ON THE USE OF DISCRETE EVENT SIMULATION IN GREEN IS RESEARCH – DEVELOPING A CONCEPTUAL FRAMEWORK

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Abstract

Discrete event simulation is a widely established approach in research on supply chain structures. However, discrete event simulation is rarely used within the context of environmental sustainability. A conceptual framework is suggested to discuss the value of discrete event simulation in Green IS research. The content of the framework is based on a systematic literature review and the structure builds upon the belief-action-outcome model. The framework contains research issues for the use of discrete event simulation in Green IS research and illustrates the causal relations between organizational, social and physical structures, individual objects as well as the outcomes in their interaction. A methodological toolkit is included to provide a starting point for the development of suitable research methodologies within the field. Due to the interdisciplinary approach of this work, the framework may be restrictive in its view on information systems. Therefore, the results do not claim to be deterministic or constrictive. Scientists and practitioners are encouraged to enter the discourse on discrete event simulation to enhance Green IS research.

Keywords: Green Information Systems, Environmental Sustainability, Discrete Event Simulation, Conceptual Framework, Belief-Action-Outcome Model

1 Introduction

The concept of environmental sustainability (United Nations, 2002) has been increasingly addressed in highly recognized information systems (IS) journals, e.g. MIS Quarterly, Business & Information Systems Engineering, Communications of the ACM or the Harvard Business Review since 2009 (Elliot, 2011; Melville, 2010; Nidumolu et al., 2009; Seidel et al., 2013; vom Brocke et al., 2012; Watson et al., 2012a, 2010). This scientific discourse has led to the creation and recognition of the term Green IS, which includes IS that are able to facilitate environmental sustainability within processes, products and services (vom Brocke et al., 2012). These publications address physical systems influenced by human behaviour. Watson et al. (2012a) argue that IS can play a significant role as they can “wrap around” the affected physical systems in order to control human interaction. In order to optimize physical systems from an ecological perspective, a “symbiotic physical and informational modelling and simulation” (Watson et al., 2012b) is needed.

Logistic systems are of particular interest for Green IS as they are major contributors to environmental degradation. The underlying transportation systems directly account for 13 %, manufacturing systems for 19 % of the world’s GHG emissions (Intergovernmental Panel on Climate Change, 2007). Moreover, they indirectly make up a major part of the emissions from energy supplies (26 %) and the consumption of electrical energy and fossil energy sources (Intergovernmental Panel on Climate Change, 2007). Thus, decision making in logistics extensively affects sustainability by the environmental impact of the underlying physical manufacturing and transportation systems.

Discrete event simulation (DES) aims to enhance business processes by providing decision support in the area of production policies as well as logistics systems design (Jacob et al., 2010; Semini et al., 2006). Compared to system dynamics approaches, DES is the preferred simulation approach for
research on supply chain structures, supply chain optimization, distribution and transportation planning as well as replenishment control policies (Tako and Robinson, 2012). Moreover, DES can be applied within research on general system performance, inventory planning/management, production planning and supply chain integration (Tako and Robinson, 2012). However, DES approaches, including environmental perspectives, are underrepresented within the literature and rarely used within Green IS research. Addressing this promising, but underrepresented research area is the motivation behind this research. The question that we would like to answer includes:

How can discrete event simulations be used to support Green IS research?

First, some basic explanations on DES will be presented in Section 2. In Section 3, we introduce our approach to conduct the literature review that will be the basis for our conceptual framework. In Section 4.1, recent work in the field of sustainable DES is analysed. The resulting conceptual framework on the use of discrete event simulation in Green IS research is presented in Section 4.2. In Section 4.3, open research issues for the use of DES in the context of Green IS are outlined. Section 4.4 contains a methodological toolkit for researchers to conduct DES research. A discussion is put forth in Section 5 and limitations and future work are outlined in Section 6.

