Simulation and Sustainability

Enhancing Event-Discrete-Simulation Software with Sustainability Criteria

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***Abstract* — Nowadays global initiatives face numerous problems: non-transparent financial developments on the global markets, only a few years after the biggest economic crisis of our times, unsolved ecological problems that, given the ascent of emerging economies, are seemingly getting worse and the almost surreal speed at, which new technologies are changing our societies. The impacts these changes are having on companies worldwide are as numerous as their effects on the population. Sustainability and Sustainable Development have become key words in the hope of addressing and managing the changes that lay ahead of human societal development. This paper attempts to highlight shortcomings in the concept of sustainability and ways to make the concept more workable by presenting the development of an Environmental Management Information System (EMIS) as a combination of discrete event simulation and ecological material flow analysis for production processes.**

Keywords – Sustainability, Simulation, Event-Discrete-Simulation, Sustainability Reporting.

I. Introduction

In recent decades there has been a significant increase in the attention paid to the concept of sustainability. Despite this positive development, there is still only a small number of simulation systems that pay tribute to the complex interdependencies of economic, ecological and social values. This chapter will address the problems of current developments and therefore describe the motivation for the development of the EMIS that will be presented in the following chapters.

A. Ecological Perspective

From an ecological point of view, the world is facing a wide variety of problems. Even though there is still and most likely will continue to be a debate about how much and to what extent the effects of climate change are anthropogenic, the results themselves have been empirically proven and will consequently change the socio-economic requirements on earth within coming decades [1][2][3]. Effects such as the extinction of species [4][5], deforestation [6], changes in ice distribution [7], droughts and increasing incidence of forest fires or other effects, such as the development of CO_2 Emissions [1] or as the overfishing of the seas [8] will have a huge impact on the quality of life in the coming century.

In this respect, the figures presented by the Intergovernmental Panel on Climate Change (IPCC) in the year 2007 [1] made it very clear how pressing the need for a community-wide approach is for sustainable development in environmental protection. Despite phases with little or no economic growth, there is no expectation that the ecosystem will experience periods of natural recovery in coming decades, quite the opposite in fact. If one looks at current metabolic rates in the world [9], one finds that they are still rising [9][10]. The World Resources Forum (WRF) estimates that global resource extraction will exceed 80 billion tons in 2020. This means that mankind will have doubled the annual rate of global resource extraction within only 40 years (1980–2020) [11]. It further states:

“Globalizing the traditional model of economic growth is leading to rapidly increasing consumption of limited natural resources, followed by ecological disruption. (…) Rising global consumption of raw materials (…) is beginning to affect the life-sustaining services of the earth, which are not replaceable by technical means. (...) Today, the fundamental flaw in human activities is the enormous consumption of natural resources per unit output of value or service. (...) The environmental safety threshold has already been surpassed, as is evident” various “developments (…). And yet, only some 20 per cent of humankind enjoy the full benefits of the mainstream economic model, while all people – in particular the poor – have begun to suffer the consequences of its flaws” [11].

This statement can be translated into a system-thinking realization, that the behavior and interaction of system-elements are currently endangering the stability of the system itself. In this respect, one can consider various escalating curves, the result of catching-up processes involving emerging industries and countries such as China and India and the physical impossibility [10] of extending the present consumption patterns of the industrialized countries to all parts of the world, which will ultimately lead to social problems.

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B. Social Perspective

Morally there is no argument as to why the developing countries and the poorest countries should not be "allowed" to achieve the same state of production and wealth that the industrialized countries have achieved. The only argument at this point, with our current technology, is that it is physically impossible and, even if it wouldn't be, the level of production, given a world with 7 billion citizens, would result in catastrophic ecological consequences, if processes would be rushed.

When bearing in mind the ecological part of the problem, one can see that the system is out of balance due to excessive pressure on several fronts; the keyword in this sentence is balance since this is basically the common denominator for the social problem as well. What can be considered as unjust pressure on the ecological side would be translated as unequal distribution on the social side with results/effects such as hunger, lack of education or even terrorism.

