Framework for Ecolabeling using Discrete Event Simulation

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Abstract

Ecolabled products have shown a competitive advantage to other products. Regulatory changes and market pressure creates an increased need for environmental impact assessments. The dominating method for environmental impact assessments - life cycle assessment (LCA) lacks support to properly analyze the dynamic aspects of business operations and production processes. This Paper proposes to use discrete event simulation to support more extensive and detailed environmental assessments on selected parts of the production process, keeping simplicity for parts of less importance and interest.

1. INTRODUCTION

ISO (International Organization for Standardization) defines three types of ecolabels [1], the Type I label declares products that is better than others in the same product segment. Type II labels are custom self-declarations, which only analyze and declare the LCA assessment of one parameter. Type III labels are quantitative ecolabels that measures e.g. carbon footprint or energy consumptions for products in a life cycle oriented way. Rigorous processes are necessary to manage the label and keep result updated. Analyzing environmental impact is time consuming. Thus, it is costly to manage information and data on ever-changing products and product with short life cycle up to date. Tools that support the calculations and analyze are necessary but rare.

Studies have shown positive effects on evaluation of environmental metrics while integrating discrete event simulation (DES) with environmental impact calculations. However, an environmental impact analysis in a DES environment requires case specific coding. Skill in DES is essential, consequently skilled environmental impact assessment professionals cannot use DES by default.

This paper proposes to build a user-friendly tool (EcoProIT tool) that uses a conceptual model approach to produce a DES model for environmental impact analysis with Type III ecolabeling. The EcoProIT tool gives the designer the ability to model the product lifecycle from raw material to recycling, i.e. from cradle to grave/cradle. However, compared to current Life cycle assessment (LCA) tools this approach enables more detailed focus on stages of interest during the product life-cycle. Detailed analyses should be performed on sensitive parts in the life cycle, but also for parts important to the analyst, e.g. a production part of interest to the production engineer.

The detailed parts in the environmental impact assessment are analyzed in a dynamic context more similar to real world than static calculations with e.g. LCA. The dynamics is simulated utilizing time dependent events and statistical information from resources, e.g. machine data such as process times, energy consumptions, capacity, sizes, breakdowns, etc. The simulation environment uses distribution and randomness to mimic the real system. This makes it possible to view the effects of dynamic processes in regards of environmental impact, including dynamic chain effects, scrap rates effects, and variations in lead-time and utilization rates.

This paper aims to present and discuss one concept for implementation of dynamic environmental assessment for type III labeling using DES. This includes specifications of necessary functionality and user interface. The approach is based on standardization efforts in three aspects; Ecolabeling [2], LCA methodologies [3] and input data for simulation utilizing Core Manufacturing Simulation Data (CMSD) [4]. First part describes previous that evolved to EcoProIT, The later part describes approaches, methods and concepts for EcoProIT.

1.1. Ecolabeling

An ecolabel is a label placed on a product or service to declare to the costumer the products environmental impact. Ecolabels communicate all or parts of the environmental impacts from defined parts of the life cycle of a product or service. Different ecolabels have been around for several decades. The ecolabels are frequently categorized into three different types. The requirements for each type of label have been defined by ISO through the ISO 14020-series [2], Environmental labels and declarations. The types differ in considered factors and by the validation and verification process required and by whom it is supposed to be performed. Below is a short summary of the types and their characteristics:

Type I [5] multifactor label that is issued by a third party organization, either private non-profit or government. The label signifies good environmental performance relative to comparable products. There are plenty of examples from both Europe and the US. examples of type I labels are The Blue Angel and Nordic Swan [6].

Type II [7] single factor labels and supplied by the manufacturing company itself. Examples of type II eco-labels could be the number of particles emitted by a car or the percentage of recycled material in a paper coffee mug.

Type III [8] Multi factor labels that quantify the emissions and impacts without any performance classification. Studies behind type III labels should be based on the ISO LCA standards, 14040 [9] and 14044 [3]. An example of a type III label is the Swedish Environmental Product Declaration (EPD®) system [10].

