Simulation in Produktion
und Logistik 2021
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Cuvillier Verlag, Göttingen 2021

A Criteria-based Database for Research and Applications of Energy-oriented Simulation in Production and Logistics

Eine Datenbank für klassifizierte Forschungs- und Anwendungsberichte zu energieorientierter Simulation in Produktion und Logistik

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Abstract: Within the Section "Simulation in Production and Logistics" of the association for simulation in the German-speaking area (ASIM), the relevance of energy-related considerations led to the foundation of a dedicated scientific workgroup. One of their primary results is a comprehensive literature overview of related approaches from research and industrial perspectives. The experts cooperated to identify, evaluate, and classify relevant literature. Interim findings have been published with special emphasis on logistics and manufacturing. Recently, work was focused on converting the findings into a structured database, to foster the involvement of other experts by providing consistent access to all results in the public domain and to provide means to submit new contributions proactively to the group. Thus, the workgroup intends to raise awareness and motivate other researchers to join the effort. This paper summarises the rationale and methodology of the activities as well as the provision as a public database.

1 Introduction

Simulation has been established as a tool that is of great value in both planning new and revising existing processes in production and logistics. The method and the respective software suites have evolved to cover a wide area of applications within different industrial branches and planning scopes. When the societal awareness for climate change grew, it was natural that this would be reflected in research and application of simulation. A primary reason for this shift is the environmental impact of the industrial and the transport sectors. As of 2016, the operations of these two

sectors caused approx. 24 % and 16 % of all yearly greenhouse gas emissions worldwide (Ritchie and Roser 2020).

Initial works that integrated energy-related considerations into simulation studies in the production and logistics sectors were primarily focusing on the economic effects of energy utilization. This came at a time (from approx. 2005 onward) when electricity and oil prices were rising to the extent that energy costs became a notable issue especially for energy-intensive manufacturers as well as logistics operators. In parallel, the awareness for the overall environmental impact grew in some industries, which also prompted actions to increase transparency on and reduce the footprint of economic operations. In addition to the afore-described energy efficiency and eco efficiency, more recent works focus on energy flexibility. The latter focusses on aligning industrial energy demands with volatile, decentralised energy supply (e.g. from renewable energy sources) (Uhlig et al. 2018).

The Section "Simulation in Production and Logistics (SPL)" of the association for simulation in the German-speaking area (Germany, Switzerland, and Austria) (ASIM), responded to the importance of these developments by founding the "Workgroup on the Investigation of Energy-related Influences in SPL" in 2014. It has gathered an extensive and structured collection of relevant works to shed light on findings of various groups or organisations as well as on knowledge gaps (Wenzel et al. 2017; Uhlig et al. 2018; Poeting et al. 2019). To make these results even more widely available and attract further contributions, the workgroup has recently decided to publish a database of its findings on research and applications of energy-oriented simulation in production and logistics, which is structured by a set of classification criteria. The database will be made accessible through a specific website that allows for filtering, according to specific criteria in terms of content keywords, year of publication, authors or institutions, and others. This paper is intended to provide an overview of the workgroup's results, the methodology of the literature review conducted, and the realization of the new online database. The structure of the paper will follow these main topics and conclude with a brief summary.

2 Overview on Workgroup's Results

The initial impetus for founding the "Workgroup on the Investigation of Energy-related Influences in SPL" within the ASIM Section SPL came in the wake of the section's bi-yearly conference in 2013. It consisted and still consists of a group of simulation software vendors, industrial users, and researchers. During its constituting meeting one year later and in the following assemblies, the participating parties shared insights into their respective previous and current case studies that related to the theme of the workgroup. Moving onward from there, discussions took place to decide on the scope of future work. It was agreed that standardization of vocabulary and procedures was desirable but would require an in-depth understanding of existing and documented works in the field. This prompted the group to compile an exhaustive overview on research and applications of simulation based on published articles.

The remainder of this section will review the primary findings of the workgroup's previous publications (Wenzel et al. 2017; Uhlig et al. 2018; Poeting et al. 2019). Additionally, statistics will summarise the distribution of identified works considering the criteria defined as part of the methodology that was applied in the literature review (cf. Section 3).

