Definition of Social Sustainability Criteria for the Simulation of OHS in Manufacturing Entities

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***Abstract*— This paper highlights the common factors of social sustainability criteria with economic and environmental criteria for the modelling and simulation of manufacturing entities. Its intended purpose is to demonstrate how and what kind of social criteria can be integrated in such simulation without having to change the model drastically. In addition, the paper presents the prototype of a plugin, as part of a software suite (MILAN), aimed to provide technical analysts with the means to simulate various sustainability criteria in manufacturing companies. The plugin is intended to enable analyst to freely define relevant social influence indicators as well as influence functions and combine them with the existing environmental and economic modeling approach.**

Keywords—Social Sustainability, Sustainability, Discrete Event Simulation (DES), Occupational Health and Safety(OHS)

I. Introduction

Aside from the obvious still debated definition problem of social sustainability, which stretches on different modeling levels, it is interesting to note that not many companies will argue about the major influences that social aspects have on their day to day business. The question whether social criteria have an impact on the output of producing companies and how to quantify it, is however more disputed and notably dependent on the company's processes. A consensus on social criteria relevant to more than one company and a software that integrates a resulting social perspective with existing economic and environmental perspectives seems out of reach, thus making holistic sustainability approaches to a real problem.

Considering three simple cases as an example: one company may have ergonomic criteria relevant to their production processes, which they want to have modeled, due to the unknown strain on the workers bodies; another company may have other influences on humans health due to particulate matter exposure and noise; a third may want to elaborate if a simulation study can answer the question if the work organization is beneficial considering the shift management and resulting work load of their individuals. Considering these possible cases the question is: how would the modelling software be designed to represents these very different scenarios, while also acknowledging environmental and economic aspects of the production. This is the problem this paper addresses and will answer by:

- elaborating on the background of social criteria in the manufacturing industry (section III A),
- categorizing the accorded social impacts and deducing criteria for possible simulation studies (section III B and III C),
- referencing the manufacturing simulation software MILAN as basis for the integration (section IV A),
- present the technical concept and the implementation of a software component for the integration of the social perspective in the existing simulation software (section IV B),
- highlight future results and discuss strengths and weaknesses of the approach (section V),
- lastly related work will be presented and an outlook will be given (section VI and VII).

II. The Problem of Definition in more Detail

In order to formulate a strategy for the evaluation of social criteria it is important to understand how producing companies are motivated to produce in a more (socially and general) sustainable way. Aside from intrinsic motivations of given deciders, the two main theories are legal compliance and the demand of customers, representing top down and bottom up tendencies. For both theories however a variety of limiting factors is applying. The main problem with the top down tendency is that regional and international frameworks, as basis for policy decisions, pay tribute to the different regional necessities, hence reflecting the needs and situation of the people in the region. Ultimately the given diversification results in a different prioritization of criteria, which leads to different compliance criteria for the resident entities. These differences allow for a distortion of competition and consequently to a higher prioritization of the economic orientation in order to keep up with the globalized market. For the bottom up tendency the sphere of activity between the consumer's time and the multiple sustainability criteria (price, environmentally viability, and social friendliness) create conditions that make the necessity for an elaborate research, in order to find a fitting product, to a task that is rarely applicable for all his consummation. While it is fairly easy to assess the economic value behind the chosen product, when it comes to environmental and social identifying values, it is a difficult task. With regard to firms, and particularly manufacturing companies, reports on the sustainability of their operations rarely include the social dimension. Many companies are issuing corporate reports which stress governance aspects and

environmental practices, but, e.g., tend to overlook the role of the employees or workforce [1], [2]. Normally a detailed analysis of products is hard to find and thus, in order to make a decision, consumers relay, for example, on brand identification combined with rather time restricted information on how environmental and social friendly the company is perceived/displays itself to be. In other words, the steering of the capital by the consumer is not based on the actual environmental and social impacts of the product, but by the little information they can gather about the company itself and in elaborate cases its manufacturing processes. The data to assess the environmental and social friendliness of the product itself is not at the consumer's disposition [1]. Naturally a choice regarding the price comes easier than basing the decision on facts that the consumer can hardly evaluate. With this problem in mind, the following sections will evaluate how the social perspective of sustainability can be integrated in simulation approaches in order to contribute social evaluations of products in the future and possibly counteract this problem.