Given the growing metabolic rates of the emerging countries one must be realistic and see that of course people will try to reach a similar state of wealth and prosperity and therefore, due to the impossibility mentioned, the only way to preserve the current or a current-comparable standard of living throughout industrialized countries, emerging countries and others, would be to find ways to reduce resource usage to an extent that would allow the same high level of production using only a fraction of the raw resources. In order to sustain our economy without completely revising our standard of living, the only way to achieve justice in distribution is the dematerialization of our economies and greater resource efficiency.

C. Economical Perspective

This transformation of economies would make investment imperative. The financial sector, however, is currently experiencing problems of its own. The financial crisis of 2007/08, the very recent developments surrounding the Euro (considering Greece and other European countries) and also surrounding the Dollar and the government/budget deficit in the United States ought to demonstrate how much mankind tends to worry about wealth and status and also how interdependent the global market already is today. The consequences of the crisis can be observed on the large scale already referred to, but also at the level of small and medium sized companies (SME), which are failing to obtain necessary loans from banks.

Basically it comes down to a similar problem of distribution as that, which applies to raw resources. If we consider a company as a minimal representation of an economy, we understand that with a purely economic orientation it will not lead to sustainable growth. A strong social commitment or intensive environmental management, however, will not have any positive effects if the company structure cannot bear the load they place on it either. Thus it is imperative that these three measures of sustainability are combined by means of balanced efforts leading to a synergistic increase in value [12][13][14].

This balance in efforts is what sustainability has been trying to define from the very outset. Throughout sustainability theory, from Meadows (1972) [15], Lynam, Herdt (1989) [16] and Pezzey (1992) (who already listed 27 different definitions for sustainability) [17], Pretty (1995) [18] to (Bell and Morse, 2008) [19], there has been a broad understanding that shrinking processes can also be considered sustainable. They all addressed the question of the objective that had to be protected / balanced.

For companies, the main priority and the most important commodity must naturally be the financial side; otherwise the company could neither exist nor produce. The community on the other hand has other interests when it considers this company. On the one hand, it is imperative that the company creates goods for public consumption, which bring in money, so that some of the public will obtain their income from it, but it is also necessary that the production methods do not harm the people or their environment. Allowing for the interests of the people, laws were drafted to make sure that the interest of companies does not take precedence over the interest of the people (legal compliance). In this context, there has always been a huge debate between Europe and the United States about regulation and deregulation. When it comes to ecological impacts however, this discussion seems misplaced as the market does not guarantee to reflect people's interests when their perception is limited by manufactured prices or other artificial local regulations.

II. Sustainability and Simulation

In Section I.A we stated that sustainability addresses the problems of distribution, it therefore follows the ideals of intra- and intergenerational justice and is a conclusion of the realization that human actions have consequences, if not for themselves then for other people with a shift in space or time. Consequently, we understand sustainability as acceptance of this responsibility and therefore as a need to act without a shift in time.

A. Normative understanding of Sustainability

In view of the fact already explained, that it is not possible to have an equal distribution of goods, wealth, resources and products in the world within a short period of time (where short can be 50 years or more) and to preserve the ecosystem, it follows that the ideals of intra- and intergenerational justice cannot be satisfied at this point in time. Therefore the concept of sustainability must be regarded as the means to achieve intra- and intergenerational justice and is consequently normative.

B. A Definition of Sustainability

To ensure that there is a clear understanding of the following, we will define sustainability under a capital-based approach (similar to the one used by McElroy, Jorna, van Engelen [20]).

We define sustainability mainly as the agglomeration of actions/campaigns/processes that have a positive effect on the regeneration of social, environmental and/or economical capital on the one hand, and/or reduce the degradation of this capital on the other, bearing in mind that the protection of that capital is the normative goal.

A third option being the allowance of the use of a different source, or not having to use the capital in question at all any longer. An example of this would be the usage of new processes allowing the substitution of different materials insofar as the old material would no longer be needed for the process and the new material would be less of a drain on overall capital.

