TECHNICAL CONCEPT OF A SOFTWARE COMPONENT FOR SOCIAL SUSTAINABILITY IN A SOFTWARE FOR SUSTAINABILITY SIMULATION OF MANUFACTURING COMPANIES

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ABSTRACT
This paper presents the technical concept and prototype implementation of a component developed for the modeling of social sustainability criteria, as well as the description of a software suite for the simulation of sustainability criteria in producing companies. The simulation software (MILAN) already integrates the classical economical perspective as well as an environmental perspective through the inherit usage of material flow analysis (MFA) and life cycle assessment (LCA) combined in one modeling approach. The newly developed component is intended to allow for a relative free definition of social influence indicators as well as influence functions, which can subsequently be integrated in the same model and thus allow for a rather holistic sustainability simulation approach. As most of the social indicators are still very disputed, as well as dependent on the structure of the entity under observation, the free definition aims to provide the modeler with the needed flexibility to create a model of his interest, while providing him with a strong structural guideline on how the integration of social criteria can be worthwhile.

Keywords: discrete event simulation (DES), material flow analysis (MFA), life cycle assessment (LCA), social LCA (SLCA), occupational health and safety (OHS)

1. INTRODUCTION

The classical usage of simulation considering the economical perspective of manufacturing systems and its rather output oriented point of view has already been widely discussed, see for example (Banks 2005) for DES examples and (Brousseau and Eldukhri 2011) for recent advances for innovative manufacturing.

Over the last decade the environmental perspective has become more prominent and resulted in different (simulation) approaches with a focus on the environmental sustainability of production systems; examples for sustainability oriented manufacturing simulation can be found in (Seliger 2012) and (Thiede 2012), including lists of software with status overviews of their features considering sustainability assessment/simulation.

While these developments show promise, firms, and particularly manufacturing company reports rarely include the social dimension, which is also reflected by the number of simulation studies and tools addressing this topic. Many companies are issuing corporate reports which stress governance aspects and environmental practices, but tend to overlook the role of the employees or workforce (OECD 2008, cf. GRI 2013). This identifies the first big challenge of the chosen approach, as even though not many deciders will argue about the importance social criteria have considering the day to day work, the impact and the management of social values remains largely hard to quantify and qualify, and thus is only rarely supported by more complicated software tools, such as simulation software. This may also be due to the fact that simulation software in general is usually used to answer specific question and is, in that regard, itself often designed for specific users, making its usability a lesser priority (Krehahn et al. 2012). With the intention of integrating the different perspectives however, the necessity arises for higher user-friendliness and hence poses an additional challenge to the already existing one of defining usable criteria that can be simulated and correlated in a meaningful way.

The concept of the simulation software was furthermore developed with particularly regard to the main idea of sustainability, as understood hereafter, as the positive or negative reinforcement of measures contributing to the preservation or destruction of capital (economic, environmental, and social), depending on predefined normative values for that capital in question. These normative values are needed in order to have a qualification of the measures once the simulation has delivered its results. This paper will therefore:

- present the software's background (section 2),
- state the current common features of the simulation software (section 3),
- illustrate the new component (section 4),
- define interfaces and specify the interaction of the different software components (4.2 & 4.3),
- elaborate on related work and conclude with an outlook (section 5 and 6).

2. METHODICAL BACKGROUND OF MILAN

MILAN is a software solution that has been developed over the last 13 years and has seen various implementations in different programming languages. The main concept behind its initial development was the integration of material flow analysis (MFA) with the already established discrete event simulation (DES) for manufacturing cases in one single modeling approach (i.e. just one model has to be created, instead of two different models (MFA, DES) in the past) (Wohlgemuth et al. 2001; Wohlgemuth 2005).

The first development with the intention to promote resource efficiency was realized around the year 2000, when the proposal was made to use simulation techniques for supporting the application of the Material Flow Network method (Wohlgemuth, Bruns and Page 2001; Wohlgemuth 2005). Material Flow Networks were developed at the University of Hamburg (Möller 2000) and are based on the Petri-Net theory. By their means, the software is able to depict and calculate unknown environmental quantities, such as the determination of the necessary load of connected input flows considering complex systems (see Joschko, Page and Wohlgemuth 2009; Widok, Wohlgemuth and Page 2011).

While on one hand, the discrete event simulation components allowed for an accurate analysis of typically economic and industry related aspects, the material flow analysis components on the other hand added an environmental perspective to the discrete event simulation model, i.e. a consideration of relevant material flows and transformations such as:

- the consumption of commodities, resources and additives,
- the energy demand,
- waste accumulation,
- emission generation.

