Life cycle assessment in production flow simulation for production engineers

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Abstract
Product developers are the main target for environmental impact assessment. Every day operation in manufacturing industry considers only site-specific aspects as energy consumption or material usage. Moreover, those aspects are mainly in-place for economic reasons. Discrete event simulation is widely used by industry for problem solving on a factory and logistic level. Including life cycle assessment in simulation models enable detailed assessment for production system. Yet, it requires specialization to create robust environmental models in discrete event simulation. Simplified software supporting production engineers in modelling and data harvesting reduce specialist requirements. This paper present a first version of software developed for the production engineers. The software supports modelling and analyses using discrete event simulation models with life cycle assessment.

Keywords:
Life cycle assessment, discrete event simulation, production flow simulation

1 INTRODUCTION

Life cycle assessment (LCA) is currently the state of art methodology used for environmental impact assessment. LCA consists of four main phases, goal and scope definition, inventory, impact assessment, and interpretation. During the inventory part of life cycle assessment, the analyst defines a set of static liner equations that describes needed resources and processes in target systems needed for a product or service. The static equations are unable to catch the dynamic aspects of modern manufacturing. Problems with static life LCA is according to Reap, Roman and Bras [1]:

- The use of lumped parameters and site-independent models.
- Static in nature and disregard of the dynamic behavior of industrial and ecological systems.
- Focus only on environmental considerations, not economic or social aspects.

A manufacturing company that uses environmental labels or environmental in their marketing strategy do need to analyse and present their company´s or product's environmental impact. Analysts use valid life cycle assessment method to collect and process data of the product's life cycle or the manufacturing processes consumption or declaring the total emissions from the manufacturing. A brief environmental impact study does, by default, not require much work and could potentially give a fast result for the company to use for marketing purposes. However, static LCA analyses add limited knowledge to companies. It provides limited details of the manufacturing process. It is limited in forecasting future states. The experiments possible are limited to parameters that only affect local part of the system. Manufacturing processes are intimate coupled, changes to one process affects more processes. LCA studies for complex systems possible generalise current state to extensive. The recommendations for complex systems therefore tend to be overestimated.

On approach to study manufacturing industry and analyse of dynamic aspects as variations and time is to use simulation models. Simulation engineers have been using production simulation for decades to investigate production problems and to find best solutions to meet new demands for production. Production simulation models mimics the manufacturing system, enables trustful future states analyse and change proposals. However, compared to a static analytic approach a simulation model requires more data and requires more skilled simulation engineers and modelling time. According to White and Ingalls [2] analytical approaches should be used when it is possible. However, they add that for complex manufacturing system that is seldom the case.

During the last decade, researchers developed and used production simulation for environmental impact assessment. Discrete event simulation (DES) has been shown to successfully used for life cycle assessment studies simulating manufacturing processes [3-6]. Heilala, Vatanen et. al [7] proposed an add-in to a current simulation tool to analyse environmental impact. Herrmann, et. al. [8] showed an implementation for energy analyses in simulation. Thiede et. al. [9] found that support in current commercial software is very limited. In at least two current simulation tools, it is possible by default settings to study energy consumption in manufacturing process. However, the possibility to study other important aspects of environmental impact in manufacturing industry, waste, spillage, facility, auxiliary material, is limited.

The main problem with the approach to merge LCA and production simulation is extensive data needs. By using complex simulation tools, the time for modelling and collect data are substantial. This paper will present a simpler standalone simulation tool aimed for production engineers. The production engineers are knowledge in their processes but not simulation experts. Production engineers have potential to collect correct and needed data based on guidelines faster than an external simulation expert does. However, the production engineer needs a simpler tool and good guidelines to get valid models. The tool's purpose is to test research results, modelling technics and layouts and present the approach for commercial software developers.

The first part of the paper will present the main ideas implemented in the software. The second part presents the implementation of the software and some early results from the program from an example. The results are analysed and discussed at the end of the paper.

