SIXTH FRAMEWORK PROGRAMME
HORIZONTAL RESEARCH ACTIVITIES
INVOLVING SMES
COLLECTIVE RESEARCH

Project No. 012442

PROLIMA

ENVIRONMENTAL PRODUCT LIFE CYCLE MANAGEMENT FOR BUILDING COMPETITIVE MACHINE TOOLS

Horizontal Research Activities involving SMES Collective Research Projects

D11.3 Final Activity Report

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CONTENT

Introduction

Sustainable manufacturing is one of the key challenges of producers all around the world. Despite of the frequent use of the sustainability term, it is not clear in an operational way what sustainability means applied to different industries and products. The machine tool industry plays a key role in providing production capabilities to manufacturers, so it is of significant importance to provide machine tool builders with methods and tools in order to increase the sustainability of production machinery. In fact, machinery and capital is one of the main inputs involved in the manufacturing transformation process. This publishable executive summary addresses the machine tool industry and proposes specific tools and methods to enable sustainable design of future machine tools, as an enabler for sustainable manufacturing.

The main contributions of the PROLIMA project are a Sustainable Machine Tool Design Methodology supported by a Design Support Software System (DSS) for assisting designers in building more sustainable machine tools and a Machine Tool Sustainability Index (MTSI) for assessing the sustainability of machine tools. Although the MTSI has been specifically developed for the machine tool industry, the DSS is a valid tool for designing sustainable products considering economic, environmental and social aspects in any industry

Up to now there were several methodologies and software modules of Prolima finished. These methodologies and modules are described in the following sections.

Sustainable Machine Tool Design Methodology supported by the DSS software

PROLIMA Sustainable Machine Tool Design Methodology (SMTD^{M}) aims to provide a global methodology for the **sustainable** development of machine tools, which implies the consideration of life-cycle costs (LCC), dependability and safety (RAMS), environmental impact (LCA) and industrialisation knowledge during the whole life cycle. A design methodology and supporting tools and techniques have been provided.

Sustainable Development stands for meeting the needs of present generations without jeopardizing the needs of futures generations - a better quality of life for everyone, now and for generations to come. Sustainability is understood as a three-dimensional concept, considering **economic**, **environmental** and **societal** issues.

The objectives of the Sustainable Machine Tool Design Methodology are to:

- Provide machine tool manufacturers with a machine design methodology to support sustainable production.
- Integrate sustainability dimensions and theories in use into a single methodology.
- Provide a pragmatic guidance for calculating sustainability indicators, as well as the Sustainability Index.
- Increase the knowledge base of machine tool manufacturers, allowing them to analyse design alternatives based on real-life data.

PROLIMA Sustainable Machine Tool Design Methodology can be used in late conceptual and early design stages, when most of critical decisions are made and costs are committed. However, it has a life-cycle approach and considers reliability, cost, knowledge and environmental dimensions for machine building.

Machine Tool customers are requiring more reliable, cleaner and cheaper machines, not only considering the acquisition cost, but taking into account the whole life cycle. Moreover, European manufacturing faces the challenge of strengthening its ability to compete in terms of added value, since purely cost-based competition is not compatible with the goal of maintaining the Community's social and sustainability standards. Accordingly, the development of new and consistent methodologies/protocols for implementing sustainability concepts is of significant importance.

These broad requirements and needs drive PROLIMA project. By the end of the project, machine tool manufacturers will have new methods and techniques to support the design process and build more sustainable products.

The PROLIMA Integrated Methodology for Building Sustainable Machine Tools provides a global methodology which considers life-cycle costs (LCC), dependability and safety (RAMS), environmental impact (LCA) and industrialisation knowledge in the design of the machine tool.

The methodology is described in **Figure 1**.