2 About discrete event simulation

Discrete event simulation is an approach to understand how real-world systems change over time and to compare their performances under different conditions (Tako and Robinson, 2012). A DES model typically consists of a network of activities and queues in which entities (objects, people) are represented individually (Tako and Robinson, 2012). The state of an entity, activity or queue only changes at a discrete point of time, called event, that may occur randomly (Schröber and Brunner, 2006). Hereby, DES can be distinguished from continuous simulation, in which the model states represent a network of stocks and continuous flows that are predefined at each point of time, e.g., by differential equations (Schröber and Brunner, 2006; Tako and Robinson, 2012). The main advantage of DES is its ability to represent uncertainty and dynamicity of a system resulting in more realistic and valid representations of real-world systems compared to continuous simulation (Schiefer et al., 2007; Semini et al., 2006). However, DES studies may be time-consuming, and they do not automatically generate optimal solutions to a problem (Semini et al., 2006). According to Arnold et al. (2008), DES is commonly used to derive the following four types of results: (1) DES is used to prove a system’s functionality if the system and its respective load are known. (2) DES is used to determine technical and organizational alternatives if the system is unknown or variable and the system load is known. (3) DES is used to determine performance boundaries if the system is known and the system load is unknown or variable. (4) DES is used for fundamental research and the formulation of general statements on system structures if the system as well as the system load is unknown. Within the IS research community Jacob et al. (2010) and Schiefer et al. (2007) successfully applied DES within the context of business modelling. Dorsch and Häckel (2012) already fulfilled first steps towards a sustainable use of DES in the context of energy aware cloud solutions. In the following sections, we will take a more precise look on recent developments in the field of sustainable DES research.

3 Methodology

Our research is based on a concept centric systematic literature review guided by the framework developed by vom Brocke et al. (2009). The review can be characterized using the Cooper's (1988) taxonomy for literature reviews as depicted in Figure 1. The shaded cells show the categories to which we assign our literature review. The literature search was conducted by exhaustively querying the scholarly databases suggested by Webster and Watson (2002): Sciencedirect, ISI Web of Knowledge, EBSCOhost, Springerlink, Emerald, Wiley online library and AIS electronic Library. Since we tried to identify environmental sustainability related approaches in DES, we used the search term discrete
event simulation and looked for the terms sustainability OR environment OR green in the abstract, title or keywords. The search results were limited to publications from peer-reviewed scholarly journals and conferences for quality assumptions (vom Brocke et al., 2009). Since the World Summit on Sustainable Development substantiated the goal of a sustainable development quantitatively (United Nations, 2002) at the end of 2002, the time frame was restricted to 10 years (2003-2013) to ensure the papers’ relevance to the actual discussion on sustainability. After removing duplicate entries and entries containing the terms “green” and “environment” in contexts other than environmental sustainability, 27 publications remained for analysis and synthesis.

Figure 1 Scope of the literature review following Cooper’s (1988) taxonomy

According to vom Brocke et al. (2009), the following concepts have been determined using general sources like encyclopaedias, review articles, seminal textbooks and handbooks: year of publication and discipline (Elliot, 2011; Tako and Robinson, 2012), modelled system (Arnold et al., 2008; Hughes, 2011), key performance metrics (Arnold et al., 2008; Hughes, 2011), research methodology (Arnold et al., 2008; Dangelmaier and Laroque, 2013; Elliot, 2011), simulation results (Arnold et al., 2008) as well as contributions to theories (Elliot, 2011; Melville, 2010).

In this work we allocated the model systems into the following groups: logistics systems (processing, storage or distribution of physical goods (Arnold et al., 2008), IT systems (processing, storage or distribution of information)(Pal, 2008), environmental systems (natural processes and ecosystems) (Bronfenbrenner, 1979). We allocated the simulation results according to Arnold et al. (2008) distinguishing between the four types of simulation results: (1) a proof of functionality, (2) determination of technical and organizational alternatives, (3) determination of performance boundaries and (4) fundamental research and general statement on system structures (system unknown, system load unknown).

4 Results

4.1 Literature Review

In the previous section, the literature search process and the concepts for the literature analysis were introduced. The search process revealed 27 research papers published in 25 different journals and conference proceedings between 2004 and 2013. The characteristics of environmental sustainability related approaches of DES according to the concepts are shown in Appendix I.

Throughout the last 10 years, an increase in publications relating DES to environmental sustainability can be seen. As depicted in Figure 2, between 2003 and 2010 only 2 papers per year were published. A sharp increase in the number of publications can be observed for the year 2013. Due to the fact that the literature search was conducted in October 2013, an even higher number of publications in 2013 can be expected. The increase in publications seems to indicate a growing interest in DES studies on environmental sustainability. However, this assumption should be checked on one-time anomalies over time. Figure 2 also shows that research on DES in the context of environmental sustainability mainly takes place within engineering related disciplines. This might be an initial indicator of a
dominance of applied scientific research in the field. The adoption of DES simulation studies within management and IS research is relatively low.