Recent developments have shown that regulating bodies at international level quickly can have an impact on the operations of companies. In 2003, the European Union passed a directive to restrict the use of certain hazardous substances, called RoHS [11] The directive banned certain materials from being used in electrical products. It changed large parts of the electronics industry in a very short amount of time. What was regulated in Europe spread to an almost global level as manufacturers chose to follow the RoHS regulations in all of their markets. There are indications that there could be a similar development on the environmental product declaration. An example is France, where a recently passed directive will require an Environmental Product Declaration (EPD) for all high volume consumer products in the future [12]. The system is currently under evaluation in a pilot project covering a subset of all intended products. The system in France will incorporate Type III labels, which could be an indication that future European level regulations will do the same. Either way, a feasible regulative labeling system should incorporate transparent and standardized methods as well as fair, reliable, and comparable results.

In an anticipated future where EPDs are required by law for all consumer goods it is conceivable that this would stimulate producers to profile themselves as environmentally friendly. To be competitive they need to not only declare their products impacts but also implement strategies to lower it. If both the assessment and further analyzes to improve the system is done using the same tool or method, users could save time and experience synergy effects while optimizing both against productivity and lower environmental impact.

2. BACKGROUND

Previous developments and background materials of importance to the EcoProIT tool development in this paper are presented in this chapter.

2.1. Core Manufacturing Simulation Data

In order to address interoperability issues between simulations and other manufacturing applications, the CMSD [4] specification was developed. Lee et al. [13] describes that CMSD facilitates the definition of manufacturing information related to production operations enabling information exchange between simulations and other software applications that are used to manage or analyze manufacturing operations.

The CMSD effort is under the guidelines, policies, and procedures of the Simulation Interoperability Standards Organization (SISO) [14].

CMSD is a neutral file format for manufacturing applications that exchange data with simulation models. The file format is based on the extensible markup language, XML. CMSD is defined by an information model that is specified through Unified Modeling Language (UML) diagrams. The data sets covered under the current version of the CMSD standard UML based and these packages are:

Resources

- Orders
- Calendar
- Skill definitions
- Setup definitions
- Parts
- Bill-of-materials
- Processes
- Maintenance plans
- Jobs
- Schedules
- Distribution
- Layouts

The packages contain several structures that can be used to organize input data for simulation. Leong et al. [15] gives a detailed description of these packages, and Lee, Riddick and Johansson [13] gives examples of implementation and case studies used to verify and validate the standardization development.. The standardized information model [4] provides the complete specification of CMSD.

CMSD implementation

All information added to the model is stored in the format of CMSD, which is a standard for simulation data for manufacturing application. Using the CMSD standard as the bridge to the simulation model will provide high flexibility to change between and possible support for multiple simulation tools.

The CMSD standard was developed to support and standardize simulations data management, in regards to storing, definition, management, and data exchange. It has been tested, revised and provide a stable ground for usage and extension.

The CMSD standard is an extendible framework, where an unlimited number of attributes for resources can be used. However, the converter to the simulation software has to be able to take care of the information. This can be used for to provide information of energy consumption as tested in [13]. Likewise, it can be used for other attributes as auxiliary usage or scrap rates.

2.2. Previous Cases

An **e**arly phase case at a SME (Small and Medium Enterprise) in Sweden tested the approach of analyzing environmental impact in a DES environment, see Figure 1. The analysis was performed in the same model where both economical and production efficiency parameters were analyzed. The environmental impact results were compared against data from an LCA study, which validated the approach to be correct.

Compared to the LCA study the DES model provided a more detailed experiment platform. The simulation output containing environmental impact could change by changing process flow parameters affecting the total output, inventory levels, or other simulation dependencies. By changing the process time for one machine, it will affect the energy used in that process and could also have an effect on inventory levels. Changing the size of the safety stock would affect the lead-time of the factory which would lead to higher utilization of the facility relative to other produced products. This lead to higher environmental impact for the studied product.

