real component behaviour data. Thus, frequencies of spare part replacements were reduced. This allowed increasing machine availability without causing more breakdowns.

4.2 Grinding machines

The second example was carried out with centerless grinding machines from machine tool manufacturer ESTARTA RECTIFICADORAS S.COOP. This company belongs to the Danobat Group, the biggest Spanish tool manufacturer.

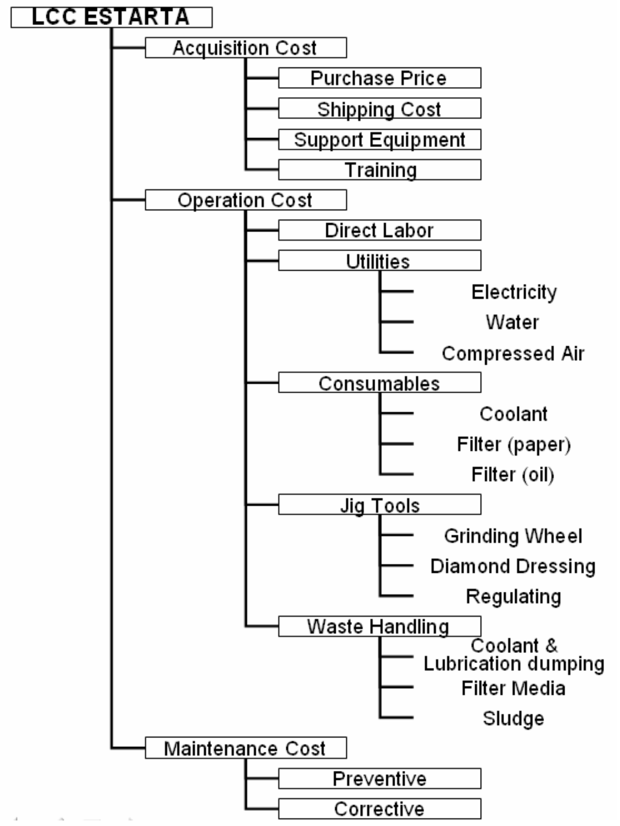

Figure 5: Cost Breakdown Structure in a centerless Grinding Machine.

The objectives of carrying out a life cycle cost analysis in a centerless grinding machine were: to define the operation cost along their life cycle, to compare the acquisition cost with the sum of the operation cost and the maintenance cost, to identify grinding wheels, energy and lubrication consumption. Finally, the other objective was analysing how the LCC would be reduced.

The hypotheses introduced in the cost model for LCC calculation were: 10 years machine life and 6504 total working hours per year. The selected parts were a shock absorber rod and a generator axis.

The first step during the life cycle cost analysis was the definition of a customised mathematical model (Figure 5).

The analysis of this grinding machine LCC study showed that 80% of the costs happen during the operation phase (operation + maintenance). In addition, it has to be emphasized that the corrective maintenance cost obtained happened to be very small as compared to the operation cost. This is due to the fact that this type of grinding machines are characterised by high reliability and maintainability, i.e., machine breakdowns are scarce and repair quick. The question for the manufacturer is whether the customer actually demands such a reliability and whether it would not be more competitive in the market a cheaper but less reliable machine.

The results of the life cycle cost analysis revealed that five activities were the ones that generated more cost burden during the life cycle of the machine (Figure 6).

Direct Labor	51%
Grinding wheel	13%
Energy consumption	6%
Purchase price	8%
Preventive maintenance	9%

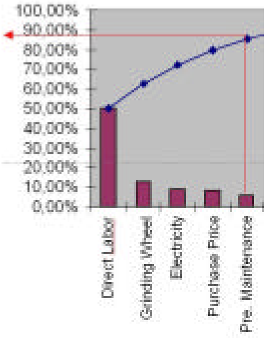

Figure 6: Pareto Diagram

As much as 87% of the total LCC is generated by the five mentioned activities. Improving them, the LCC would improve considerably.

As it is known, it is during the "Conceptual design" phase where more than 66% of the LCC is committed. The opportunities to reduce the LCC fall considerably as the project goes forward along its development process. The analysis carried out here by ESTARTA was applied to an already manufactured machine. So, it was not possible to take to major design changes.

However, observing the resulting cost breakdown structure, activities that affect more the life cycle cost were identified.

For the specific case tested here, ESTARTA presented the results from this analysis to a potential client offering him a solution with an improvement in the automation of the process: automatic loading and downloading system and an automatic wheel dressing, which reduced in 13% the LCC of the machine operating costs. In addition, ESTARTA offered the client scaling the servo-motors power to the specific works that the machine was actually going to carry out. This adaptation reduced the energy consumption cost in an extra 11%. With all these new solutions the customer obtained a 10% reduction of the whole life cycle cost.

5 SUMMARY AND FURTHER WORK

In this paper a life cycle cost calculation and management program for machine tools was presented. The program allows for the calculation of machine tool life cycle costs as well as managing machine RAM data. Further work should be developed in improving the configurability of the program and the management of different sets of RAM data along the life cycle of machines. Within the mentioned PROLIMA project, the idea is to integrate the package with an environmental impact assessing program to assist the machine tool design phase.

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