III. Social Sustainability in the Manufacturing Industry

A. *Understanding social sustainability on company level, definitions, challenges*

In the last decades various entities have made great efforts to give deciders a stronger foundation on what social sustainability implies. This section addresses these findings and elaborates the way from a broad perception of sustainability (III A) down to relevant social aspects in manufacturing companies and their orientation (III B), further down to measurable criteria for usage in simulation studies (III C).

Starting with the World Bank's sponsored Social Capital Initiative at the beginning of the millennium [3] many international and regional organizations have since created a variety of international policy/reporting guidelines, such as the G4 guidelines [2] /monitoring/auditing frameworks and other instruments, such as value chain analysis, social impact assessments and other that all aim for a broad perception and integration of social criteria in sustainability assessment. A detailed list of instruments can be found in [4].

When considering these framework approaches and social criteria, the problem arises, that different social criteria will be relevant to different regions, companies and different people. Furthermore, as the sustainability concept has an inherit function to be able to shift in time [5], potential sustainability criteria have to have their qualification flexible in those regards (hinting the change of the model used for their qualification, i.e., iterations of simulations to pay tribute to the change of normative values at the basis of the qualification). In addition to those modeling challenges, Omann and Spangenberg formulated four major challenges on how to assess social sustainability [6], namely:

- the lack of conceptual clarity (emphasizing definitions to be dependent on countries and entities),
- the complexity (questioning if the concept is manageable with current means (org./tech.),
- the "bad experience" from the past (1960's) considering the formulation of normative goals, in order to place social values in relation to the other perspectives, also[7],
- the fact that a stronger integration of social values may question the foundations of development models, cf. [6], reducing the likeliness of acceptance/introduction by deciders.

Many other authors, e.g., [8], [9], argue in similar directions, yet the first argument should not be understood as lack of conceptual clarity but maybe rather adaptability; this is because the regional/organizational shift of relevant criteria is explainable. If we consider social criteria to be in direct relation to human beings, similar to any human need categorization, regional social sustainability frameworks will represent the state of the needs of the people in that region. This does not necessarily influence the validity of existing frameworks, but only reduces their comparability. Summarizing one can observe two essential dispersions that influence the definition of social sustainability criteria in companies, shown in figure 1 and 2 beneath:

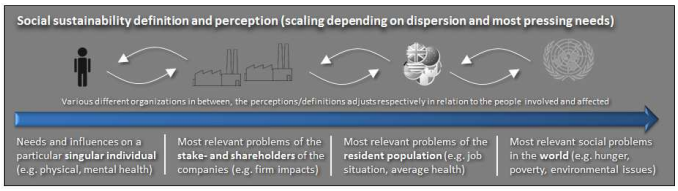

Fig. 1. Scaling of the social sustainability definition depending on the dispersion of pressing needs

The first differentiation needs to be made considering the people and organizations that are at the basis of the question of what is sustainable (i.e. sustainable for whom, for what, for how long). The definition is thus dependent and pays tribute to the different states in which the people or organizations are.

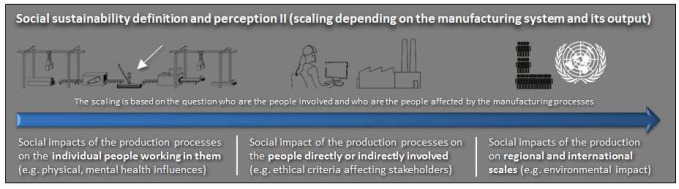

Fig. 2. Scaling of the social sustainability definition depending on people involved and affected

The second variance is in relation to manufacturing companies. It is necessary to make a difference between the social impact manufacturing processes have on the people directly involved in them (i.e. the people working for example at a workstation) and the social influences emitted by the production itself through all their processes, e.g., water usage.

In addition to these differences in definition, the technology choice for evaluation needs has to be addressed. Consequently confronted with a variety of possible input factors the question poses itself, what are the relevant criteria and how could they be integrated. These questions will be answered in the following by first categorizing the various social aspects that are occurring in companies in general and producing companies in specific.