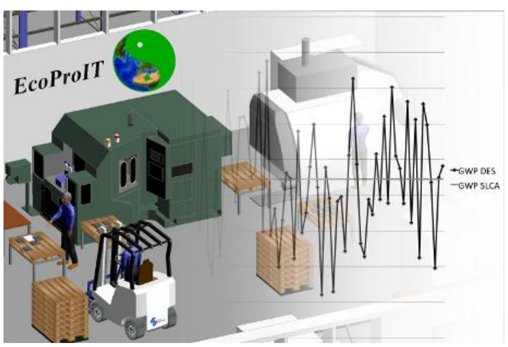

Figure 1. Pilot case for EcoProIT

2.3. SIMTER Tool

SIMTER is short for "Advanced simulation-based production development tool for traditional manufacturing industries". The results of this effort is a simulation tool that relates to the three pillars of sustainability. Social, economic and environmental metrics are included in the modeling and analysis utilizing this tool. The SIMTER tool is described in detail by Lind et al [16]. Each aspect of sustainability is described in the following publications for the sustainability pillars Social [17], Economical [18], and Environmental [19]. The development of the SIMTER tool was done only to an alpha stage and there is no official release of the software tool available to public. However, the approach to integrate social, economic and environmental assessments into one decision tool is both a great challenge, but does also incorporate quite some benefits by enabling the decision taker to see the interrelations in-between various parameters form different disciplines.

3. ECOPROIT TOOL SPECIFICATION

Deriving from ideas from the SIMTER tool [16], the EcoProIT tool shall be independent from specific simulation software and operate stand-alone. However produce specification that can be converted into simulation software. EcoProIT should be an extensive tool used for eco assessment, incorporating both static and dynamic information, and facilitate the calculation of eco-labels. From the EcoProIT tool a simulation model is generated, ready to be used by a simulator. The interface for data conversion will use a standardized framework (CMSD) to provide the possibility to use different simulation software packages through a software specific converter, see Figure 2.

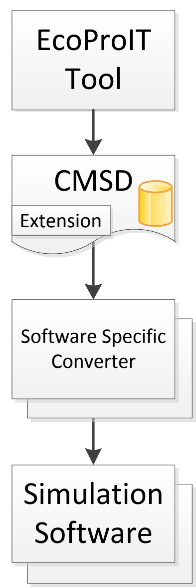

Figure 2. Generic view of software

The EcoProIT tool is aiming to produce full life cycle assessment studies through a simple interface. More information is added to the model, increasing the level of detail for environmental assessment calculations. The increased level of detail supports iterations as used in standard LCA practice. The increased level of detail is added on sensitive parts where small changes to the model result in big difference to the model output [20]. It could also be elaborated further, enabling more details is needed on parts where more detailed analysis is desired. For example, a more detailed analysis on the machines in a production cell, even though the cell only represents a minor share of the total environmental impact, e.g. more details could be added for processes that can be influenced or are of concern to the analyst. To support this Hierarchical black-box simulation is used, see 3.2.

In general, DES is a professional tool that requires knowledge and time in order to mimic the real production system well. To take advantage of knowledge from production technicians and environmental impact analysis the EcoProIT tool must be easy to learn and use. It is of importance that the EcoProIT tool's design is simple and has a steep learning curve. Hence, does not include DES theory or programming knowledge. These requirements do, of course, narrow the possibilities to do in depth simulation on extensive and complex production flows. However, for environmental impact assessments purposes it is not a necessity to have a detailed simulation model. The simplicity is supported by a user-friendly user interface, see 3.5, and a conceptual model approach, see 3.4.

3.1. Dynamic Eco Assessment in Discrete Event Simulation

Thiede, Herrman and Kara [21] made a study of the current state of the art for studies on environmental impact assessment using DES. The paper presents twelve approaches from other studies. It is clear that DES is possible to use, but the methods varies. To be able to label products in early design phases of creating production systems will require a standardized method, which can verify that the result will be reliable and correct according to the input data.