The first presentation of the Material Flow Simulator MILAN was made in 2006 (Wohlgemuth, Page and Kreutzer 2006), its first implementation realized using the Delphi version of DESMO-J, called DESMO-D, the framework and components in high level language Delphi. The component-based architecture was realized using COM-Technology (Wohlgemuth, Page and Kreutzer 2006). This realization, however, seemed outdated and has been renewed since 2009 two times using two different approaches. Once using the EMPINIA Framework (see http://www.empinia.org/). EMPINIA, which was developed in the course of a project called EMPORER, is designed for the development of complex domain-specific applications especially in the field of environmental management information systems (EMIS) (Wohlgemuth, Schnackenbeck, Panic and Barling 2008). It is a component-orientated extensible application framework based on Microsoft's .NET (http://www.msdn.microsoft.com/de-de/netframework) technology with the purpose of supporting and simplifying the development of complex software systems (see Figure 1).

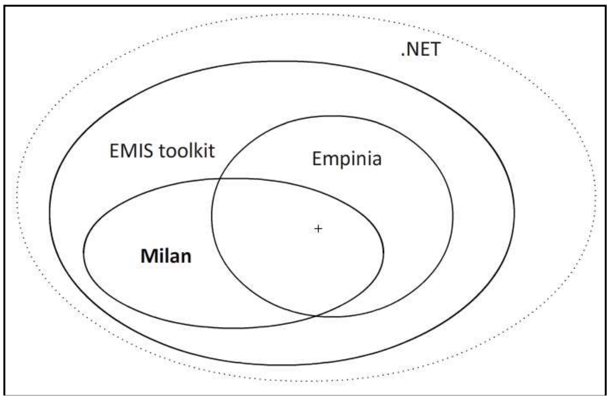

Figure 1: Environment of the 2009 implementation

In order to take advantage of newest .NET development patterns, a switch from the implemented version using model-view-controller (MVC) patterns (Jahr et al. 2009) was made to more contemporary model-view-viewmodel (MVVM) patterns within the last years. Furthermore, recent advances also facilitated the integration of LCA data in the same modelling approach (different scope) allowing for the integration of the life cycle perspective (see Reinhard, Zah and Wohlgemuth 2013).

3. FEATURES OF THE SIMULATION SOFTWARE MILAN

In order to be able to provide the described methodological functionalities different components had to be developed; their key features will be briefly outlined in the following (see also figure 1):

- a simulation core (central simulation service, interfaces and abstract base classes for models),
- a bundle for discrete event simulation (specific for DES, with scheduler, timing aspects, etc.),
- stochastic distributions (e.g. Bernoulli, Exponential, etc., to generate streams of numbers),
- a graph editor (enabling the visual representation and manipulation of models),
- property editors (facilitating the parameterization of model entities and given metadata) new editors with the same principle, were developed for the social aspects,
- a reporting suite (creating the simulation results and preparing charts depending on the scope, also facilitating export functionality),
- the material management (for the creation, management of materials, batches, bills),
- the material accounting (by its means it is possible to show, save and manage material and energy bookkeeping resulting from the simulation. The bookkeeping is realized using accounting rules, which can be added to all discrete events in combination with relevant model components),
- a LCA browser, which enables an easy, string-based search and the subsequently integration

of LCA material data, enabling life cycle inventory (LCI) and LCA in the simulation and the results.

For more information about the technical aspects of base functionalities of the simulation software, see (Jahr et al. 2009).

4. THE SOCIAL DOMAIN MODEL

4.1. Architecture overview

Figure 1 is illustrating the main components relevant for the social domain. The elements in the first two lines are building the backbone of the social component; the ones in line 3 and 4 represent elements relevant for the sustainability assessment, while those below represent simulation and technical entities facilitating the functioning of the components above.