B. Categorization of company based social criteria

The following categorization of social sustainability aspects is oriented on Porter and Kramer's depiction of social impacts of the value chain of companies [10], [11]. Extending their description of different criteria and placing them in a manufac-

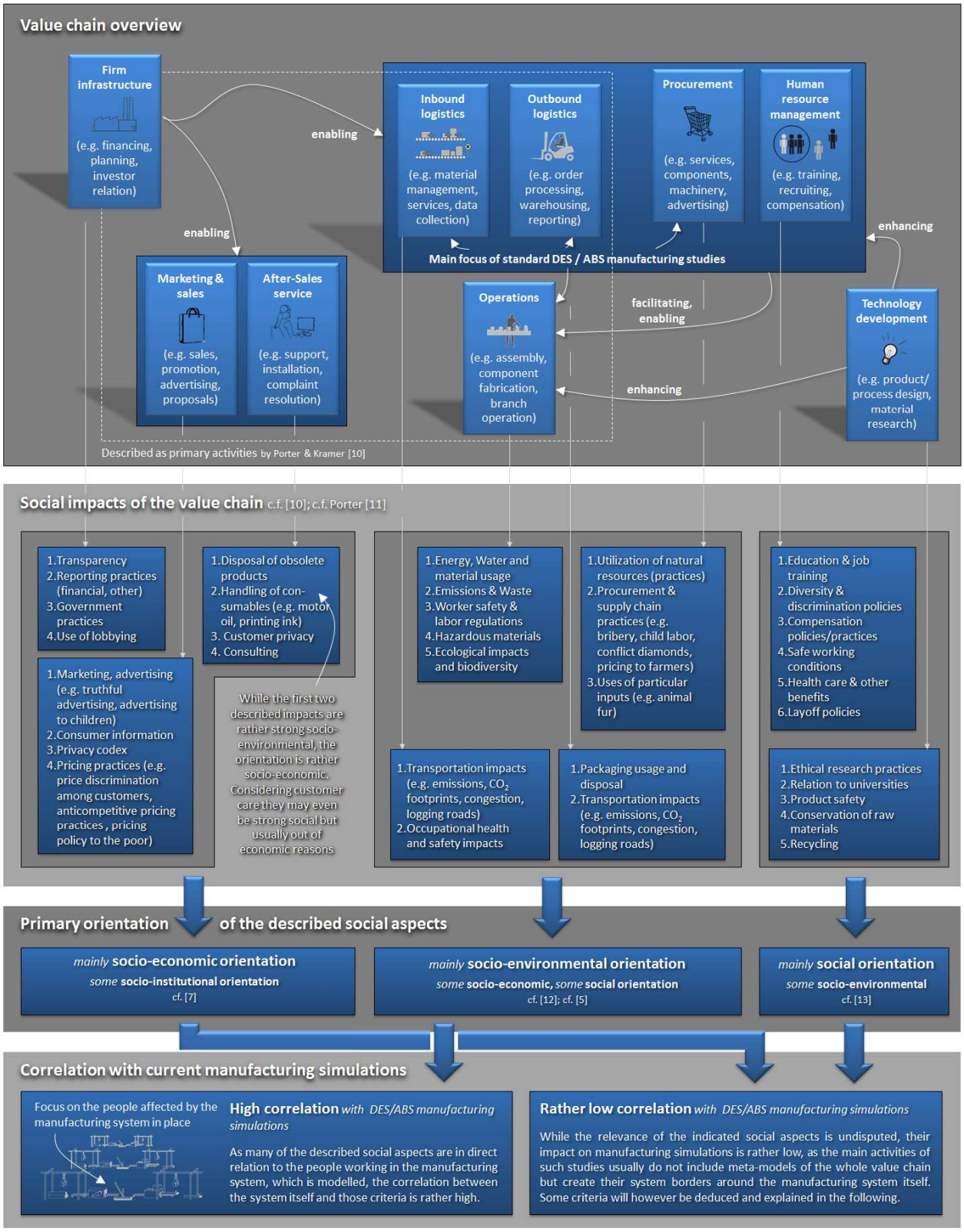

Fig. 3 Social criteria along the value chain and categorization of their impact/orientation, cf. [10]; cf. [11]

turing company's perspective (their elaborations are more general). The main thesis that figure 3 is trying to highlight, is that many of the social impacts at operation's level and generally in the primary value creating activities of manufacturing entities (mainly operations, but also inbound/outbound logistics, procurement) have high correlations with existing discrete event simulation (DES) and agent based simulation (ABS) modeling approaches. This is because the social impacts are mostly directly linked to either the materials in usage (socio-environmental orientation and socio-economic if we consider efficiency aspects) or the people working and facilitating the functioning of the workstations (social orientation, occupational health and safety (OHS)).

C. *Definition of social criteria relevant to the simulation of manufacturing companies*

One can thus note, that a limited integration of a social perspective in existing economic, environmental orientated manufacturing simulation models is possible without having to change the model itself drastically, opening the possibility for a more integrated holistic modeling approach. In that regard the choice for a first set of resulting criteria was based on the described social impact criteria from these aspects (OHS and material/substance interaction, physical exterior influence exposure). Also note, that the indicated social impacts are naturally not complete, further elaborations of social impacts at midpoint level can be found in [14]; the given figure was intended to demonstrate groups of impact criteria and their categorization. Furthermore, as these have been categorized as socio-environmental, basically representing the original sustainability perception of conservation, and as socio-economic, the correlations between the pillars of sustainability should become even more apparent.