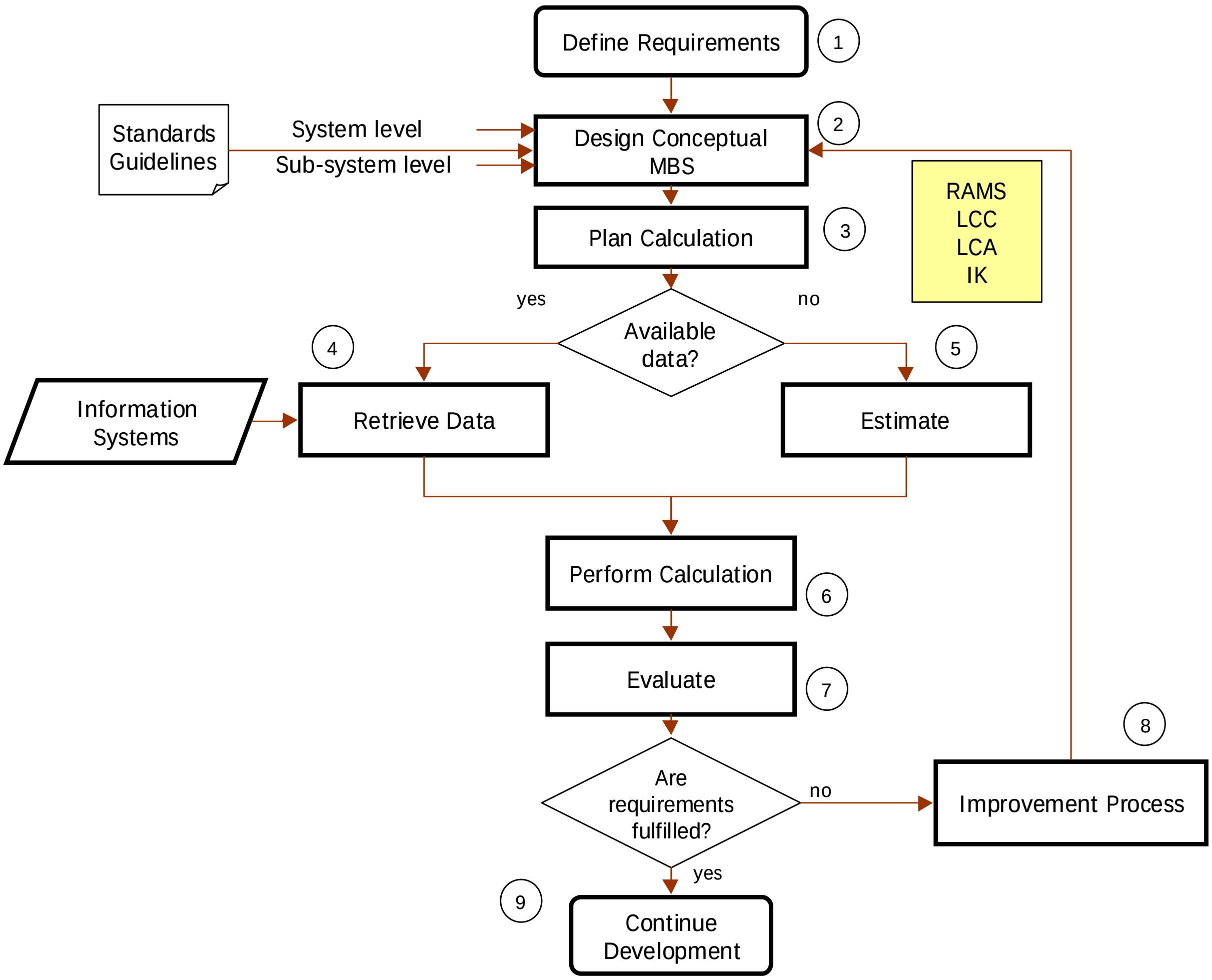

Figure 1: Integrated Methodology for Building Machine Tools

1.- Define Requirements

The design process begins with a definition of the requirements the new machine tool must meet. Apart from technical requirements which depend on the machining capability expected for the machine, the sustainable design of machines implies the establishment of cost, environmental, reliability and industrialisation requirements.

The Requirements Model Management provides the functionality for creating and editing requirement models. These models guide the user through the decision-making process between the alternatives generated during the project. A Requirement model (RM) is a set of requirements for the evaluation of design alternatives. A project will have an associated RM. The user will be able to create a new RM, to edit, copy and save it with another name and to delete a RM. A RM will consist of a tree with different requirements. The last level of the tree will be related to existing tables: cost elements (for cost related requirements), impact categories (for environmental related requirements) and system data (for general data and machine data). A “Requirements model” will have an associated “Cost Model”, in order to interpret how cost elements are calculated. For each new requirement model a cost model has to be selected so a connection between the LCC module and the DSS is needed here. An example of the main interface is shown in **¡Error! No se encuentra el origen de la referencia.**.