1.1 System description

Industry uses production simulation to solve production flow related problem. The problems solved using production flow simulation are complex, has many interactions, and is not obvious solved. A common task is to analyse and find problems in systems where each process has higher individual capacity than the total system. The following section describe the system this paper concern.

Companies that solve problems using simulation seldom do the analysis themself, but analyse their problem using consultants for the specific problem or project. However, the simulation engineer is in this paper is considered to be the production engineer that also has possibility to influence the manufacturing system based on simulation result. The production engineer is the main actor for the system presented in figure 1.

Company leaders set targets for the engineer that try to find the optimal solution. The production engineer models and analyse the production system using a simulation tool. Improvement proposals generated to fit the need are tested in the model. The engineer discusses proposals with other departments and influences the system to preform better. The implementations affect the manufacturing behaviour, and the production characteristics change. This means different capacity, dependability, quality, costs, lead-time and environmental impact. The production engineer gets feedback of the result by local measurements of emissions, consumptions and by costumer who are affected by the manufacturing performance and consuming its products. The feedback Is flirted and discussed by leaders and other departments in the company. The production engineer uses the new feedback results for further improvement analysis in the simulation tool.

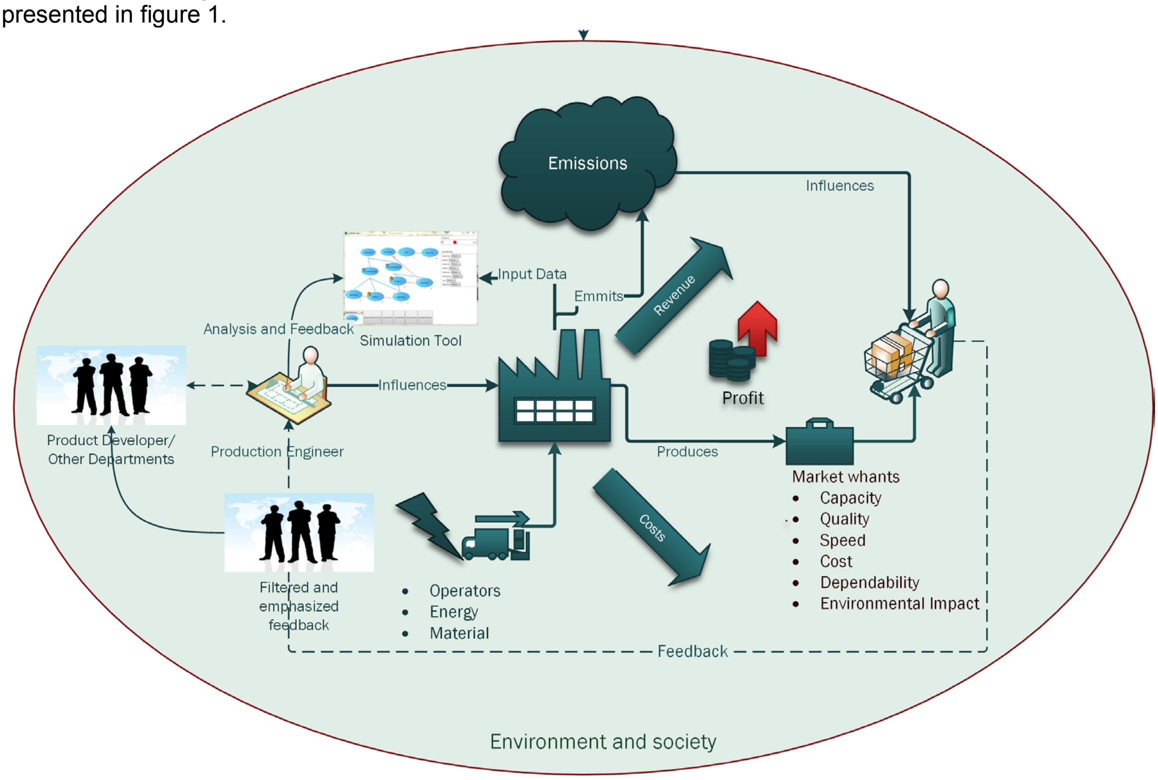

Figure 1: the system studied in this paper

2 METHOD

This paper base the results on experiences collected from multiple previously performed and documented case studies. All cases have are preformed from year 2007 and forward. The cases has been analysing the environmental impact of manufacturing industry in small to middle sized companies. The simulation engineers have been experienced in production simulation but have limited experiences of environmental impact assessment methods in general. [10, 11] summarize the experiences in detail.