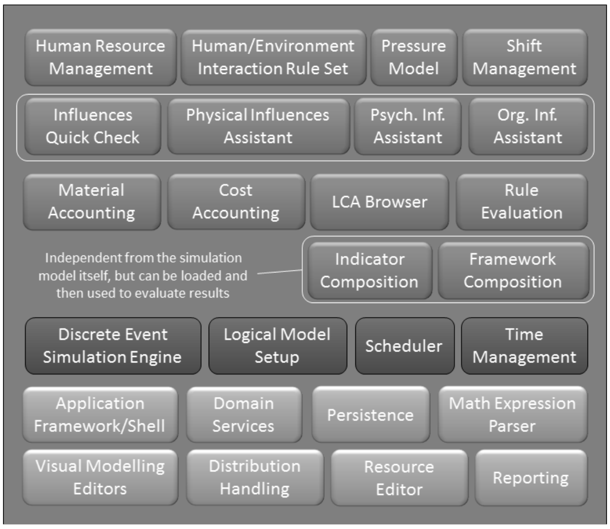

Figure 1: Relevant entities for the social domain

The concept for the social prototype was mainly oriented on two major drivers. First, the component architecture – aside from normal component-development reasons, such as high reusability and the easier understanding of the code, through clear, small packages, this also means that the usage of the social perspective is not enforced, i.e. it is possible to model social aspects through the software, but one does not have to. The software also allows to only build DES simulation models and not integrating MFA or LCA, but if the data is existing and the intention is to have a strong, holistic model, one can use the different techniques combined in one modeling approach and only a single model has to be created, incorporating the methodologies. Secondly, the free definition of influences – this is based on the conviction that social criteria, as well as their measurement, are still disputed. Based on this, it was decided that an open definition of different influences would be made possible, with different editors for the most common influences (physical, organizational, psychological), incorporating current knowledge considering the measurement of such criteria and their impact on human resources over time. These impacts however are not validated by the tool itself, i.e. the reasonableness of the defined influences and their impact lays currently with the modeler (except for logically excluding behavior).

As a result of these convictions the social criteria integration was coupled with the resource system, allowing for the integration of human resource into the model or not. Furthermore special editors were designed for the easy modelling of different influence factors which, combined with various mathematical functions, would allow for the creation of an influence on the resources over time.

The result of these influences may, once the modelling of the resources is complete, be combined with different events, such as a termination event for the simulation (for example in case of the destruction of needed resources – see also figure 3), or general state changes (considering the failure, inoperability or reduced output of workstations).

In order to allow these possibilities the resource system had to be renewed, paying tribute to different kinds of resources (human resources, usable resources (tools) and substances, hence enabling different internal handling of them and editors for their modelling. In addition the resources have a property with a list of categories, enabling for example the localization of resources. This was important in order to associate locally existing influences with human resources (noise for example). The influence would then be a logical consequence of the modelled influence factor in combination time and the chosen pressure model (see also figure 4).

4.2. Selected interfaces

The following figure shows them main interfaces for the human resource system. To note is the interface IResourceTypeAmount, which is basically a combination used to derive different quantities of different user defined types of resources and map them to the accorded resource pools. The modelling of different groups of workers, as organizational entities or in order to research age groups and other possible influence factors is in this way easily achievable.

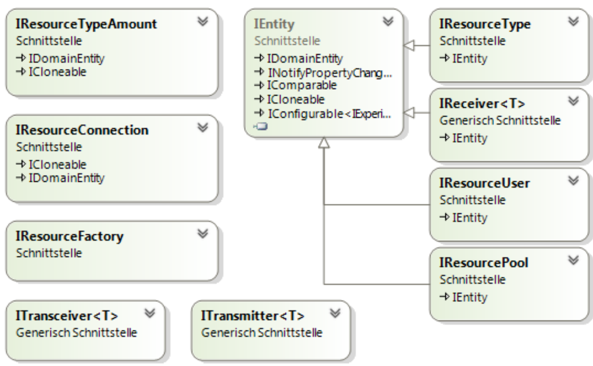

Figure 2: Interfaces of the Resource System

To note is also the observer-based functioning of the simulation routine. Figure 3 displays an example of two interfaces for the standard simulation observer and its related interface for simulation termination criteria. Through the observer-based handling of the routine feedback is easily steerable.

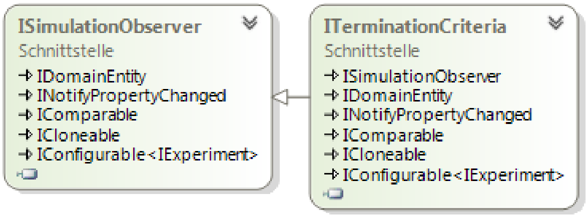

Figure 3: Simulation-flow-handling through observers

4.3. General workflow and related components

Figure 4 depicts the general workflow for integrating the social aspects into the simulation. Given that the resources were modelled in the human resource editor (where one can adjust for skill set, integration of distributions considering illness or weaknesses (also usable for the modeling of elderly workers and many others), one has different possibilities to combine the resource with the model. One way is through the workstations themselves, allowing for the modelling of necessities, i.e. an amount of a type of resource is needed for different states, or in combination with the shift management. Either way, the resource usage is giving the first answer to the question how people would be affected through their interaction, by giving the timespan of a certain influence.