To validate the use of DES for environmental impact assessment other assessment methods could be used. Then the same data should be used in both a standardized LCA method and in the EcoProIT tool itself. Comparing the results should give similar results with the difference in the case of DES more detailed information on the time dependant data can be provided as output, e.g. detailed machine emissions, individual product machining data etc.

The benefits of doing the analysis in a DES is the dynamic outputs from the model [21, 22]. The dynamic corresponds to e.g. changes in demand and machine conditions. The model reacts to different scenarios and gives dynamic output data depending on statistical variations in the production rates. The information will be even more important from a process perspective, were individual process conditions and production rates will vary and be more or less important to the results of the analysis. A production analyst will be able to better predict unwanted behavior of the system or parts of the system. A major benefit is the possibility to analyze both economic and ecological aspects at the same time.

3.2. Hierarchical black-box simulation

The concept Hierarchical black box simulation describes an iterative simulation approach where different parts of the simulation are simulated in varied level of detail. The target of the simulation in this case is the product life cycle. Initially, the simulation is carried out based on static inputs and outputs from the total real lifecycle and its different steps, e.g. production, distribution, use, and end-of-life/recycling. For the production node, the simulation input contains data for lead-time and capacity of the production. If the production is the target of deeper analysis the next step is to divide the production into different production parts or suppliers, adding lead-time and capacity for those boxes and the interactions between the boxes gives the model a dynamic behavior. For deeper analysis, some production nodes can be examined deeper by adding nodes for the production division or facilities. This iterating process will end at the desired level of detail, e.g. at the production processes and include the machines and buffers. This would allow the user to have a fully dynamic production flow analysis. Figure 3 shows an example of the Hierarchical black-box.

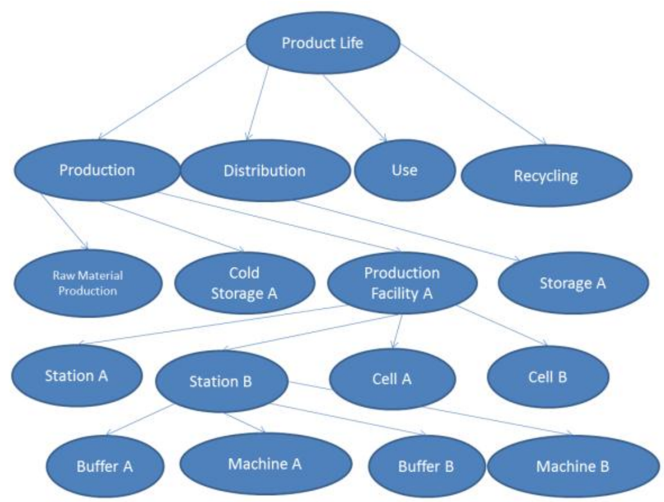

Figure 3. Hierarchical black-box simulation

For multiproduct production the interactions has to consist of data for routing and production principles. This logic has to be added to the information from the EcoProIT tool. The routing logic for a multi variant production is of major concern for a realistic simulation.

3.3. Activity-based Costing

Activity-based costing (ABC) is a detailed accounting method for companies in all fields. It tracks and account cost object (e.g. products or services) performing activities (e.g. use machine or repair machine). All activities cost money depending on cost drivers (e.g. based on the weight of the cost object or/and based on the time the activity is preformed). The costs for the activities are calculated depending on the amount of objects that use that activity. The costs origins from real cost for the company's resources (e.g. facilities, machines, operators). In a correct ABC model all the costs for the resources has been allocated to the cost objects. All products that are using the resource through activities therefore share the cost for that specific resource. Figure 4 visualize the ABC model.