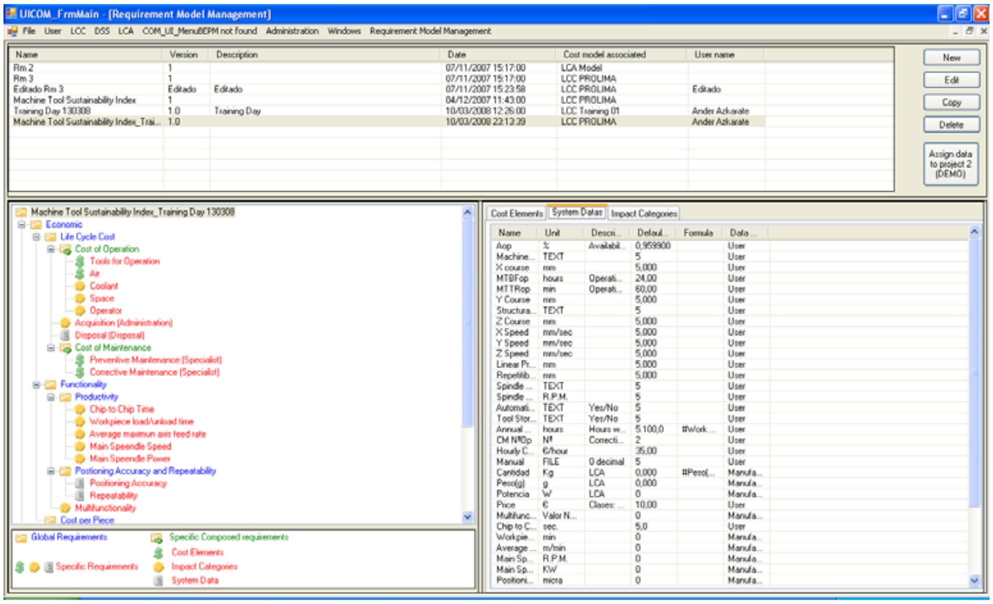

Figure 2: Requirement Model Management Interface

The Machine Tool Sustainablility Index (MTSI)

The Machine Tool Sustainability Index offers a way of measuring the sustainability of a machine tool. It has a multi-dimensional approach, considering both the economic, environmental and social aspects of the machines. The development of this indicator has been based on Ford of Europe’s Product Sustainability Index (PSI), following the same guidelines but adapted to the Machine Tool Industry:

- Key environmental, social, and economic attributes.
- Controllable (mainly influenced by the Product Development team).
- No additional data needed.
- Bottom-line issues only (the overall life cycle impact).

- Reduce to manageable amount of indicators.

The aim of the sustainability index is to provide a holistic view to the designers and the whole development team on the most critical aspects of the machine. It does not replace the detailed LCC and LCA calculations, but focuses on the most significant factors.
This sustainability index can be used to:

- Study the product portfolio evolution in terms of sustainability. This objective would be integrated within a sustainability strategy of the organisation.
- Analyse sustainability improvements when redesigning a machine.

For the economic aspect, both cost and value aspects have been considered. On the one hand, cost is covered by the Life Ownership Costs and the Cost per Piece, being these two indicators determinant for the competitiveness of the machine tool customer. On the other hand, value is assessed taking into account concepts such as multifunctionality, accuracy ad reliability.

Environmental impact is considered by the inclusion of three elements: electrical consumption, metal working fluids and materials. Electrical consumption is the most important environmental impact. Metal working fluids and materials are of critical importance for the lubrication of the tool-workpiece interface, tool life, machine tool speeds and feeds and chips removal. Finally, the impact of materials is considered. It has to be pointed out that more than 50% of the commercial value of machine tools is produced outside the manufacturer's premises from different suppliers. For this reason, some information of commercial parts is not available for the material assessment.

The social dimension of the machine considers the safety and the user-friendliness in order to assure the well-being of employees and machine operators. Safety involves the actions taken by the machine tool builder to avoid risks of harm. On the other hand, the user-friendliness assesses the ease of operation and enhanced functionalities to assist the operators-

The Sustainability Index is composed of 8 main factors. Each of these factors is measured with different units. It is not intended to have a single value of machine tool sustainability, but the comparisons will be done for each of the factors. Furthermore, the sustainability values can be used in a two-fold way, this is, showing absolute values or showing the relative values compared to a previous similar machine. In fact, the comparisons will make sense when similar machines (e.g., similar technology or function) are compared, due to the high heterogeneity within machine tools (structure, function, critical performance variables…). Due to this heterogeneity, some of the factors may have different importance levels, so they must be properly considered and weighted.

2.- Design Conceptual MBS

The second step of the methodology is the definition of the Machine Breakdown Structure, which implies a high level design of the main systems and sub-systems of the machine.

In the system tree the machine tool parts a listed so the system tree management enables the user to create, remove, edit, move and copy nodes of the tree, set restrictions on trees, manage system data and generate and manage alternatives. It is an easy way to set up different systems because a security prevents the user from changing existing system where parts can't be replaced anymore.