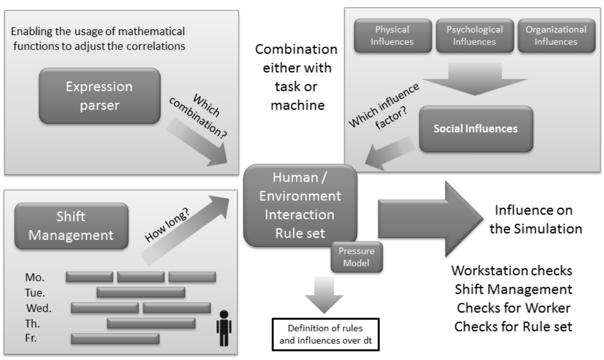

Figure 4: Relevant entities for the social domain

The shift management is basically a standard shift planning tool, which is used for both, the workstations, i.e. one can define if production processes are continuously or with breaks for a period of time. This is of course relevant for the warm up phases and different states of the workstations. Furthermore the shift management is used to attribute different human resources to their respective work-related entities. These could be different workplaces (although a workplace editor is yet to be integrated). For the moment these are the respective workstations (i.e. the rather classic DES workstations model entities). In addition the possibility is given to attribute a type of influence on the resource over time. These possible strains can be either physical, or otherwise, depending on the modeled influences through the different influence editors and the following choice of the modeler.

These editors allow for different types of influences, the main differentiation is between physical, psychological and organizational influences, where the physical editor guides the definition of a physical influence through possible input choices (strong relation to German OHS guidelines, as in strains for lifting, crouching, carrying, but also general, as in workload dependent, biological interaction, noise, etc.) all of the possible choices are backed up with known formulas for the development of the influence (such as the physical basics of noise development (and combination considering different machines) or basics for the development of particulate matter in production processes), as well as known limit values considering the strain on an average human being. The psychological editor does currently have a completely free definition of influences, while different types are suggested, no choices of formulas is, but rather the definition of a type is mandatory, which can subsequently be used in the rule set editor. The same procedure is implemented for the organizational influences. Even though many studies were incorporated in a knowledge basis for these components (a systematic review of occupational musculoskeletal and mental health studies for production systems can be found in Westgaard and Winkel 2011), the definition of the non-physical influences was implemented without structural restriction.

In order for the influences to take affect another component was needed, the human environmental influences rule set component. In this element one can choose from the previously defined social influences and by the usage of a math expression parser and the existing model of shifts and or the production system (i.e. the workstations), combine time with influences to create an impact over time. Different dose concepts were evaluated in that regard, which are also integrated in a knowledge base and selectable (note: the tool is only making a basic validation for reasonable combination choices). Once an influence is attributed to a shift or a workstation, the simulation is then calculating an impact of the indicated influence over time.

This allowed for the combination of economic, environmental and social reporting on the results of manufacturing simulations and thus combined different perspectives in a single model. Currently the reporting suite is being worked on, as the best way to visualize the different outputs has not been found yet. What can already be observed however is, that it is now possible to relate strategic question considering workload on different individuals. In this regard the planning of, for example new shifts is made easier and the planning of new production lines, which need an amount of skilled workers, can now directly be related with consequent influences on worker exposure (to different substances, workload, other influences).

5. RELATED WORK

5.1. Focus on environmental sustainability

In the course of the last decades the environmental perspective has become more and more prominent considering the simulation of manufacturing entities, examples for this focus can be found in (Thiede 2012, Seliger 2012, Reinhard et al. 2013, Andersson 2014). These references were used as orientation during the development cycles. Most other existing simulation software tools are not integrating the life cycle approach. It seems that the perception of the system borders of the simulation approach, which logically inhibits the gate to gate focus, is hindering the other. In order to change that and integrate upstream data, two strategies can be observed: on the one hand, through the integration of LCA data (for used material) at least the environmental and some social aspects of the downstream can be integrated, examples in (Kellens et al. 2011 as well as the mentioned Reinhard et al. 2013 and Andersson 2012), while on the other hand different simulation techniques (for example DES and SD and or ABS) are combined in order to model and integrate different parts of the life cycle in appropriate and possible detail/granulation. These will logically be integrated once the simulation has finished; a comparison of the output of such differently combined modelling approaches can be found in (Jain et al. 2013). The combination of these different models is however usually happening via interfaces not integrated in a single model, while the here presented approach depicts the integration of LCA and DES in one modeling approach, see also (Widok et al. 2011) and (Widok et al. 2012) for more details on the environmental sustainability perspective.