The main problem with this definition lies in the specification of what social/economic/environmental capital is. While no one will argue that it exists, one can argue about the concrete indicators and the attributed values behind them or, more specifically, about the value-correlations between them. This is also what makes it so difficult to define a sustainable process. While a process may be very ecologically sustainable when measuring the amount of material used, it may also be very expensive and therefore drain economic capital or vice versa.

The question is how the three aspects are correlated or rather, which indicators have been attributed to each of the aspects in the first place. For that matter we argue that environmental and indicators related to Corporate Social Responsibility (CSR-related) processes have been greatly undervalued in recent decades. While we do not believe that every single process in a company can or even should be broken down into a value, we believe it to be possible, to do this with many more processes than is the case at present and especially with more environmental and social processes. More than that, it is important to do so because most of the negative influences on environment and or people do in fact happen due to the lack of knowledge about correlations and impact scenarios.

Last but not least, one must take into account that consumption (a reducing effect on capital) may also be sustainable if natural or otherwise regenerating capital, which is of value in a certain quantity becomes a danger at a higher concentration. An escalating feedback-loop can therefore come from the capital at some tipping-point of its existence, which has to be managed. This would make an inversion of the signs imperative in order to achieve equilibrium between existence and effect of the capital.

While we realize that the definition of sustainability indicators is one of the most critical parts of sustainability assessment, this definition in conjunction with intended usage in simulation experiments allows many different approaches to be tested when assessing the sustainability-enhancing potential of intended measures. Thus simulation is a way to assess the sustainability of new processes.

C. *Simulation as a way to get closer to the immeasurable (Sustainability)*

Simulation can be used to show the possible effects of alternative conditions and courses of action. It is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist [21]. In that regard simulations are perfect tools when it comes to experiment with uncertain outcomes, which may be harming or contra-productive.

As stated in Section I, we see one of the main challenges of our time in the dematerialization of the economy and consequently much higher resource efficiency. Under those premises the simulation focus had been laid on usage in production. The rational use of goods, such as the production, consumption and distribution is widely known as economic activity. Its improvement is directly connected to the in- and output relations and consists of the attempt to get more returns while investing lesser resources [22]. This process is also called optimization and it is target-oriented (e.g., optimizing the costs, quality, efficiency or effectiveness). Optimizations can also be achieved using an operations research approach [23]. The operations research approach and most analytic methods however become problematic once one has to deal with many variables. That is precisely when simulations are more worthwhile. The simulation of production addresses a variety of different indicators, the most common measures of system performance being the following [24]:

- Throughput under average and peak loads;
- System cycle time (how long it take to produce one part);
- Utilization of resource, labor, and machines;
- Bottlenecks and choke points;
- Queuing at work locations;
- Queuing and delays caused by material-handling devices and systems;
- Work in progress (WIP) storage needs;
- Staffing requirements;
- Effectiveness of scheduling systems;

These indicators can be considered as the standard value set of today's production optimization, they however do not incorporate environmental or social indicators and hence an optimization of the production using those key-indicators would go only in one direction, leading to a higher output. Even though a higher production can of course have other positive effects, they are far from guaranteed. In the coming chapter we'll illustrate the integration of the environmental perspective in the same model, which is used for simulation runs. In Section IV we'll then propose our current vision on how to even integrate the social perspective in the simulation model and thus acknowledging all three pillars of sustainability.

III. The Road So Far – Development

A. *The earlier years*

The techniques of modeling and simulation have been established as an important instrument for the analysis and planning of complex systems in many domains [25].

The deduction from investigations around year 2000 was the proposal to use simulation techniques for supporting the application of the Material Flow Network method [26] [27].

Following that proposal, simulation can be used to calculate unknown environmental quantities. For example, it allows determining the necessary load of connected input flows considering complex systems [28].

In a sense, the material flow perspective is more general than the discrete event perspective [29]. Information is rarely linked to objects like products or process steps. Material Flow Networks, which were also developed at the University of Hamburg [30], are based on the Petri-Net theory.

During one of the latest research projects, the prototype modeling- and simulation software named MILAN was developed. On one hand, its discrete event simulation components allow an accurate analysis of typically economic aspects and industry related aspects, presented under point II.C, and on the other hand, its material flow analysis components did add for the first time an environmental perspective to the discrete event simulation model, i.e., a consideration of relevant material flows and transformations such as:

- consumption of commodities, resources and additives;
- energy demand;
- waste accumulation;
- Emission generation.