The reports and working papers from these cases serve as a basis for the collected experiences. Two case studies during 2012 and 1 during 2013 tested concepts and resulting methodologies from the other cases. The simulation tool presented in this paper implements the most promising concepts concerning modelling.

3 CONCEPTS

Andersson [12] describes the concept framework in detailed. The concepts presented here are further improved base on resent results and experiences, but the main structure is reserved.

3.1 Hierarchical

Several commercial simulation software support hierarchical modelling to support incremental detail throughout the project. The simulation engineer can fast get basic models of complex models, which later can be more detailed modelled. Abstracted hierarchical levels lacks logical function but give the simulation engineer and others an easy overview of big and complex models.

In the case of environmental impact assessment, the hierarchical levels have a vital function. In order to allocate the environmental impact from facilities and other common function it must be possible to trace the use of those entities. By model machines, transports and other direct resources as belonging to a facility or production cell. The product processed in the lower level node is then possible to track to higher-level nodes using the hierarchical diagram.

3.2 Levelled equations

Include environmental assessment to simulation models increase the complexity of the code and reduce readability. Simple code in a simulation support verification of code, validation of models, flexibility of the model, increase development speed and support understandings of the model[13]. Reducing the calculations done inside the model, and do as much as possible when the model has finished the simulation run decreases complexity of the simulation model, and the model can still be maintainable and verifiable while environmental impact results are calculated.

To be able to perform calculations after the run, the simulation model need an extended standardized output format. In a levelled approach resulting environmental impact and emissions computes in equations feed by the amount of consumed consumables which computes in equations feed by from the extended simulation output.

Output needed from the simulation model is:

- Processing times for each product in each process
- Setup-time for each product in each machine
- The time each machines has been in other states as broken down, idle or off.
- When a product entered a facility, production line, conveyor or machine and how long it stayed.

After the model have run, and based on the extended model output and external tool can calculate the consumption. For consumptions of material and energy that are based on the process used, time or event is multiplied with the consumption rate, e.g. processing time in machine multiplied by machines electricity effect. For consumptions that is static and not affected by time the consumptions added per time used e.g. gram of cut-off steel waste.

A levelled approach makes it possible to verify and validate the simulation model using conventional verification techniques. The simulation engineer can validate the equations separately by comparing results from the equation using data from the model and from the real production. Using a levelled approach the verification and validation can be limited to parts of the model logic.

Choose right consumption drivers

Consumptions from processes can be modelled in three ways or combinations of those. [14]

- A static or stochastic consumption each time a process is executed
- A static consumption based on a physical property of the processed/previous product
- A static consumption multiplied by process time.
- A static consumption multiplied by process time and a physical property of the product.

The choice made may not impact the result of the current state analysis. However, future state and improved scenarios depends on the modelling of consumptions. The simulation engineer has an important choice to make that impact data collection, modelling, and experimentation possibilities.

The main issue is the process time dependency. Process time dependency states the equality that shorter/longer process time is equal to lower/larger consumption. This equality is not true for all common processes in manufacturing industry. Nevertheless, for processes where equality between process time and consumption is true the modelling technique should be used.

Using physical properties as drivers further improves the models adaptability to introduce new products. Physical properties as volume, area, shape or mass are for some processes important consumption drivers.

3.3 Increasingly detailed modelling

Highly detailed models implemented correctly decrease the difference between reality and model. However, more details are hazardous for model maintainability, data requirement and makes analyse overview harder. Only allowing detailed modelling on needed parts and simplify others keeps the model maintainable.