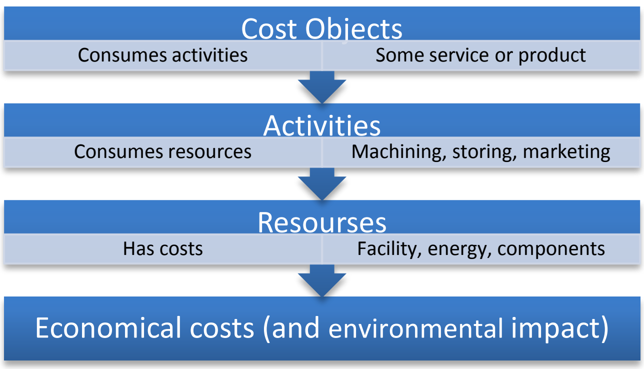

Figure 4. Activity-based Model

ABC modeling can also be utilized for environmental impact assessment thus the concepts of costs can be converted to "costs" in form of emissions [23]. ABC can with advantage be used together with DES [22]. DES eliminate problems and automate many calculation and data management. By using the ABC concept as the main framework in the environmental impact calculation within the DES model the effort will be lower than doing a separate LCA analyze and DES analyze [22]. Common cost drivers contribute to lower combined time spent on the total analysis time.

3.4. Conceptual Modeling

Conceptual modeling is used to transpose a problem formulation to a model definition. The conceptual model substantializes the problem and stipulates system boundaries and specifications. It is however a simplified representation for the final model [24]. Conceptual models are simplified representations and therefore fast implementations. Furthermore, is the conceptual model independent on simulation software.

For the EcoProIT tool, a conceptual model approach is an important and noteworthy choice. Choosing to stay on a conceptual design will make it hard to implement advanced logic and to fully support all production cases. The choice results in loss of details, but it will result in time for more extensive models in concern to information of other stages in the life cycle. An analyze with EcoProIT aims to cover the whole life cycle with less details at low impact stages and more, high details on important and sensitive parts and possibilities for the modeler to be able to increase the level of details at spot of interest.

3.5. User Interface

An important major goal for the success of the EcoProIT tool is a simple but powerful user interface. An easy user interface contains few windows and guides the user with the help of highlights and color codes. Supports standard operations as drag and drop and enhance it, e.g. prepare operations associated to that file type or object dropped [25]. Figure 5 shows an early version of an experimental user interface used to demonstrate and test concepts.

Recognized requirements for the user interface:

- Short learning curve
- Visual
- Simple
- Prepared for increased details
- Extensive enough without unused features
- Helpful

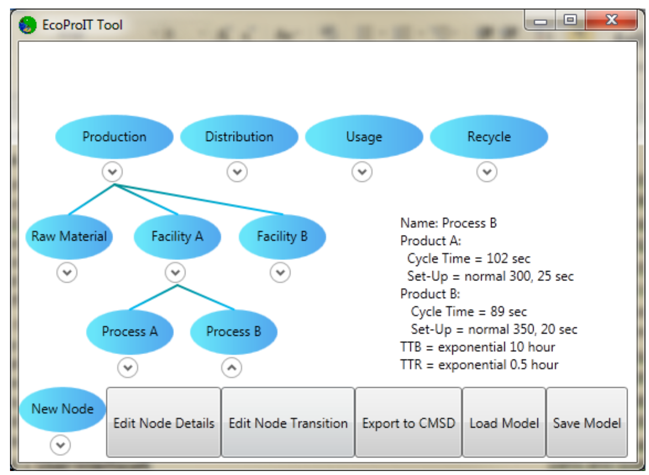

Figure 5. Early phase experimental user interface

3.6. CMSD Converters

Once there is a simulation model and a corresponding CMSD file, the data need to be transferred between the two in order to populate the model. A common situation is that the entities, logics and graphics are pre-defined by the model builder and that the quantitative data are extracted by parsing the CMSD file with regards to existing model entity identifiers. For example, if a production resource is named OP10 in the model code, all data associated to the resource with exactly the same identifier in the CMSD file are extracted and stored in related tables within the simulation software. This approach is demonstrated by Johansson et al. [26] in an automotive case study developing a translator between CMSD and Enterprise Dynamics (ED). A similar description is provided in Boulonne et al. [27] (CMSD to

ARENA). The latter publication uses an intermediary database for storage and supply of data to the model.