Discrete event simulations are a powerful method to represent production processes close to reality and to follow time intervals of different sizes from few hours up to several business years for investigating aspects depicted in the introduction. With the generation of pseudo-random numbers following given stochastic distributions natural variations such as varying inter-mediate arrival times of production jobs can be represented.

In 2006, we presented the first application of the Material Flow Simulator Milan [29], since then we intensified our work on different levels of the architecture and extensions of the simulation engine as elucidated in the next chapter.

B. Recent developments

The first implementation of MILAN was 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 [28]. This realization however seemed outdated and was renewed since 2009 and MILAN was re-implemented.

The new development of the material flow simulator MILAN is based on the open-source plugin framework EMPINIA (http://www.empinia.org) (comparable to the Java framework Eclipse (http://www.eclipse.org)). EMPINIA, which was developed in the course of the EMPORER project, is designed for the development of complex domain-specific applications especially in the field of environmental management information systems (EMIS) [31]. It is a component-orientated extensible application framework based on Microsofts.NET (http://msdn.microsoft.com/de-de/netframework/default.aspx) technology with the purpose to support and simplify the development of complex software systems.

For MILAN it was necessary to provide libraries of simulation components (e.g., for production systems: machines, transporters, system boundaries), which enable the modeler to represent and simulate his system adequately. These components can be added to an application i.e., as building blocks via a plugin mechanism and thus can be used to build a user-specific model.

This implementation may lead to an easy development of user-specific components with low dependencies and an attachment to a modeling tool box for a certain application field, which is not possible with other simulation tools [32] [25]. These components can either be generally applicable or might be used for very specialized purpose. Specialized entities are developed for a whole production sector (e.g., semi-conductor sector with coater, stepper and dispatcher) [33][27] or they represent a production component of a certain company with its specific parameters. In contrast general components are highly abstracted and are applicable for many production systems [34]. The goal of this project was the development and implementation of such general entities for MILAN.

Another important gain resulting from the EMPORER research project was the implementation of very abstract simulation entities for the analysis of production systems. These entities enable users to model and simulate a broad set of production systems. Because of their modularity and the plugin mechanisms of EMPINIA it is very easy to add more specialized entities to the production system's domain and to use them for a material flow simulation.

After that the production components were verified by performing a simulation study in a company that produces solar panels. The problems, results and experiences of this validation were used to improve and enhance the components, the simulation infrastructure and MILAN as a simulation tool, itself.

Besides the components, which come with EMPINIA there are many plugins taken from a designed EMIS toolbox and were then combined with MILAN. The simulation capabilities of the MILAN software consist of the simulation core, a bundle for discrete event simulation and simulation components.

The simulation core consists of the central simulation service, interfaces and abstract base classes for models, experiments and model entities. These are used in each kind of simulation. The simulation service provides models and experiments in a way that other software parts can use them. The simulation core gives models and their entities access to the functionality of a domain model service. A domain model defines the domain of an EMPINIA-based application, its elements and their relations as well as rules that apply to this domain. MILAN consists of the domain 'simulation' with elements like 'model' and 'entity'. Among other important functionalities the domain service provides possibilities to persist its elements. That is the reason why this service is used in MILAN to save and load formerly created models.

A bundle for discrete event simulation extends the simulation core with classes specific to the discrete event simulation approach. These classes are using an EMPINIA extension that enables the development of logical graphs in order to combine entities of a model to a network diagram. The basic generic experiment component is extended with an event list and a scheduler, which are used to simulate time in discrete steps.

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The simulation components have access to many stochastic distributions (e.g., Normal, Bernoulli). They are used to generate streams of random numbers, for example to schedule an event, which follows a certain arrival probability. Additional to these existing distributions user-defined distributions can also be added via plugins.

In the following the common features of the MILAN software will be summarized.