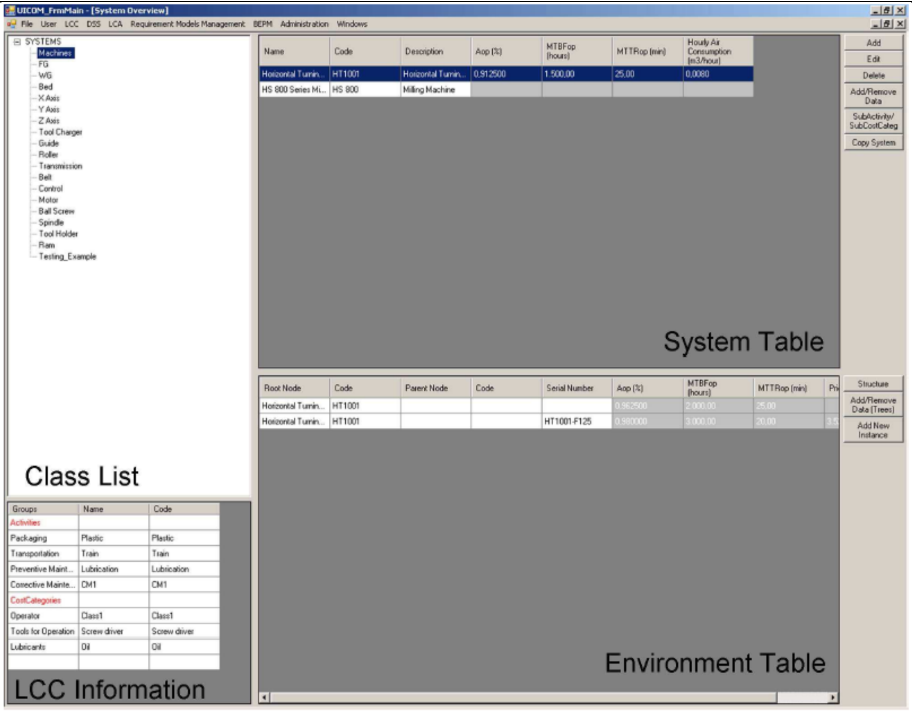

Figure 3: Systems Tree Management Interface

The system management window (**¡Error! No se encuentra el origen de la referencia.**) is subdivided into four areas. The upper left area shows the existing classes (class list), the lower left area shows LCC information, the upper right area shows the entries for each class within the database (system table) and the lower right area shows the information about the environment where the systems are built in as a subsystem (environment table).

3.- Plan Calculation

Once the machine breakdown structure has been established and before going into detail in the design process, the calculations required to perform RAMS, LCC and LCA analysis have to be planned.
The calculation of these indicators imply several actions, such as the following ones:

- Define the scope of the analysis, the functional unit and machine working scenario
- Define required variables
- Define data sources
- Check the availability of data, in order to calculate or estimate
- Establish the data collection plan
- Determine the data analysis methods and software

4.- Retrieve data

Retrieve data from available sources, such as:

- Reliability data sources: TAS reports, customers, Reliability Monitoring System…
- Environmental data sources
- Cost data sources: PDM, ERP, Machine, Customer…
- Industrialisation Knowledge: ERP, Production…

5.- Estimate data

If there is not available data for some of the system or sub-systems of the machine, an estimation procedure will be started. The main estimation techniques for cost, reliability and environmental impact estimation are commented briefly.

Analytic estimation: This technique requires the decomposition of the work in elementary tasks, parts and materials. This method generally leads to precise results, but needs detailed product and manufacturing process information.

- Analogy-based estimation techniques: Estimation by analogy is the process of finding one or more elements that are similar to the one to be estimated and then derive the estimate from the values of these elements. It is based on the assessment of degree of similarity among elements. The attributes or features to compare can be: main characteristics, function, geometry, process, material… Case Based Reasoning technique will fall within this category, which is based on the search of similar solutions in previous registered cases.
- Parametric estimation: It requires the identification of significant parameters influencing the dependant variable. The regression model represents the relationship of the parameters (independent variables) and the dependent variable.
- Feature based estimation: This is a relatively new estimation technique, based on feature based modelling (CAD/CAM systems). Products can essentially be described with their associated features (holes, flat faces, edges, folds, etc.) and these features are related to different impacts (cost, environmental…).

6.- Perform calculation

Once the data have been retrieved or estimated, the final indicators must be calculated. This requires the existence of a model or expression for the calculation of LCC, RAMS and LCA.

LCC Calculations:

Whereas purchase decision of a machine tool has been governed by the acquisition costs so far, this decision-making process is currently moving towards a global approach considering life cycle costs of a given machine tool. Indeed, machine tools users are asking always for more information on the costs generated by the use of a machine tool during its whole life cycle. The Prolima Life Cycle Cost Module (LCC) provides machine tool manufacturers with the capability to define customised Cost Models to be applied to their machines so that they can provide their customers with reliable and precise information about the Life Cycle Cost of their machines. The definition of the Life Cycle Cost model for machine tools include a cost breakdown structure and mathematical models, linking the cost of components with the global system (see **¡Error! No se encuentra el origen de la referencia.**).