While this only considers a limited view on social impacts (reducing the perception to the manufacturing processes), it is important to note, that the life cycle approach can consequently be incorporated through the integration of social life cycle assessment (SLCA) data for the materials in usage and general upstream input data. To clarify this, consider a classical manufacturing model, which depicts the system borders at the in- and output flows before and after the existing manufacturing processes. This model has and produces little life cycle knowledge but only considers the manufacturing aspects (which depending on the used materials make more or less of the overall impact). It is however possible to have a combination of classical DES/ABS manufacturing approaches in combination with life cycle assessment (LCA) upstream data (and possibly even downstream data, depending on the modeling approach), as has been demonstrated among others by [15], [16] and [17] for the environmental LCA (ELCA) part. Taking SLCA parallel to ELCA, it can thus potentially be used for two different overall purposes, already discussed in 1997:

- to compare the social impacts of two comparable products or services (or compare a product or service against a standard),
- to identify hot spots or improvement potentials in the life cycle of the product or service.

There are different approaches, which use different simulation techniques in order to model and simulate the bigger picture (apart from the LCA integration), i.e. changes in customer demand (due to marketing for example) or the abstract term of innovation (tech. dev.) can be modeled and simulated using system dynamics, examples can be found in [18], [19], [20] and then combinations of these can be found in [21] and [22] using also LCA.

Since the integration of social issues into LCA, SLCA methodology now advanced to the point where it is left with many of the same unresolved issues as ELCA [23].These include:

- the challenges of tracking down site-specific data,
- the challenges of integrating location sensitive information,
- the challenges of integrating information collected at different scale (from general sectors to specific unit processes),
- developing characterization methods [4].

Yet, even though the data situation is always a problem to be taken seriously, the concept of integrating social impacts for the production processes in the simulation model, as was already done for environmental criteria, while integrating social impacts for the different other life cycle stages through SLCA data, was found worthwhile and is at the basis of the depicted prototype that will be elaborated in the following.

IV. Integration of Social Sustainability Criteria in the DES/MFA/LCA Simulation Software

A. *The basics of the simulation software MILAN*

The software MILAN has its origin in 2001, when the conviction began, that the combination of material flow analysis (MFA) with existing simulation approaches was worthwhile [24].

The concept of combining discrete event simulation and material flow analysis in a component-based approach was then presented in 2006 [25] and its re-implementation on .NET basis was elaborated in 2009 [26]. The integration of DES with the material flow perspective of MFA within a single integrated modeling approach was made possible in order to strengthen the perception of correlations between environmental and economic questions. Based on the dynamic, tactic and strategic character of the simulation approach itself, the perception of material and energy flows, which was at that point not part of the operative level, was intended to be given a more strategic, proactive tendency.

In 2011, a capital measurement approach for a more holistic sustainability perspective was presented, hinting the beginning of the integration of the life cycle approach [5].

In 2012, the ELCA integration was elaborated and the integration of the social perspective was discussed in the outlook [15]. Since then the simulation software has constantly been enhanced with new features and has been used for case studies with companies in Germany and Switzerland (under a

different scope (EcoFactory) with a MILAN core). The most basic components of the software are:

- 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),
- a reporting suite (creating the simulation results and preparing charts depending on the scope),
- the material management (for the creation, management of materials, batches, bills of materials),
- 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 the simulation software, see [26].

B. Thesocial perspective prototype

When the social prototype was first designed the two attributes found to be the most important were:

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 states, 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.

The free definition of influences: this is based on the conviction that social criteria, as well as their measurement, are still very 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).

The main features of the social component will be elaborated in the following (Figure 4 shows a highly abstracted/simplified illustration of the major components of the new domain for the social criteria):

Fig. 4. Main components of the social criteria domain and correlated elements

Human resource management/editor: based on normal resource management approaches a functionality was created to split existing resources into three different resource types, 1) human resources, 2) tools and 3) usable resources. Each of these resource types has a different editor, facilitating for the human resources possibilities to adjust for skill set, integration of distributions considering illness or weaknesses (also usable for the modeling of elderly workers and adjustment of strengths in the following) and many others. Furthermore a new pooling mechanism was created based on a list of categories attributable to the existing resources, for example one could attribute a human resource different locations, workplaces and others (also at different time steps). The categorization/pooling then manages for example the availability of the resource.