The graphical manipulation of building blocks leads to a faster development of a model. The graph editor can be used to manipulate and create models. The editor itself can work in different domains. Domain specific functionality and the graphical representation have to be defined by plugin developers enabling the editor to handle new domains and their components, which are also using plugin definitions.

Manipulating model parameter for the simulation and material flow perspective is done by means of property editors enabling a simple and consistent way of setting values for all types of properties. For the production system domain there are standard editors implemented. These allow the change of component specific parameters like setting distributions, accounting rules, queue lengths or capacities etc.

No analysis can be done without results. These are shown in reports, which can be designed with the help of the reporting system. The data for the reports is aggregated during simulation runs by a system of observers that listen to changes in the material accounting and simulation entities.

The development of new features and the testing of the full capacity of MILAN’s functionality are ongoing. The Combination of economical and ecological indicators in one model has already been achieved. In the following chapter we’ll outline visions on how MILAN might get even closer to a sustainability enhancing simulation system.

IV. Conclusion and Future Work

In an often cited interview the Nobel Prize Winner Milton Friedman said: “So the question is, do corporate executives, provided they stay within the law, have responsibilities in their business activities other than to make as much money for their stockholders as possible? And my answer to that is no, they do not” (February 1974) [35].

Even if one would tend to agree with Friedman, there are already examples of when and how this statement would be economically disadvantageous, considering Nike and their incident with child labor in their supply chain [35][36] or the case of Brent Spar and their sinking of an oil platform [35][37], which made obvious that the long term goal of profit maximization can only be achieved when parts of the social responsibility are also acknowledged [35][37][38][39]. In case of Nike, the sales figures dropped after the incident, resulting to a stock loss of 20 per cent [35][39][40][41]. The connection is already there.

Also the range of management approaches that look at social sustainability is relatively vast, so that one faces an unmanageable diversity of what are referred to as ‘solutions’. There are however not many software solutions that pick up on social aspects and where they do their usage is rather infrequent. This fact alone narrows down the search for universal applications, but also opens another perspective on the much more discussed “opposition” between the achievement of economical and ecological objectives [42].

To make companies realize that they must aim not merely for financial stability, it is mandatory that corporate social responsibility (CSR) and environmental efforts become a financial attribute and thus have an economic value too. The lack of these values, or rather their unspecific nature in the past, has led to many of today's undesirable developments, as profit is often solely attributed with financial growth while social, human, environmental profit is only of relevance when it comes to legal compliance [42].

In that regard current research at the HTW Berlin also tries to incorporate social indicators for the assessment of sustainable growth in production. Through the EMPINIA extension mechanism it is possible to define new resources, in this regard, human resources. These resources are then getting attributes, such as, for example, workload/contract information and references to the workstations, these references are basically the skills of the current employees. In order to pay tribute to the different abilities of the employees the workstations/building blocks themselves are more or less in dependence of human resources to function properly and the human resources have a variety of criteria that, for example inhibits them to work 30 hour shifts. There is a whole framework of social criteria possible to be attributed to these new “resources”; however research is still on its very beginning. The first focus of the introduction of social criteria will be health. Employees should not work longer then a certain amount of time; they should have the possibility to take all their vacation and should not get in contact with any harming emissions, noise, particular matter or other harming material. Even though that does not sound revolutionizing it is the first step in addressing more complex interactions, such as financial equilibrium, daycare for children or other criteria.

We hope that in the future, after testing the introduction thoroughly, we can implement more criteria and define new functions of correlation and interdependencies. In this paper we tried to give further input to the ongoing discussion on how to assess sustainability and more precisely the sustainability of producing companies. We tried to show in the introduction that no matter, which pillar of sustainability is considered the negative influence, the loose ends, are likely to be a result of a system-imbalance. They are the underlying conditions for most of the problems we face today. We also tried to show that the change of human economies will become imperative and must be managed in a way that intends to address the issue of participation, which we consider to be one of the main problems of the sustainability dilemma. People and companies, as system-elements will not intensify their positive influence unless the instability of the system is made obvious to them. The combination of different perspectives of sustainability in one model might contribute to this thesis and will therefore be our ongoing focus in the future.

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