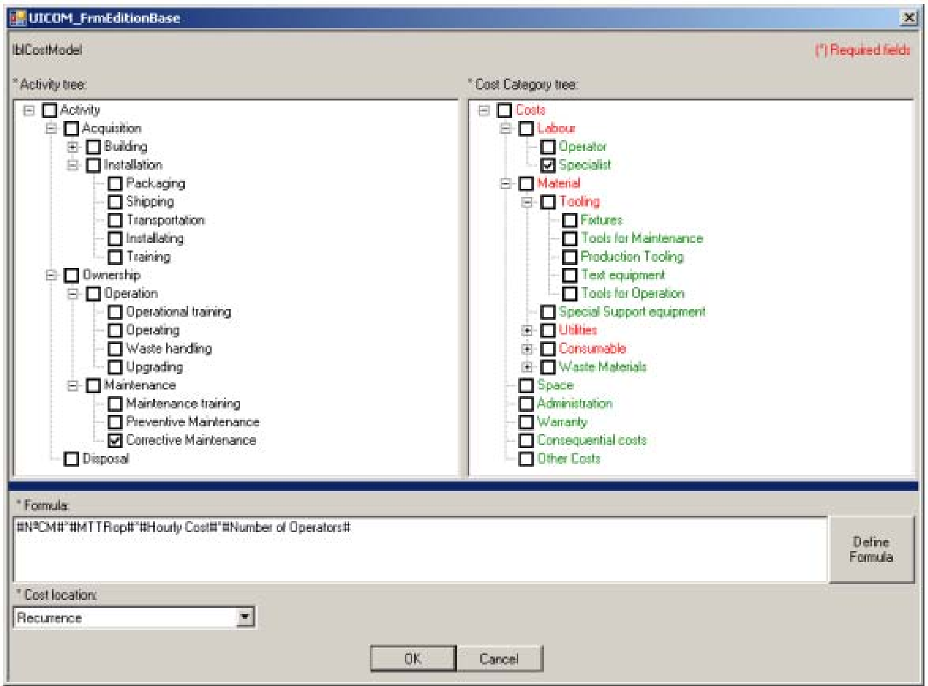

Figure 4: Cost Models Definitions

Results obtained by means of the LCC Management Software will allow the SMEs to produce different LCC outputs adapted to the requirements of their customers (see **¡Error! No se encuentra el origen de la referencia.**).

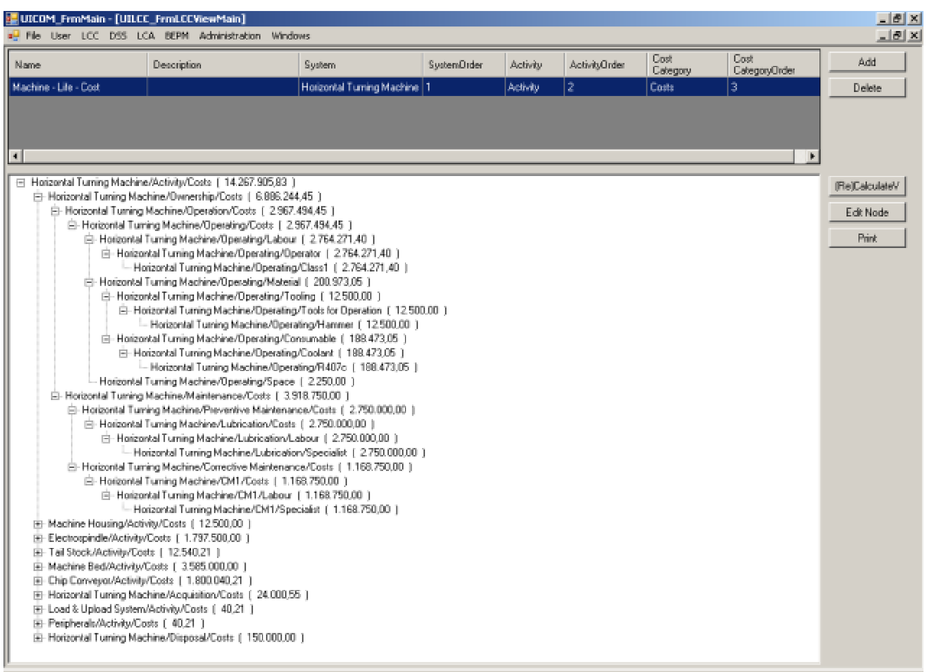

Figure 5: Life Cycle Cost Analysis View

LCA Calculations:

Life cycle assessment (LCA) includes the whole life cycle of a machining tool from extraction of raw materials, manufacturing, transporting, assembling, use, maintenance and recycling. Following standards are in use: ISO 14040:2006, ISO 14044:2006, ISO/TR 14047:2003, ISO/TS 14048:2002 and ISO/TR 14049:2000.