Shift management module: the shift management is basically a standard shift planning tool that 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 that regard a classical resource usage over time can be calculated and attributed to locations as well as workstations and other categories that were defined in the resource categorization. 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.

Social influence layer: in this layer, different editors for different types of influences were developed, 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 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 [27], the definition of the non-physical influences was implemented without structural restriction.

Human environmental influences rule set component: this is the second key element for the integration of the social criteria. 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.

V. Results and Discussion of Strenght and Weaknesses

The social component is currently being tested in two use cases, respectively in one plastic processing company and one company that is creating technical boilers. Aside from the classic results, such as new information on resource usage, failure times, etc. new information considering workload and strains on human resources are expected as results. Different scenarios are still under evaluation (noise, repetition, material exposure influences). What can however be observed, is that the bringing into focus of social aspects, already created ripple effects, considering the perception and the management of social impacts.

In light of the current feedback, we argue that the main weaknesses/challenges of this approach (bad data situation, privacy issues, fear of abuse, wrong evaluations) are manageable and that it is similar as with the environmental sustainability assessment in the past, i.e. that the best way to address the complexity is by making one step at a time, without losing focus of the needed flexibility and adaptability of further models, simulations and their result qualification. This approach is intending to do just that. While others have shown that different social aspects can be integrated in DES manufacturing approaches, it is our intention to create the scientific basis for the step by step integration of new impact criteria, by delivering results of successful integration and evaluation of social criteria through the depicted method in the future. The concept for a worthwhile integration of SLCA criteria is currently being worked on.

VI. Related Work

A. *Classical perspective on manufacturing systems and their simulation*

The classical usages of simulation considering the economical perspective of manufacturing systems and its rather output oriented point of view have already been discussed in much detail, examples from a discrete event simulation approach can be found in [28]. In [29] recent advances on key technologies for innovative manufacturing are discussed. In the same regard, a general review on supply chain performance measures/metrics can be found in [30].

B. *Combination of different perspectives (i.e. environmental, social, economic) in simulation*

Over the last decade the environmental perspective has become more prominent, examples for the focus on the environmental sustainability of production systems can be found in [31], [22] and [32]. In [33] one can find a list of simulation tools with a status overview of their features considering sustainability aspects, furthermore material and energy flow data are under observation in [34]. Most existing simulation software is 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 [16] and [22], 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 see for example [17]. The combination of these different models is however usually happening via interfaces not integrated in a single model, while [5] and [15] depict the integration of LCA and DES in one modeling approach.

C. *Social criteria and OHS in simulation of manufacturing systems*

Social criteria are only very rarely considered when considering the sustainability of manufacturing system in general [35], [1] and when it comes to the simulation of these even less. In [36] ergonomic criteria are, as part of the social domain, integrated in one simulation approach; [37] displays the results in more detail. In [38] stress at the workplace is analyzed and ergonomic workstation factors categorized. Implications towards the work performance of following measures can be found under [39]. Detailed analysis of occupational musculoskeletal and mental health with specific focus on production systems can be found in [27], they also show an overview over relevant studies as well as highlight the significance of the findings of these studies. The European Agency for Safety and Health at Work Report 2013 is also highlighting OSH risk and trends [40]. A detailed analysis of

historic occupational safety measures and trends can be found in [41]. Examples and guidelines for shift-management /workplace fatigue can be found in [42]. In [43] a case study about a conceptual framework for the improvement of business performance with lean manufacturing and human factors interventions is given. 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 [44]. Lastly [45] are making suggestions for systematic workplace/assembly redesign for aging workforces.

D. Capital approach, (social) sustainability assessment and SLCA

Aside from the already mentioned summaries of the Social Capital Initiative [3] and [46], more holistic approaches considering social sustainability can be found in [6]. The capital approach for sustainability evaluation is explained in chapter v. of [47], which is relevant for framework compositions. Social capital in relation to quality of life is discussed in [48], productivity in [49].

When talking about holistic sustainability approaches one should consider [50], where the authors find many good arguments against the reductionist approach. Another holistic perception sustainability design approach can be found under [51]. In [35] one can find a good example of breaking down criteria from a macro management oriented (OECD – Sustainable Development) perspective, to social criteria in firms (see also [7]). Further extensive reviews of social sustainability can be found in [8]. A literature review of social sustainability assessment methodologies can be found in [4], this paper is also very valuable considering LCA integration and possible SLCA adaptations. Considering SLCA, one has to note author Jørgensen, who published many excellent papers [14] for example on the integration of SLCA criteria in companies, summaries of his work are in [23].