Another situation arises when CMSD data is applied to initiate or self-generate a simulation including part descriptions, process sequence, production resources, layout specifications, etc. Such information, which is often handled by the model builder, can here be included using CMSD classes such as part, process plan, job, and layout. Fournier [28] exemplifies such an approach and further describes a set of developed translators between CMSD and commercial software packages (e.g. Quest, ProModel, and FlexSim). This approach is less sensitive to possible differences in entity identifiers and names of data elements since the interaction between the model builder and the data file is reduced.

In addition to the type of data to transfer, Fournier [28] states that the translators work slightly different depending on the world view of the simulation software. The data has to be extracted and structured in another way for process-oriented software than for resource/object oriented packages. The parsing necessary to identify specific data points is, however, similar and either done by XML-functions (if available) or simply by strategically looping through the CMSD files to identify and extract the searched data point from the CMSD XML hierarchy.

4. DISCUSSION

It is well stated that the major corner stone in an environmental impact analysis is valid input data. A requirement for valid results independently of what method that has been used, the input data must be correct. The EcoProIT project does not address data management or other issues with non-valid data. For the data collected for cases within EcoProIT it is assumed that the gathered data is correct. Instead, an EcoProIT analysis is discussed and compared between methods using the same input data.

The CMSD standard covers the need for simulation data in EcoProIT. However, advanced logics cannot be covered. Basic logic for the production system as describing a production flow is possible to describe in CMSD. However, the framework does not support advanced logic in the production system. A fully implemented EcoProIT tool would therefore need an extra information interface for advanced logic. There is no current solution to this problem. Initially the implementation of EcoProIT will only support simple processes, i.e. production processes without any parallel processes or advanced interaction between different products.

ABC is a well-used framework, which supports a DES approach for environmental impact assessments. ABC is extensive and very detailed. It requires more data than a traditional approach. However, sufficient data required for the ABC method will in most cases be extracted directly from the simulation model. Most downsides of an ABC approach do not apply to a simulation model where different output data is extracted from the model more or less automatically.

Simplicity with increased detail is an important feature of the EcoProIT tool. It enables analysis to be performed iteratively and could be used for static analysis as well. However, the competitive argument is the ability to analyze processes in great depth and include dynamic aspects using the power of DES.

5. CONCLUSION

The paper sums up on set of concepts, approaches, and methods available for environmental assessments using DES. The paper will serve as the standpoint for further development of the EcoProIT tool.

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BIOGRAPHY

Jon Andersson is a PhD student at Chalmers University of Technology department of Product and Production Engineering. Jon is mainly a researcher in in the field of production simulation and especially in the project called EcoProIT (http://www.ecoproit.com). The project aims to build a industrial tool for environmental impact analysis in a powerful DES environment.

Dr. Björn Johansson is Assistant Professor and vice head of Production Systems division at the Department of Product and Production Development, Chalmers University of Technology, Sweden. He serves as Production Modeling Corporation director for the European office in Gothenburg. His research interest is in the area of discrete event simulation applied for manufacturing industries, including environmental effects modeling, modular modeling methodologies, software development, user interfaces, and input data architectures.

Jonatan Berglund holds a MSc. in Production Engineering from Chalmers University of Technology. He is currently working as a research assistant at the Department of Product and Production Development at Chalmers University of Technology in Gothenburg. For a year between 2010 and 2011 he held a position as a guest researcher in the Life Cycle Engineering Group at the National Institute of Standards and Technology in Gaithersburg, MD, USA, where the work behind this paper was conducted. Jonatan's research interest is mainly in the field of modeling sustainability aspects of production systems utilizing life cycle assessment and discrete event simulation.

Dr. Anders Skoogh is a researcher and lecturer in the area of Virtual Production at the Department of Product and Production Development, Chalmers University of Technology, Sweden. He received the degree of Licentiate of Engineering in 2009 and his PhD in Production Systems in 2011, both from Chalmers. Before starting his research career, he accumulated industrial experience from an employment as a logistics developer at Volvo Car Corporation. His main research area is virtual tools for decision support in development of sustainable production systems. The current focus is on efficient input data management in simulation of production flows, for example by developing and evaluating methodologies for automated data processing.