Figure 2 Year and discipline of identified publications

As described in Section 1, the predominant application area for DES are logistics systems (Jacob et al., 2010; Semini et al., 2006). This also applies to sustainability related DES approaches. Within these studies, logistics systems are the main systems under observation as depicted in Figure 3. But DES has also been used for the simulation of IT systems: Hlavacs et al. (2008), Berl et al. (2010), Hlavacs et al. (2011) as well as Berl and de Meer (2011) use DES to estimate energy savings as a result of virtualization in offices and homes. Dorsch and Häckel (2012) assess the potential of exchanging excess capacities of cloud service infrastructures using DES.

Figure 3 Systems within environmental sustainability related approaches of DES

The range of metrics used to quantify performance and environmental impact of the system under study within the publications is twofold. First, a small number of widely established metrics were used to quantify the technical and economic performance of the systems, e.g. production cost or infrastructure utilization. Afterwards, different metrics were applied to quantify the environmental impact or environmental performance, e.g. NO$_x$, SO$_2$, CO$_2$, VOC- or dust-emissions, global warming potential, environmental footprint or km$^2$ deforestation. It can be noted that no common metric for the different groups of environmental impact has established.

The collected research papers’ results and methods indicate the predominance of articles pertaining to applied scientific research in the field of environmental sustainability in DES. In 17 publications, applied scientific research results, proof of functionality, determination of technical and organizational alternatives as well as determination of performance boundaries, were derived. Only 6 papers, 4 from computer science, 1 from IS and 1 from engineering research, aim for general statements on system structures. Additionally, the methodology in the field can be characterized as applied science. In this sample, 24 out of the 27 research methods are case studies, design science or systems modelling.

Melville (2010) and Elliot (2011) have identified the starting point for a theoretical debate on environmental sustainability in IS by making a list of used theories. Out of this list, we determined the theoretical background of our sample. As shown in Appendix I, our DES papers indicate theoretical backgrounds including: stakeholder theory, production theory, systems theory, economic theory of public goods, queuing theory and organization-environment theory. It is clear that DES research addressed fewer theories than Green IS research in the context of environmental sustainability. This can be explained by the DES community’s lack of interest in informational, social and organizational
issues and its focus on physical systems. However, it also shows a partial overlap of the theoretical background of both, DES and Green IS research.

In summary, it can be seen that environmental sustainability related approaches in DES are already applied within the context of several theories also discussed in Green IS research. Though, current research in the field addresses single, unique cases and only contributes to non-physical systems structures on a minor scale. However, an increase in the number of publications, applied scientific approaches and research into logistics systems indicates the growing interest for a deeper understanding of environmental impact using DES approaches as well as the practical relevance of the topic. Therefore, advanced Green IS research in the field is required to understand the relations between environmental damaging logistics systems and the surrounding informational, organizational and social structures in which decisions are made.

4.2 Conceptual Framework

Our review of the recent publications in the field of DES reveals that sustainability related approaches do not satisfactorily relate to the the latest results from Green IS research. Neither symbiotic, physical and informational models have been developed, as proposed by Watson et al. (2012b), nor deeper theoretical examinations, as proposed by Elliot (2011) and Melville (2010), have been conducted using DES. However, approaches within the logistics domain point at the advantage of DES, namely: the ability to represent uncertainty and dynamicity which results in more realistic and valid representations of real-world physical systems (c.f. Section 2). In this section, we suggest a conceptual framework in order to discuss the opportunity of conducting research in the theoretical overlap of DES and Green IS research and highlight how to make use of this advantage.

The formulation of our conceptual framework is based on the research by Coleman (1986) and Melville (2010). Coleman (1986) provides a model of micro-macro relations between social structures, psychic states, individual behaviour and the behaviour of the social system. Melville (2010) emphasizes the organizational context of IS research on environmental sustainability by adding a second macro-level to the model as depicted in Figure 4. Melville's (2010) framework accounts for a dual socialization of individual psychic states by societal and organizational structures (link 1 & 1´) and dual outcomes of individual actions (link 3 & 3´). Moreover, Melville (2010) adds dashed lines (4, 4´, 5, 5´) to include research approaches on a macro-macro level.