In life cycle impact assessment environmental impacts identified in the inventory stage are enumerated with eco-indicators, such as the environmental impacts of generating energy for the processes and the hazardous wastes emitted in the manufacturing process. To calculate impact assessment of a machining tool it is necessary to have eco-indicators of all the inputs and outputs. Once the environmental impacts of all the inputs and outputs of a machine tools is analysed, the life cycle assessment generates one number that represents how much the environment is affected. It is important to understand that the absolute values of eco-indicators are not very relevant because the main purpose is to compare relative differences between products or components.

With LCA Module the user can analyse the environmental impact of a machine tool. All life cycle phases of a product are taken into account:

1. On a machine tool LCA you specify all relevant aspects of the product concerning the production, usage & maintenance, and disposal.
2. Then you assign environmental points to them to express the environmental impact the product in scores. These points are stored in the Prolima Database that are delivered together with Prolima software.
3. Finally, you can display the results graphically and calculate product improvements.

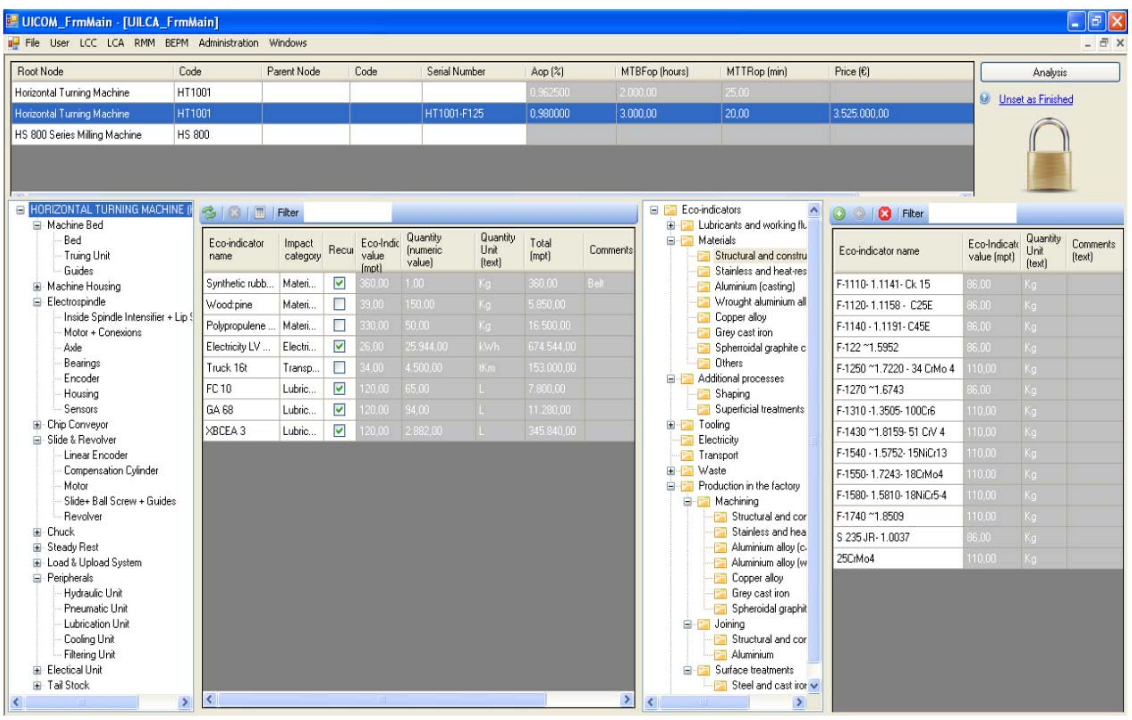

Figure 6: Life Cycle Assessment Tool

7.- Evaluate design

The obtained results must be evaluated attending to the requirements, in order to select the more sustainable design. The evaluation of the design involves:

- Calculation of design requirements
- Fulfillment of all the requirements
- Prioritising of designs

The prioritising is typically a multicriteria decision analysis (MCDA). A MCDA problem involves:

- Different attributes: These are the cost, reliability, environmental and industrialisation requirements ($x_{i,j}$)
- Different levels of importance in the attributes, this is, weighting of criteria. The weights are often normalised in such a way that the sum of the weights equals one. ($w_{i,j}$)
- Option of evaluating several alternatives

Multiattribute value theory (MAVT) can be used in problems where the decision maker has a set of alternatives to choose from and a set of attributes on which the decision is based. The problem is often structured into a hierarchical form called a value tree. The objective is to obtain values for each alternative. The values are composed of the ratings of the alternatives with respect to each attribute, and of the weights of the attributes.