The production engineer should start with simple models that later are detailed at needed parts. By preforming sensitivity analyses on the model and the result equations, the simulation engineer increase model detail on sensible processes and system parts. Simultaneously, increases the engineer quality of input data for the model part. The engineer should also enable detailed parts for system parts of special interest.

3.4 Simplified modelling

A successful simulation project has the right choice of detailed level. Choose to model on a too detailed level result in a far costly project than needed. Choosing to model too abstract makes the project unable to answer the questions asked. The approach taken is to stay on an simplified modelling level in general. Two reasons are stated:

- Keep down the needed modelling skills for simulation engineers too be a production engineer.
- Limit the modelling time give more time to collect the needed data that will increase for this type of simulation project.

3.5 Life cycle assessment

Simulation models of manufacturing processes combined with environmental impact assessment give the production engineer opportunities to improve the system with less environmental impact. However, the analyst is in target for sub-optimization focus on the local manufacturing system. The gained improvements in the simulated system can be even greater outside the simulated system. E.g., an outsourced process reduces the environmental impact locally but the product still needs the process. It is therefore important to keep the product as the functional unit and include the total product lifecycle in the analysis, however not as detailed as in the local manufacturing system. The production engineer should aim to reduce emissions from the total system instead of local processes.

LCA is a static standardized method to assess environmental impact for product or services. The method account all emissions released to the environment from activities during a life cycle of a product or service. Fully implemented LCA considers all stages in the life cycle. That is material extraction, manufacturing, distribution, usage, and end of life. Cradle-to-cradle or cradle-to-grave commonly refers to LCA studies that accounts for all life cycle stages. However, often the studies ends before end of life because not the focus of the study is within the company and that other data is hard to retrieve or too insecure. Then the study is referred to as is cradle-to-gate ore gate-to-gate. An LCA study consists of four parts, goal and scope definition, inventory analysis, impact assessment, and interpretation. International Organization for Standardization (ISO) standardized LCA in 1997, and revised it in 2006 called ISO 14044:2006 and ISO 14040:2006.

The manufacturing system is in focus because that is what the production engineer can influence. However, it is important that the study consider and/or include all other important produced product life stages. Those stages can be declared vague, but enough to compare total in-house manufacturing, and to avoid sub-optimization of a products environmental impact.

4 IMPLEMENTATION

The project EcoProIT developed software to test the proposed concepts presented in this paper. The purpose of the software is to show how design choices for simulation design can help simulation engineers to develop successful models.

A simulation engineer is not an expert in life cycle assessment or other environmental impact methodologies. It is therefore important that the software help the simulation engineer by guiding through data collection, modelling and analysis.

The tool is a modelling and analysing tool. The tool uses a commercial tool for the practical simulation. The tool auto-generate a model to be run in the commercial tool. The commercial tool sends the results from the run to a database. The tool extracts the model output from the database to be able to calculate, productivity, consumptions and emissions for multiple entities as machines, facilities, product types, individual products or entire system.

4.1 Tool

The project has focused to build the tool simple to support non-simulation experts to use the tool with a steep learning curve. A simple modelling tool release project time for data collection and analysis. Figure 2 shows the overall project flow for the tool. Figure 3 shows a schematic structure of the software. The structure describes how a system is modelled and the needed part for a complete analyse

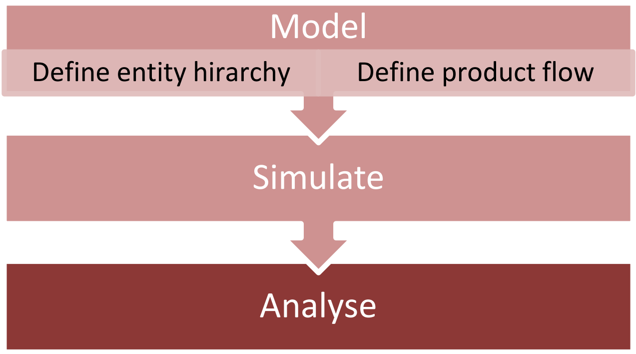

Figure 2: Tool process

The tool has two phases in the modelling process. First are all entities in the model defined. An entity is a product life stage (production, use, distribution or recycle), a facility, a transport of any kind, a machine, or a buffer. Those entities are base entities for manufacturing processes that this tool is limited too. Complex commercial tools use detailed entities as e.g. vehicles and cranes. However, such tools also require more from the production engineer than to use a few simplified nodes. The models will lack in detail but the approach will support a steep learning curve.