Looking at Figure 4 it is hard to find physical structures determining individual actions or outcomes representing physical environmental impact. The physical system structures and outcomes are implicitly subsumed by Melville's (2010) framework only. Considering that societies and organizations exist within the natural and build (physical) environment (e.g. streets, buildings, machines, rivers), and considering that the physical systems are major contributors to environmental degradation (Intergovernmental Panel on Climate Change, 2007), there is a particular need for symbiotic modelling approaches for the improvement of physical systems (Watson et al., 2012b). Partnerships between IS scholars and engineers, that combine information management and analysis
skills with knowledge about physical system structures and outcomes, are necessary in order to make those systems more sustainable (Watson et al., 2012b). However, by the absence of explicit links to a physical level, the existing framework cannot facilitate such a partnership.

Our conceptual framework (c.f. Figure 5) contributes to fill this gap by fusing Melville's (2010) framework with the perspective of DES. The framework in Figure 5 contains elements and causal relationships that can be represented within a DES model to support Green IS research. We will take a transport information system (Watson et al., 2012b) as a typical example of Green IS research to illustrate our thoughts.

Figure 5 Conceptual framework for DES in Green IS research

Following the idea of a symbiotic model, we consider a system’s state as a symbiosis of informational (social and organizational) and physical structures on a macro level and individual entities (objects, people) on a micro level. A public transportation system, for example, consists of informational structures (e.g. social conventions, customer information systems), physical structures (e.g. streets, railways, landscapes) and individual entities. Individual entities and their behaviour within the system are shaped by both kinds of macrostructures (link 1&2). For instance, the driving speed of a commuter sitting in a car can be influenced by information about the traffic and by the physical constitution of the street. To improve a transportation information system, the causal relationships between the information system and the individual entities (link 1) but also the relationships between the physical structure and the individual entities (link 2) may be represented within a DES model.

Actions can be represented in DES models by the use of events. Therefore, they have to be interpreted as changes within the state of individual entities, happening at certain discrete points of time. When an event occurs an entity converts its state from n to n+1 (link 3). Actions might be conversions of individual human behaviour as well as physical reactions. When a commuter gets the information that there is a traffic jam on the route, he has the choice to take the train. However, physical obstacles or queues at the train station might keep him away from using it. To support the development of a transportation information system, physical and informational triggers for events may be represented by DES models.

For the representation of informational and physical outcomes of actions, causal relations between individual entities (state n+1) and changes in informational and physical structures can be represented by a DES model (link 4&5). Changes in physical structures (rivers, air, landscapes, energy sources etc.) are of particular interest within Green IS research and always have to be included within DES to derive relevant simulation results. In our example, the commuter has a better carbon footprint when using the train instead of the car. He will probably tell his colleagues about his experiences with the transport information system. To improve a transportation information system, a DES model may represent the causal relations between the state of individual entities and the generation of emissions as well as the consumption of physical resources (energy, water etc.). Moreover, the DES model may be applied for the representation of relations between the state of individual entities using a transportation information system and the organizational and social outcomes.
Table 1 contains short descriptions of the causal relationships that may be represented within a DES model for Green IS. Furthermore, it shows which analysis levels and constructs are involved and which publications contain first steps to a model based representation of the referred link.

<table>
<thead>
<tr>
<th>Link</th>
<th>Description</th>
<th>Analysis Level</th>
<th>Constructs</th>
<th>Example Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Formation of individual object states by the state of informational system structures, e.g. cultural patterns or organization of work</td>
<td>Macro-Micro</td>
<td>Informational structures and entities</td>
<td>(van den Bergh et al., 2000) (Scott and Bruce, 1994) (Middlemiss, 2008) (Williams and Edge, 1996) (Berl and de Meer, 2011)</td>
</tr>
<tr>
<td>2</td>
<td>Formation of individual object states by the state of physical system structures, e.g. landscapes, segmentation of machines</td>
<td>Macro-Micro</td>
<td>Physical structures and entities</td>
<td>(Carneiro et al., 2013)</td>
</tr>
<tr>
<td>3</td>
<td>Translations of individual entities states</td>
<td>Micro-Micro</td>
<td>Entities</td>
<td>(Schriber and Brunner, 2006) (Tako and Robinson, 2012)</td>
</tr>
<tr>
<td>4</td>
<td>Formation of informational outcomes induced by individual conversion, e.g. change in organizational performance</td>
<td>Micro-Macro</td>
<td>Entities and informational structure</td>
<td>(Byrne et al., 2010b) (Tako and Robinson, 2012) (Huang et al., 2007) (Muresan et al., 2013)</td>
</tr>
<tr>
<td>5</td>
<td>Formation of physical outcomes (i.e. environmental impact) induced by individual conversion, e.g. increase in CO$_2$-Emissions</td>
<td>Micro-Macro</td>
<td>Entities and physical structure (i.e. physical environment)</td>
<td>(Page and Wohlgemuth, 2010) (Thiede et al., 2013) (Löfgren and Tillman, 2011) (Salonitis and Ball, 2013)</td>
</tr>
</tbody>
</table>