In order to obtain the value function $v_{i,j}$, different attribute (requirement) ranges must be established, this is, the maximum and minimum level of each of the criteria. The ranges depend on the requirements and other values proposed by the designer. As the objective of the prioritisation of design alternatives is to compare only existing alternatives, it is better to select as maximum (minimum) level of each the criteria the worst of the scores of the alternatives:

- Criteria to maximise:
  - Minimum value: Requirement
  - Maximum value: The highest score for that criteria among alternatives
- Criteria to minimise:
  - Minimum value: The highest score for that criteria among alternatives
  - Maximum value: Requirement

The module M6 provides functionalities for evaluation and classification of the results produced with the DSS. That includes data check procedures, summarisation of evaluation results and score calculation based on the weighting selection. There is also a method for the selection of the winning alternative. This module is a functional module because it includes important and comprehensive calculation methods that are only used at this place and so are not common. An example of a case study performed under the prolima project can be seen in Figure 7

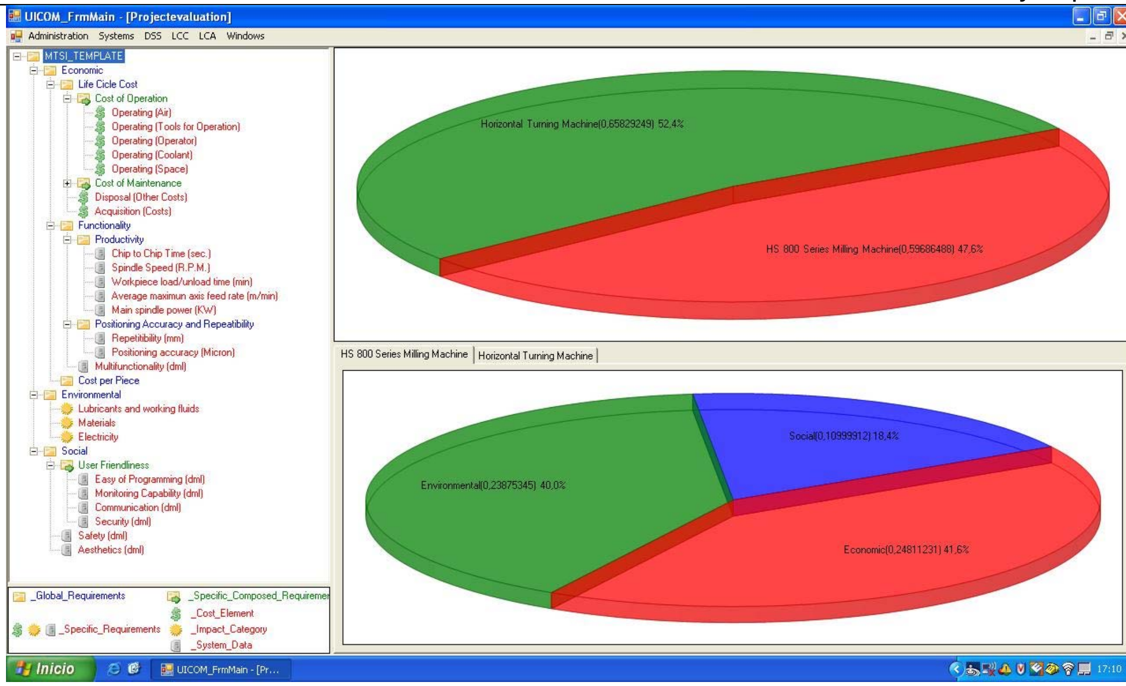

Figure 7: Evaluate & Classify Solutions

8.- Improvement process

If any of the requirements are not met, an improvement process begins in order to achive a design that fulfils all the requirements. The Best Environmental Practice Manual is a list of guidelines on relevant topics such as energy consumption, safety or waste handling. These guidelines make a better 'green' design and exploitation of machine tools possible. It is made as a html-based document. This BEPM will help designer to improve their designs.

BEPM (Best Environmental Practice Manual)

When designers are choosing materials, components and techniques, it is sometimes very difficult to estimate the impact of their choices on environmental-linked subjects. A lot of new developments are published and it is not easy to detect which development could be interested and when to use it.

When someone is designing a part of a machine tool and he has the objective to reduce the energy consumption of that part, he can start the program and use the search function for getting a list of all guidelines concerning the energy consumption. Of course not everything will be useful for him, but he will have a quick overview of all rules that can lead to a reduction of the used energy. He can click on the rules and get more information and explanation with it. Also some figures, tables or graphs are possible. And if he wants to have the background information he can consult the sources.

The search function is very widespread. A user can search on topic (energy consumption, noise & vibration, coolant & lubricant, safety, waste handling & recycling and heat generated), lifecycle phase (from the obtainment of materials to the end of life), machine structure (bed, motors, spindle, etc.), type of machine tool (e. g. milling centers, lathes, etc.) and it is also possible to use some keywords. So it is very easy to use and to filter the guidelines. A last aspect is that the guidelines are also evaluated. An environmental score is given and presented, so priorities can be made.