5.1. Focus on social sustainability and OHS

Social criteria remain a lesser focus of the simulation of manufacturing entities (Schneider 2008, OECD 2008). In (Heilala et al. 2008) ergonomic criteria are, as part of the social domain, integrated in one simulation approach; (Lind et al. 2009) displays the results in more detail. These references were used to validate the possibility of a broader social sustainability approach and thus helped to depict and conceptualize the ergonomic part of the influence factors. In (Makhbul et al. 2013) stress at the workplace is analyzed and ergonomic workstation factors categorized, which gave ideas for the integration of the organizational and psychological influence editors. Implications towards the work performance of following measures can be found under (Yahaya et al. 2011), while these findings were very interesting they are currently only integrated through a knowledge base, accessible during the modelling process, due to the complexity of the possible internal feedback. Detailed analysis of occupational musculoskeletal and mental health with specific focus on production systems can be found in (Westgaard and Winkel 2011), they also show an overview over relevant studies as well as highlight the significance of the findings of these studies. This paper can be used to assess what criteria are worthwhile to be modelled and how possible results should be questioned. A detailed analysis of historic occupational safety measures as well as trends can be found in (Luczak 2002), these helped to categorize the chosen integration approaches and depict the general functioning of the "work system". Examples and guidelines for shift-management/workplace fatigue can be found in (Department of Labour New Zealand 2007). The given guidelines helped to design the interaction between the shift-management and the influence/pressure models. Furthermore, in Germany a new guideline by the association of German engineers has been published, depicting the representation and physical strains on humans in virtually modeled manufacturing halls, an analysis is described in (Zülch et al. 2013), those were used in combination with (Zaeh and Prasch 2007) where the authors are making suggestions for systematic workplace/assembly redesign for aging workforces, in order to work out the influence factor operations in the modelling process.

5.1. Focus on ELCA and SLCA integration

A literature review of social sustainability assessment methodologies can be found in (Benoît and Vickery-Niedermann 2010), this paper was also very valuable considering LCA integration and possible SLCA adaptations. Considering SLCA, one has to note author Jørgensen, who published many excellent papers (Jørgensen et al. 2007) for example on the integration of SLCA criteria in companies, summaries of his work are in (Jørgensen 2010). Most of his work has been reviewed and different methodologies tested for the SLCA integration.

Lastly the capital approach for sustainability evaluation is explained in chapter v. of (UN 2007), which was relevant for framework compositions and consequently result qualification, i.e. reporting mechanisms (see also Spangenberg et al. 2010 and GRI guidelines (GRI 2013)).

6. CONCLUSION

At the basis of the integration of social criteria stands our experiences from the past considering the integration of environmental perspective in the simulation tool MILAN. At the time environmental criteria overcame the once thought immeasurability as over the last decades their data maturity grew. It is our understanding that the high focus on environmental sustainability aspects in the past decades could when focused on social aspects lead to similar enhancements in data accessibility and maturity. Especially the SLCA development seems promising in order to achieve this goal.

There are a few reasons often mentioned against the introduction of social criteria in manufacturing simulation, namely, for example the false angle – emphasizing that simulation of manufacturing systems should focus on classical aspects and let social criteria be managed by human resource management and corporate social responsibility practices. To that we argue that simulation, understood as a strategic method, is meant to give deciders a stronger foundation for their decision making process. In the past these decision were solely based on the outcome-oriented perspective, a change of this would be good for the involved human beings. Even though we agree with (Gasparator et al. 2007) conclusion, considering methodological pluralism (very simplified: more is not necessarily better), the key idea of the approach in this paper is the attempt of the integration and ability to put different perspectives in correlation. It is clear that the social aspects have yet to mature in their scientific provability, yet potentials can clearly already be indicated. This is what the tool already delivers as result, potentials compared to limit values (i.e. elevated by x%, without qualifying beyond stating that it is a positive or negative tendency and putting it into context).

Furthermore it is often argued that every human is different and hence a measurement would be pointless. The fact that every human is different is valid, however the main aspects of human health and psychic are not as different as a variety of studies suggest (see Westgaard and Winkel 2011). Of course it is complicated to derive exact numbers, but that is where the free definition of influences comes into play, by allowing for the modelling of workers, as well as the impact on different levels. So while the presented approach is far from scientifically established, its purpose is rather to promote the re-integration of social values in existing manufacturing processes and further develop on holistic perceptions of human actions.

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