VII. Conclusion and Outlook

Last year's Amnesty International Report [52], titled "the dark side of migration" was discussing the exploitation of humans as workforce under inhuman conditions. While this very terrifying problem is less occurring in western countries, it is common sense, that as long we cannot track and measure the social impacts of production processes, it is less likely that consumers will be empowered to choose social friendly created products, and hence not be able to steer their capital accordingly.

Even though we agree with the conclusion of Gasparatos et al. [50] 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).

The main arguments against the integration of social criteria are usually their fuzziness and the fact that every human is different. These points are valid; however the main aspects of human beings are not so different as a variety of studies suggest [27]. 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 more to promote the re-integration of social values in existing manufacturing processes. Human development author and activist Max-Neef mentioned in his keynote at Zermatt Summit 2012 that sustainability has been misused to promote rather economical concepts than actually bringing the essence of what sustainability incorporates into prominence, hence it is the intention of this paper to clarify that the deficit of social integration in these regards can be overcome.

References

[1] OECD "Measuring material flows and resource productivity." OECD Report. Paris, France, 2008.

[2] GRI "G4 Sustainability Reporting Guidelines Implementation Manual" GRI Report, Netherlands, 2013.

[3] Grootaert, C., van Bastelaer, T., Assaf, S., Rossing Feldman, T., Ochieng, G. "The Initiative on Defining, Monitoring and Measuring Social Capital." In: Social Capital Working Paper Series, Social Capital Initiative Working Paper No. 1. Washington, DC, USA, 1998

[4] Benoît, C., Vickery-Niederman, G. "Social Sustainability Assessment Literature Review." White Paper. The Sustainability Consortium, Arizona State University and University of Arkansas, USA, 2010.

[5] Widok, A. H., Wohlgemuth, V., Page, B. "Combining Event Discrete Simulation with Sustainability Criteria." In Proceedings of the 2011 Winter Simulation Conference. IEEE. Phoenix, USA, 2011.

[6] Omann, I., Spangenberg, J. H. "Assessing Social Sustainability - The Social Dimension of Sustainability in a Socio-Economic Scenario." In: Proceedings of the 7th ISEE. Barcelona, Spain, 2002.

[7] Colantonio, A. "Social sustainability: an exploratory analysis of its definition, assessment methods metrics and tools". In EIBURS Working Paper Series, 2007/01. Oxford Brooks University, UK, 2007.

[8] McKenzie, S. "Social Sustainability: Towards some definitions." In Hawke Research Institute Working Paper Series, No. 27. Magil, Australia, 2008.

[9] Pelletier, N., Ustaoglu, E., Benoit, C., Norris, G. "Social Sustainability in Trade and Development Policy." . European Union. Ispra, Italy, 2013.

[10] Porter, M. E., Kramer, M. R. "The Link Between Competive Advantage and Coporate Social Responsibility." In: Harvard Business Review, UK/Germany, Vol. 84, Issue 12, 2006, pp. 78-92.

[11] Porter, M. E. The Competitive Advantage. NY Free Press, 1985.

[12] Wohlgemuth, V. Komponentenbasierte Unterstützung von Methoden der Modellbildung und Simulation im Einsatzkontext des betrieblichen. University of Hamburg: Thesis (PhD). Shaker. Germany, 2005.

[13] Widok, A. H., Wohlgemuth, V. "Simulating Sustainability." In Proceedings of the 27nd Int. Conference Environmental Informatics. Shaker, Hamburg, Germany, 2013

[14] Jørgensen, A., Le Bocq, A., Narzarkina, L., Hauschild, M. „Methodologies for Social Life Cycle Assessment." In International Journal of Life Cycle Assessment, Vol. 13, Issue 2, 2007, pp. 96-103.

[15] Widok, A. H., Schiemann, L., Jahr, P., Wohlgemuth, V. "Achieving Sustainability through the Combination of LCA and DES integrated in a Simulation Software for Production Processes." In: Proceedings of the 2012 Winter Simulation Conference. IEEE. Berlin, Germany, 2012.

[16] Kellens, K., Dewulf, W., Overcash, M., Hauschild, M. Z., Duflou, J. R. "Methodology for systematic analysis and improvement of manufacturing unit process life-cycle inventory (UPLCI)" In:

International Journal of Life Cycle Assessment, Vol. 17, Issue 1, 2011, pp. 69-78.