The simulation engineer defines each entity individually with simulation data (cycle time, changeover time, and breakdown) and with consumptions. The simulation engineer specifies the used consumption for each job the machine preforms on different products and for other states as idling and being broken down. A consumption is any material or energy that is consumed by running a process. The more detailed the production engineer is while adding data to the nodes the more detailed results can be harvested from the tool.

Product life stages after manufacturing models through generic nodes that add static consumptions to the product entering it. Product entering the user phase node gets the average needed energy and other materials or components added to their total consumption.

The second part is the product definition part. This part starts by defining the products bill of material. It is a simplified bill of material used to get a ruff understanding of the manufacturing lifecycle part compared to the material production part. After a product is defined, the simulation engineer defines the products job order, what the product should do in the manufacturing. That is defining the product flow in the production what job to do in each machine, and in which order to claim the machines.

After the modelling phase, the tool generates logic to an external simulation tool. The simulation writes the output from the simulation to a local database as the logic runs. The result is gathered for analyse from a local database by the EcoProIT tool. The output from the external tool contains times for how long the products was located or used the different entities as explained in the concept section. The external simulation tool does no further processing of the data. Instead is all calculations done inside the EcoProIT tool-

The analysis starts by processing the added results and visualize them as the simulation engineer intend. The simulation engineer can then revise his current model definition depending on the result. The simulation engineer export the new model to the external software and run the new simulation again. If the simulation engineer only change consumptions and nothing that affects the logic the tool calculates the new results without interfering with external simulation model. This is a consequence coupled to the levelled equations concept in the previous section. Figure 4 shows screenshot from the main modelling environment.