Table 1 Terminology of the framework

4.3 Research Issues

We identified 5 research issues referring to link 1-5, depicted in Table 1 and Figure 5, and the related work (Section 4.1). These research issues contain the basic approaches to support Green IS research using DES.

Existing DES approaches have not yet sufficiently comprise informational structures within simulation models. Incipient stages exist in DES studies representing consumer behaviour within their models (Berl and de Meer, 2011). Though, it might be helpful to consider the influence of information systems on existing DES models of environmentally relevant systems, such as DES models of transport systems or supply chains. Therefore, research on the formation of an individual entities state by social and organizational structures has to be conducted represent link 1 within a DES model. Information systems play an important role in the formation of people’s states, such as beliefs, opportunities, preferences and desires. Theories of psychic state formation and environmental sustainability include contingency theory, information processing theory, media richness theory, social presence theory and stakeholder theory (Melville, 2010). In environmental sustainability related DES, these theories can be used to model choice behaviour, e.g. of customers or workers, represented by entities. Important research questions include: How do social norms, trends, organizations and information systems shape the state of individual objects? How can informational structures be implemented within DES?

Research on link 2 is a major topic for recent existing environmental sustainability related DES approaches. The central research issue for relation 2 is to understand how physical structures relate to the state of individual entities in order to develop a convincing simulation model. An example study
can be found in Mardan and Klahr (2012). However, existing studies primarily focus on objects (e.g. machines). An important open research questions within this context is: How do physical structures shape the behaviour of people? How can these relations represented within a DES model? What are the relevant physical structures to be implemented within a DES model?

Link 3 refers to research on the conversion of an individual entities state at a certain event. For the physical entities within DES, events are determined by natural laws. For informational and human objects Melville (2010) suggests theories including game theory, the technology acceptance model or theory of reasoned action to describe their actions. Representation of link 3 within the simulation model is based on a comprehensive and appropriate understanding of natural laws as well as behavioural patterns. Windisch et al. (2013) suggest that information systems have a strong influence in this context as they manipulate decisions making of individuals. In this way they affect the behavioural patterns of persons, e.g. customers within a public transport system (Watson et al., 2012b). It is therefore necessary to represent the influence of information systems on human behaviour within the simulation model. Important research question regarding link 3 are: How can laws and patterns for the behaviour of human and physical entities be represented within DES model? How can events within DES depict the effect of information systems on individual entities within the simulation experiment?

Research on the social and organizational outcomes of events is included in the analysis of link 4. The central issue is to understand changes of the informational structures and system performances induced by conversions of single entities. Example theories in this regard are: absorptive capacity theory, dynamic capability theory, production theory, resource-based theory and systems theory (Melville, 2010). Information systems can be interpreted as catalysts for the change of social and organizational structures or the information system itself can be interpreted as an informational structure that develops according to the entities conversion. Important research question regarding relation 4 are: How do conversions of single entities relate to the development of informational structures? How do information systems affect this relation? How do conversions of single entities affect information systems?