[17] Andersson, J., Skoogh, A., Johansson, B. "Evaluation of Methods used for Life-Cycle Assessments in discrete event simulation." In Proceedings of the 2012 Winter Simulation Conference, Edited by Edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A.M. Uhrmacher. IEEE, 2012.

[18] Georgiadis, P., Besiou, M. "Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: a system dynamics analysis." In: International Journal of Advanced Manufacturing Technology, Springer Verlag. Greece, Vol. 47, Issue 5-8, 2010, pp. 475-493.

[19] Venkateswaran, J., Son, Y.-J. "Hybrid system dynamics - discrete event simulation based architecture for hierachical production planing." In: International Journal of Production Research, Taylor & Francis Group. Tucson, AZ, USA, Vol. 43, Issue 20, 2005, pp. 4397-4429.

[20] Rabelo, L., Helal, M., Jones, A., Min, H.-S. "Enterprise Simulation: A Hybrid System Approach." In: International Journal Computer Integrated Manufacturing, Vol. 18, Issue 6, 2005, pp. 498-508.

[21] Jain, S., Sigurðardóttir, S., Lindskog, E., Andersson, J., Skoogh, A., Johansson, B. "Multi-Resolution Modelling for Supply Chain Sustainability Analysis." In: Proceedings of the 2013 Winter Simulation Conference.", IEEE. Washington, DC, USA, 2013, pp. 1996-2007.

[22] Andersson, J. Environmental Impact Assessment using Production Flow Simulation. Licentiate Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2014.

[23] Jørgensen, A. Developing the Social Life Cycle Assessment: Adressing Issues of Validity and Usability. Thesis (PhD). Lyngby, Denmark, 2010.

[24] Wohlgemuth, V., Bruns, L., Page, B. "Simulation als Ansatz zur ökologischen und ökonomischen Planungsunterstützung im Kontext betrieblicher Umweltinformationssysteme (BUIS)." In: L. M. Hilty; P. Gilgen (Eds.): 15th International Symposium Informatics for Environmental Protection, 2001

[25] Wohlgemuth, V., Page, B., Kreutzer, W. "Combining discrete event simulation and material flow analysis in a component-based approach to industrial environmental protection." In: Environmental Modelling & Software, Elsevier Ltd. Germany/New Zealand , Vol. 21, Issue 11, 2006, pp. 1607-1617.

[26] Jahr, P., Schiemann, L., Wohlgemuth, V. "Development of simulation components for material flow simulation of production systems based on the plugin architecture framework EMPINIA." In: Proceedings of the 23nd Int. Conference Environmental Informatics.", p. 151-159, Germany, 2009.

[27] Westgaard, R. H., Winkel, J. "Occupational musculoskeletal and mental health: Significance of rationalization and opportunities to create sustainable production systems - A systematic review." In: Applied Ergonomics, Vol. 42, Issue 2 (2011), pp. 261-296. Elsevier Ltd and The Ergonomics Society, 2011.

[28] Banks, J., Carson, J., Nelson, B. L., Nicol, D. Discrete-event system simulation, 4th edition, Upper Saddle River. New Jersey, USA, 2005.

[29] Brousseau, E., Eldukhri, E. "Recent advances on key technologies for innovative manufacturing." In Journal of Intelligent Manufacturing, Vol. 22, Issue 5 (2011), pp. 675-691. Springer, LLC, 2011.

[30] Gopal, P. R. C., Thakkar, J. "A review on supply chain performance measures and metrics: 2000-2011." In: International Journal of Productivity and Performance Management, Vol. 61, Issue 5 (2012), pp. 518-547. Emerald Group Publishing Limited. Kharagpur, India, 2012.

[31] Seliger, G. Sustainable Manufacturing. 1st edition. Springer Verlag. Berlin, Germany, 2012.

[32] Reinhard, J., Zah, R., Wohlgemuth, V., Jahr, P. "Applying Life Cycle Assessment within Discrete Event Simulation: Practical Application of the Milan/EcoFactory Material Flow Simulator." In Proceedings of the 27nd Int. Conference Environmental Informatics." Hamburg, Germany 2013.

[33] Thiede, S. Energy Efficiency in Manufacturing Systems. 1st edition, Springer-Verlag. Germany, 2012.

[34] Thiede, S., Herrmann, C., Kara, S. "State of Research and an innovative Approach for simulating Energy Flows of Manufacturing Systems." In: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering. Braunschweig, Germany, 2011.