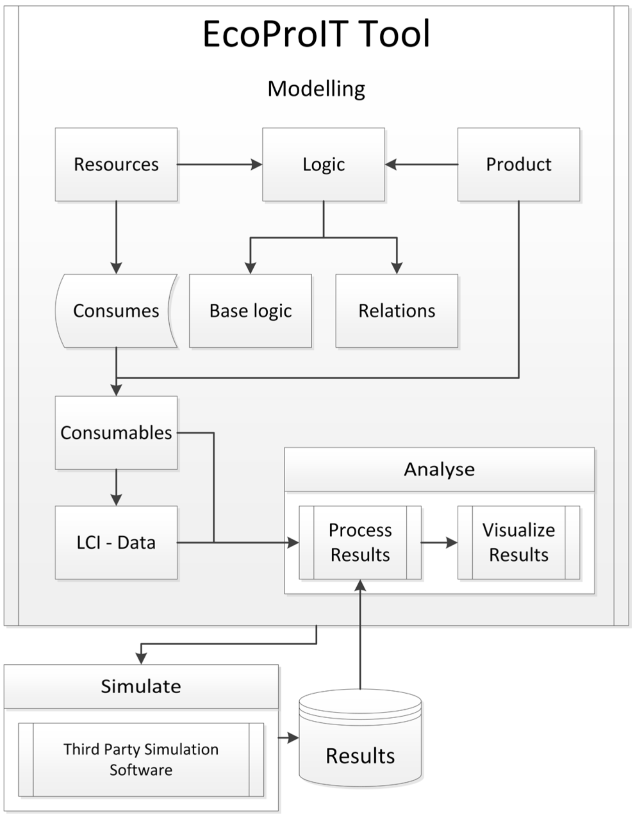

Figure 3: Tool design

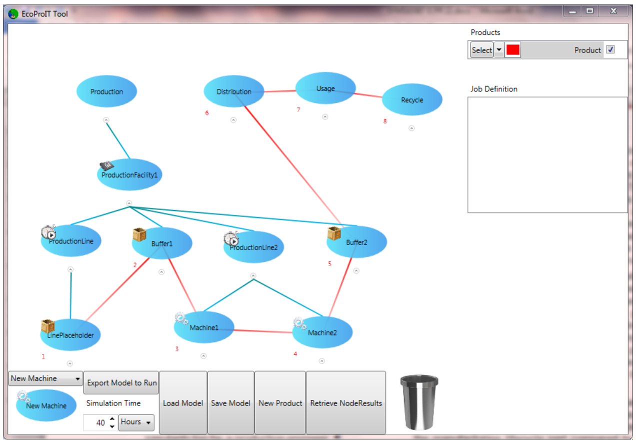

Figure 4: Tool main user interface

5 EXAMPLE CASE

The example system consists of a small manufacturing line with one conveyor and tree machines working on the products on the conveyor. The conveyor speed is 1 m/s and consumes 0.2 kW electricity. The first machine has a normal distributed cycle time with mean 60 seconds and standard deviation 5 sec. The second has a normal distributed cycle time with mean 55 sec and standard deviation of 8 seconds. The third has a normal distributed cycle time of 60 seconds and standard deviation of 3 seconds. Each station consumes 1 kW electricity when it is working and 0.2 kW while idling. The machines have a normally distributed mean time to failure of with mean 8 hour and standard deviation 0.5 hour. Mean time to repair for all machines distributes normally with mean 5 min and standard deviation 30 seconds. On the conveyor is the machines distanced by three meters from each other. However, currently is the conveyor not used as a buffer. Figure 5 visualize the machines with the conveyor belt where products moving from left to right. The problem is, what needs to be done to increase productivity by 10 % and what does that affects energy consumption.

Figure 5 Example of a manufacturing process

Considering the longest cycle time for the system, this system produces one product each 60 seconds, but that is not the current system output. Measuring the output at the end of the real line results in average a product every 66 sec due to system losses. Consequently is the takt time set to 66 seconds in this example. Using static Excel calculations the takt time result in 90 % utilization for the first and last machine. For the second machine, the utilisation stays at 83%. The resulting electricity consumption for the system is 2.9 kW, which is 0.054 kWh electricity energy per product.

Modelling the system in EcoProIT tool takes about 10 minutes from adding first machine until results are back for analyse. As expected are the results from the EcoProIT tool equal or close to equal, they differs on the fourth digit.

Changing any system parameter affects more than one node. However, using static analysis, a first test could be try to improve machine one and machine three by 10 %. The machines improved by 10 % results in a mean cycle time of 58 seconds. Nevertheless, it is impossible to verify that the solution give 10 % more output. Alternatively, if there is a need to improve the cycle time even more. In a true case, we would have to experiment on the real system to find out if the solution is enough, which drive costs and time.

Instead to experiment the EcoProIT tool is used to improve machine one and three by 10 %. The simulation engineer use the EcoProIT tool to modify the model. The exported logic run in the external simulation tool, which export the output to the database. The model in the EcoProIT tool is before the analysis prepared with the assumption that the electricity consumption increases 10 % while speeding the machines. When the output data is processed show the analysis that the system reached 62 seconds takt time, which is a 6 % improvement. EcoProIT also provide the results that there was an increase in energy consumption to 3.1 Kw for the system but no change per product.

Next experiment is to add buffers between the machines. Start by adding one buffer space between all machines. The run results in a takt time of 56 seconds and a very high utilization of the system. The energy consumption for the system increased to 3.3 kW however, the product consumption decreased a bit.

6 ANALYSE

This analyse is divided into three sections. The first analyse when to use complex simulation tools or simplified simulation tools as the one presented in this paper. The second part analyse the use of environmental impact data in simulation tools compared to use static approaches.