Research on link 5 aims to create an understanding of the physical outcomes of individual entities conversions. A physical outcome in the context of environmental sustainability may be a decrease or an increase in emissions, waste or consumptions. The physical outcome represents the environmental impact of the simulated system, i.e. an environmental impact is a change of physical structures. Therefore, research that quantifies and aggregates environmental impact for further interpretation requires a deep understanding of materials, energy forms, chemical substances as well as metrics. Life cycle assessment and environmental foot printing methodologies are frequently used for the quantification of environmental impact, e.g. by Johansson (2010), Löfgren and Tillman (2011), Page and Wohlgemuth (2010), Thiede et al. (2013) and Wohlgemuth et al. (2006). Within life cycle assessment physical entities, e.g. material stock, are characterized by a life cycle inventory (Guinée et al., 2002). The inventory contains all emissions, waste or natural resource consumptions generated to produce a certain amount of a material or energy, e.g. 1 kg steel or 1 MJ electrical energy. Inventory data for many common materials, substances and energy forms is available in commercial and open source databases such as the ecoinvent database (http://www.ecoinvent.org) or the European reference database (http://lct.jrc.ec.europa.eu/assessment/data) (Finnveden et al., 2009). After combination of several entities within DES, the resulting inventory for the simulated system can be processed using life cycle impact assessment. The impact assessment encompasses the aggregation and weighting of different substances to a certain impact category, e.g. aggregation and weighting of methane and CO₂-emissions to the category greenhouse gas emission (ISO, 2006). Important research questions within this context are: How can life cycle inventories be integrated into DES models? What are relevant impact categories and metrics to measure environmental sustainability?
### 4.4 Methodological Toolkit

The methodological toolkit developed from the literature can provide instruments for environmental sustainability related approaches in DES. The toolkit does not claim to be complete. Rather, it presents a basic set of general instruments for research on the issues presented in Section 4.3 and indicates a starting point for the development of suitable research methodologies. In-depth studies of certain research issues require profound knowledge of the research methods in use and have to be supported by more context specific methodological literature. The introduced instruments have been determined by backward search starting from the search results in Appendix I and are depicted in Table 2.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
<th>Type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum information about a simulation experiment (MIASE)</td>
<td>A guideline for researchers to report all information, necessary to reproduce a DES simulation experiments.</td>
<td>Guideline</td>
<td>(Waltemath et al., 2011)</td>
</tr>
<tr>
<td>Design science research guidelines</td>
<td>Seven guidelines to assist researchers understanding the requirements for effective design-science research. The guidelines will help researchers to conduct a rigorous design of DES studies.</td>
<td>Guideline</td>
<td>(Hevner et al., 2004)</td>
</tr>
<tr>
<td>Guideline for theory building research methods</td>
<td>Guidelines for researchers that may help to build theory out of DES research.</td>
<td>Guideline</td>
<td>(Wacker, 1998)</td>
</tr>
<tr>
<td>Design science process model</td>
<td>A process model to help researchers planning the procedure of DES research on Green IS with a focus on scientific quality.</td>
<td>Process Model</td>
<td>(Peffers et al., 2007)</td>
</tr>
<tr>
<td>Steps of a sound simulation study</td>
<td>A process model to help researchers planning their procedure for DES studies with a focus on time efficiency.</td>
<td>Process Model</td>
<td>(Law and Kelton, 2007)</td>
</tr>
<tr>
<td>Life Cycle Assessment Framework</td>
<td>A framework to guide researchers to estimate the environmental impact of their systems. The framework will help DES researchers to evaluate the environmental performance of results.</td>
<td>Framework</td>
<td>(ISO, 2006)</td>
</tr>
<tr>
<td>Energy Consumption Estimation Framework</td>
<td>A framework to estimate the energy consumptions of IT infrastructures. The framework will help DES researchers representing the energy consumption associated with IS.</td>
<td>Framework</td>
<td>(Seo et al., 2009)</td>
</tr>
<tr>
<td>Modelling framework for discrete event system specification</td>
<td>A framework to enable the development and execution of environmental models within DES models.</td>
<td>Framework</td>
<td>(Filippi and Bisgambiglia, 2004)</td>
</tr>
<tr>
<td>Framework for simulation-based decision support for manufacturing</td>
<td>A framework helping researchers to turn the results of their DES studies into decision support in manufacturing context.</td>
<td>Framework</td>
<td>(AlDurgham and Barghash, 2008)</td>
</tr>
<tr>
<td>Modelling framework for supply chain simulation</td>
<td>A framework helping researchers to turn the results of their DES studies into decision support in supply chain context.</td>
<td>Framework</td>
<td>(van der Zee and van der Vorst, 2005)</td>
</tr>
<tr>
<td>Discrete event systems</td>
<td>An introduction for researchers to get in touch with DES.</td>
<td>Tutorial</td>
<td>(Cassandras and Lafortune, 2008)</td>
</tr>
<tr>
<td>Discrete event simulation</td>
<td>A very comprehensive introduction for researchers to get in touch with the principles of modelling and DES.</td>
<td>Tutorial</td>
<td>(Banks et al., 2009)</td>
</tr>
</tbody>
</table>
Methodologies and Case studies within simulation for more sustainable logistics systems

A collection of methodologies and case studies to support researchers with the analysis of energy systems in the production context using DES.