[35] Schneider, R. "Measuring Social Dimensons of Sustainable Production." In: Measuring Sustainable Production, Chapter 4, OECD Publishing. Paris, France, 2008.

[36] Heilala, J., Vatanen, S., Tonteri, H., Montonen, J., Lind, S., Johansson, B., Stahre, J."Simulation-based Sustainable Manufacturing System Design." In Proceedings of the WSC 2008." IEEE. USA, 2008.

[37] Lind, S., Johansson, B., Stahre, J., Berlin, C., Fasth, A., Heilala, J., Helin, K., Kiviranta, S., Krassi, B., Montonen, J., Tonteri, H., Vantanen, S., Viitaniemi, J. "SIMTER - A Joint Simulation Tool for Production Development." In VTT Working Paper, No. 125. Espoo, Finland, 2009.

[38] Makhbul, Z. M., Abdullah, N. L., Senik, Z. C. "Ergonomics and Stress at Workplace: Engineering Contributions to Social Sciences." In: Jurnal Pengurusan, Vol. 37, Issue 1, 2013, pp. 125-131

[39] Yahaya, A., Yahaya, N., Bon, A. T., Ismail, S., Ing, T. C. "Stress level and its influencing factors among employees in a plastic manufacturing and the implication towards work performance." In: Elixir Psychology, Elixier, Vol. 41, 2011, pp. 5923-5941.

[40] EASHW (European Agency for Safety and Health at Work). "Green jobs and occupational safety and health: Foresight on new and emerging risks associated with new technologies" EU Report, Spain, 2013.

[41] Luczak, H., Cernavin, O., Scheuch, K., Sonntag, K. "Trends of Research and Practice in Occupational Risk Prevention as Seen in Germany." In: Industrial Health, Vol. 40, Issue 2, 2002, pp. 74-100.

[42] Department of Labour New Zealand. "Managing shift work to minimise workplace fatigue - A Guide for Employers." Crown. Wellington, New Zealand, 2007.

[43] Sharma, R. "Conceptual Framework for Improving Business Performance with Lean Manufacturing and Successful Human Factors Interventions - A Case Study." In: International Journal for Quality Research, Himachal Pradesh, India, Vol. 6, Issue 3, 2012, pp. 259-270.

[44] Zülch, G. „Ergonomische Abbildung des Menschen in der Digitalen Fabrik – Die neue VDI-Richtlinie 4499-4." In: Simulation in Produktion und Logistik 2013, edited by Dangelmaier W., Laroque C. and Klaas A., Paderborn, Germany, 2013.

[45] Zaeh, M. F., Prasch, M. "Systematic workplace and assembly redesign for aging workforces." In: Production Engineering, WGP, Munich, Germany, Vol. 1, Issue 1, 2007, pp. 57-64.

[46] Lochner, K., Kawachi, I., Kennedy, B. P. 1999. "Social Capital: a guide to its measurement." In: Health and Place, Elsevier Science Ltd. Boston, MA, USA, Vol. 5, Issue 4, 1999, pp. 259-270.

[47] UN, (United Nations) Indicators of Sustainable Development: Guidelines and Methodologies. 3rd edition, United Nations. New York, USA, 2007.

[48] Grünberger, S., Omann, I. "Quality of Life and Sustainability. Links between Sustainable Behaviour, Social Capital and Well-being." In Proceedings of the 9th Biennial Conference of the European Society for Ecological Economics (ESEE)." Istanbul, Turkey, 2011.

[49] Reagans, R., Zuckermann, E. W. "Network, Diversity, and Productivity: The Social Capital of Corporate R&D Teams." In: Organization Science, INFORMS, Vol. 12, Issue 4, 2012, pp. 502-517.

[50] Gasparatos, A., El-Haram, M., Horner, M. "A critical review of reductionist approaches for assessing the progress towards sustainability." In: Environmental Impact Assessment Review, Elsevier Inc. Dundee, UK, Vol. 28, Issue 4-5, 2007, pp. 286-311.

[51] Spangenberg, J. H., Fuad-Luke, A., Blincoe, K. "Design for Sustainability (DfS): the interface of sustainable production and consumption." In: Journal of Cleaner Production, Elsevier Ltd.. Cologne/Hornbæk, Germany/Denmark, Vol. 18, Issue 15 2010, pp. 1485-1493.

[52] Amnesty International "The Dark Side of Migration - Spotlight on Quatar's Construction Sector ahead of the World Cup." Amnesty International Report 2013. London. UK, 2013.