6.1 Conceptual modelling

The general production engineer is in no place to learn complex simulation tools. Neither be expert on environmental impact assessment. Strategies to focus on sustainability and environmental sustainability force the organisation to react. By using simple tools, the engineer is possible to analyse the system. A consultant expert could potentially provide better results using complex tools, especially for complex systems.

In more depth the pros for using a simplified tool as the one presented in this paper is in contrast to using complex tools are:

- Steeper learning tool
- Takes less time to model which give faster results or more time for data collection.
- Easier to get others involved and understand new experiments and results for improvements

Pros for using a complex simulation tool are:

- Precise models
- Analytic freedom
- Possible to model complex systems

A production engineer using simulation has to put lot of time modelling using complex simulation tools. A skilled simulation consultant could do the same work in less time. In a case where complex and precise modelling is not required, the production engineer could use simple software and still get enough results to increase the knowledge of the manufacturing system.

The tool presented in the paper is simple with few functions but still enough for simple production flows. Because of its simplicity in the basic logic more time is allocated to data management. Adding consumptions for the processes drastically increase the need of data. This approach sacrifices complex modelling.

The simplicity and conceptual modelling user interface makes it fast to understand the process. If the user interfaces present well-chosen and adaptive analyse results, the project team can it for discussions and decisions.

In the example case the simplified modelling techniques was helpful and did not need any major simplifications. However, the example did not contain any complex system. In complex manufacturing environment simplifications is inevitable using the current version of EcoProIT Tool and thus the deferens to the real system would be larger. However, for limited production parts the simplification enables fast modelling and rapid results.

6.2 Environment impact analyse

Using simulation to analyse consumption compared to a static study calculating current state for the manufacturing give a model that mimic the total system largely. A static model is not able to mimic the behaviour when parameters that affect the dynamics in the production system are affected. The example case in this paper shows that simulation can help avoid practical experiments. The example also shows how a simulation model can help to find better improvements without major process improvement.

It is also important to notice that the consumptions accompanied with the simulation results are not the primary aspects in this example. The primary goal in the case is to increase productivity. Nevertheless, sustainability parameters are increasingly important. The purpose is to keep consumptions and environmental impact on watch and present in improvement work. The production engineer can use consumptions to compares different solutions that all fully solve a problem.

7 DISCUSSION

The production engineer has been in focus during the tool development in this project. The focus has a major impact on the design choices. By changing the target to be a skilled simulation engineer, change the possibility to develop a more complex simulation tool with more features. Such target would provide simulation models that had better represent the real production, especially for complex systems. Moreover, the numbers of possible applications to addressed with an extended tool would increase.

However, the tool intends to use the skill possessed by the production engineer that better understands his own production, and therefore understand what is important to model. Knowledge of the own processes is also an important factor while choosing the production engineer as a target.

Advanced simulation engineers have possibilities to use many of the proposed concepts but using another simulation tool. Simulation engineers should consider the concepts of hierarchical modelling, levelled calculations, and increased details for environmental impact simulations of manufacturing systems. The concepts increase the possibility to understand the model, support modelling speed, and support verification and validation.

The purpose for developing the tool is to test research ideas. Using the tool for future applications and development enables a research platform for new ideas in the field. Practitioner in mini projects currently uses the tool. The tests intend to both to test usability aspect but also to verify the functions and find potential improvements.

8 CONCLUTIONS

This papers present a software implementation of a modelling tool for environmental impact analyses using simulation. The concepts for the tool focus on support for validation, verification and analysis. The implementation is one example to use the concepts. The tool is available for download at http://tool.ecoproit.com.

9 ACKNOWLEDGMENTS

This research is partly funded through the project EcoProIT founded by ProViking, which is gratefully acknowledged.

This work is carried out within the Sustainable Production Initiative and the Production Area of Advance at Chalmers. The support is gratefully acknowledged. VINNOVA and the Swedish Research Council are thanked for financial support to the Sustainable Production Initiative.

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