Collection of methodologies (Solding et al., 2009)

Extensible toolbox for modelling nature-society interactions

A toolbox to support researches modelling nature-society interactions combining various simulation approaches such as DES.

Collection of methodologies (Carneiro et al., 2013)

Table 2 Methodological toolkit

In addition to the presented theoretical and conceptual instruments, a large number of modelling and simulation software tools are available for environmental sustainability related DES. The selection of an appropriate simulation tool depends on the chosen research approach and context. An overview of DES simulation tools can be found at Law and Kelton (2007), Klingstam and Gullander (1999), Carneiro et al. (2013) and Byrne et al. (2010a). A current overview of life cycle assessment tools and databases is available at http://lca.jrc.ec.europa.eu/lcainfohub/providerList.vm.

5 Conclusions

The research on environmental sustainability is still a growing topic within IS research. Understanding and shaping the informational and physical systems surrounding us is an essential for a more sustainable future. IS research plays an important role already as it combines knowledge of human behaviour with knowledge of information technology. DES research could provide more realistic and valid simulation models in this regard to represent symbiotic physical and informational real-world systems.

We suggest that DES experiments can be applied to evaluate the impact of Green IS on physical systems, e.g. transport information systems. Using Green IS results for the implementation of individual entities within DES models could be a promising step towards understanding and explaining the links between physical and informational structures, individual objects and environmental impacts. Proving the efficacy of Green IS through experimental research in a real-world logistics system can be expensive, or not viable, particularly when involving errors, crashes, large scale environmental damage or injuries. DES approaches can be used in this regard to conduct simulation experiments at lower expenses and within systems of uncertainty. However, due to the current alignment of DES research on physical structures and objects, more research on the representation of human behaviour within a symbiotic informational and physical system as well as metrics for the representation of environmental impacts is necessary.

Understanding the relations between information, physical structures and individual objects is crucial to implementing more sustainable business processes. DES is already used to support a wide range of managerial decisions within supply chains (c.f. Section 1). We suggest a link between established simulation models, environmental performance metrics as well as established software tools and new applications in Green IS. Therefore, current DES models have to be checked from an environmental perspective, existing sets of key figures or performance metrics have to be extended by environmental metrics and the software tools in use have to be integrated with databases and methods for the environmental representation of objects and structural changes.

6 Research Outlook

This research project explored the scope for DES studies in Green IS research and concludes that DES can be productively applied to examine relations between Green IS and physical systems. Our research is not meant to be deterministic nor constrictive. We tried to structure the field based on a rigorous
proceeding that covers a structured literature review, the development of a belief-action-outcome framework and the formulation of research questions. However, to certain extend conceptual research and especially the formulation of research questions comprises a creative momentum as well. The formulation and combination search terms within the literature research (c.f. Section 3) may be one of the cases, where intuitiveness and imagination coincide with rigorously defined method. Also the formulation of research questions (c.f. Section 4.3) may be biased by personal experiences to some degree. The scope of our framework aims at an interdisciplinary research approach at the interface of IS and logistics research. It might therefore be restrictive in its view on information systems and the formation of believes. Despite these limitations our framework reveals that DES facilitates Green IS research with new means for theory testing and enables decision makers to make more sustainable decision. We encourage scientists and practitioners to enter the discourse on DES in Green IS in order to refine and concretize our conceptual framework.

Future research will integrate behavioural and natural sciences. Design oriented research may be required due to the absence of software tools relating DES with LCA and environmental impact assessment tools as well as life cycle inventory databases. Partners from the business community should be involved with the system modelling and evaluation in order to ensure the practical relevance of the research. This research would be a first attempt at symbiotic informational and physical modelling in DES as well as in simulation based research on LCA and environmental impact assessment. Moreover, examples from the Green IS literature will be used to implement DES models in order to demonstrate and evaluate the value of DES for Green IS research.

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References


## Appendix I

Overview of environmental sustainability related approaches of DES.

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| Sum                          |       |                             |                         |                           |                   |                                               |                                    |                                    |                                   |

Appendix I