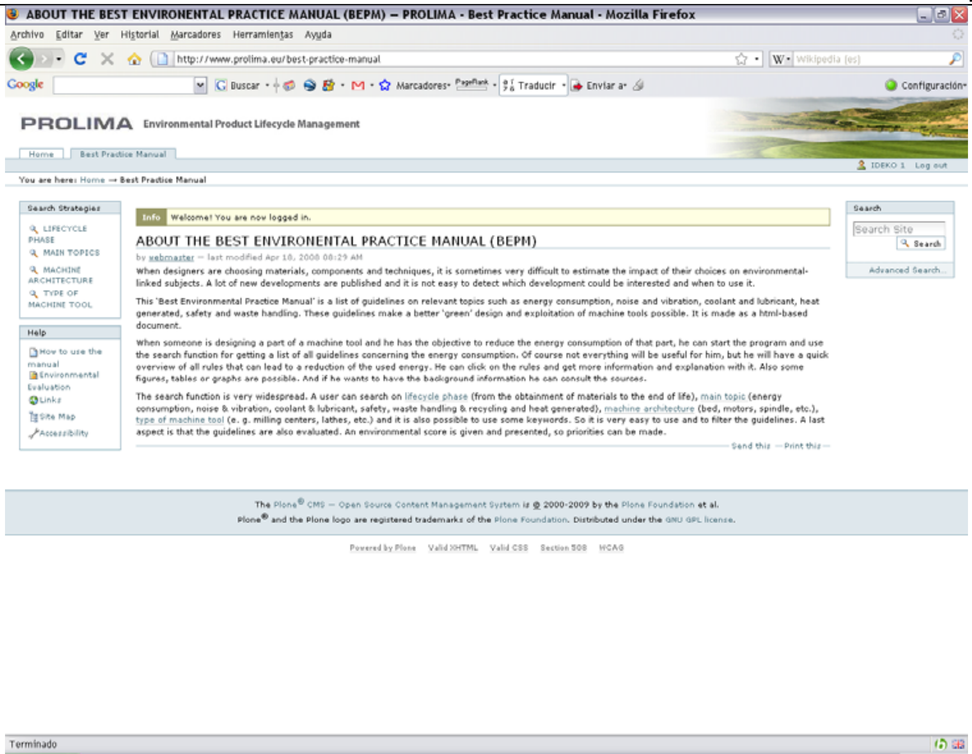

Figure 8: Best Environmental Practice Manual (www.prolima.eu)

9.- Continue Development

The integrated design methodology assists in the sustainable design of machines, since provides a method to consider the reliability, cost, environmental impact and industrialisation aspects in the erly stages of design. After evaluating and selecting the most sustainable design (according to the requirements, defined criteria and weight of criteria), the designer will continue with the detailed design of the machine.

Conclusions

The presented work offers a machine tool sustainability indicator and a software tool to support the design of sustainable products. Moreover, the software tool can also be used by commercial people in the bidding process, as a commercial tool to assess the sustainability of the machines (evaluating cost, functionality and environmental impact trade-offs).

The machine tool sustainability index provides a method for assessing the sustainability of the machine, an important topic in the sector, increasingly more concerned with factor beyond the initial cost of the machine, such as the life cycle cost and environmental aspects. Furthermore, the software contributes with a machine tool focused design tool, supporting the MTSI with a design support system and integrated LCC and LCA assessment tools.

The software has been developed for the machine tool industry, but it could be applied to other industries characterized by complex product structures. The novelty of the software consists on the combination of several tools used in industry, such as LCC and LCA, and the use of MCDA to provide a design support system considering the three dimensions of sustainability, economic, environmental and social. The architecture of the tools enables the reuse of information, since cost or environmental data are linked to systems, and can be reused in other machines where the systems appear. This fact speeds the analysis process up.

The pilot implementation in the milling machine company confirms the benefits of the software and the MTSI for sustainable design for the machine tool industry. As a future activity, the authors will discuss the suitability to customize it to other industrial sectors which share some of the characteristics of the machine tool industry, such as the complexity of the product and the concern for sustainaibility.

Acknowledgement

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PROLIMA
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CO	IAG	1	Spanish machine tool builders association	AFM	Spain
CR	IAG	2	The multisectoral federation for the technology industry	AGORIA	Belgium
CR	IAG	3	Technology Industries of Finland	TIF	Finland
CR	IAG	4	Asociacion Espanola para la Calidad	AEC	Spain
CR	IAG	5	Vereniging voor Produktietechniek	VPT	Netherlands
CR	IAG	6	European committee for cooperation of the machine tool industries	CECIMO	Belgium
CR	IAG	7	The Nederlands Corrosie Centrum	NCC	Netherlands
CR	SMEP	8	Soraluce S.Coop	SORALUCE	Spain
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