Previous publications have shown the diversity of knowledge that is comprised in such literature overviews: By plotting the number of literature entries that were determined to be relevant by the workgroup categorised by publishing year, Uhlig et al. (2018) showed an increased interest in this topic's exploration, starting from 2011. Apart from the quantitative analysis, causal interpretations have been made possible. Mutual dependencies between applied key performance indicators and the level of detail for modelling could be discerned as well as their effect on additional requirements for simulation input data. Furthermore, particularities resulting from either a logistics or manufacturing scope of the case studies were investigated by Poeting et al. (2019). These showed, e.g., that fewer documented simulation applications could be found for logistics than for manufacturing. Reflecting the workgroup's aim to identify actors in the field from academia or industry, distinct inferences were made, e.g. by mapping the origin of the included literature's authors by country and region within Central Europe (cf. Wenzel et al. 2017). The initial Germany-centred focus of the workgroup's findings came naturally from the members' ASIM affiliation and their self-conception as a German-speaking institution, which made German publications more available. However, the workgroup diligently worked to meet expectations of the internationally linked research community by incorporating English publications wherever possible. A recurring topic that has been discussed by the members was the ambivalence of usually discrete simulation of production or logistics processes and the usually continuous flow of resources or energy. Considering this aspect, Uhlig et al. (2018) referred to Thiede (2012) concerning typical paradigms for the simulation of energy flows in manufacturing systems. Poeting et al. (2019) built on this classification for simulations with a focus on logistics and underpinned it with empirical findings.

As extension to the previous analyses, Fig. 1 gives a combined overview of those paradigms and the related architectures to the simulation tools that were used in publications over the years. Quite clearly, discrete event simulation (DES) with integrated consideration of energy turns out to be the most dominantly used architecture. These approaches were mainly implemented with tools like Plant Simulation and Arena. The strong increase of publications with this approach especially after 2012 can certainly also be explained through the introduction of standard energy features with Plant Simulation version 11. However, when it comes to other architectures, a diversity of further tools comes into play. This includes, for example, multilevel approaches that bring together different elements into overall system simulations (e.g. a factory with different subsystems). This can either take place within one tool, e.g. in hybrid tools that can incorporate different modelling paradigms like AnyLogic (e.g. Thiede 2012) or Matlab (e.g. Pawletta et al. 2017). The alternative is to couple several tools and enable communication through a middleware interface or directly (e.g. Peter and Wenzel 2017).

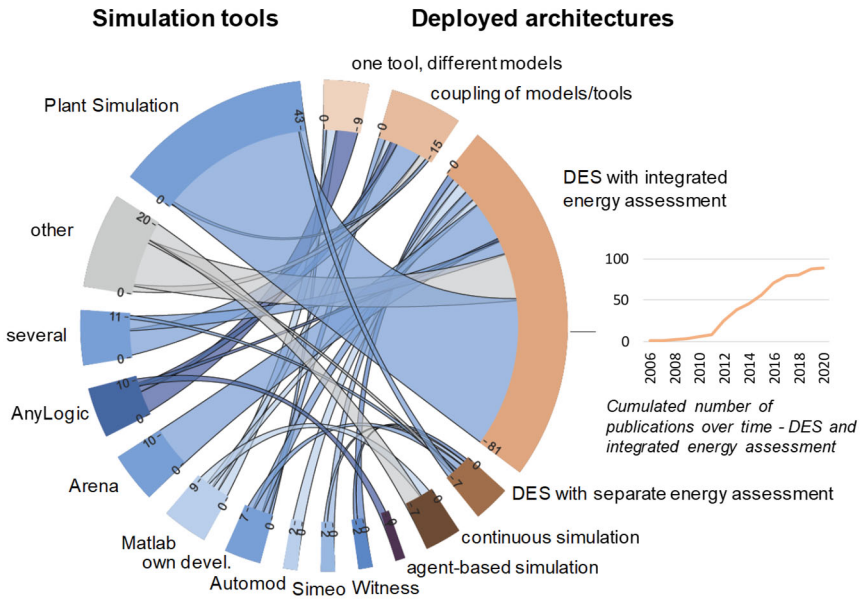

Figure 1: *Deployed architectures in relation to simulation used in documented publications (Note: "own devel." refers to self-developed simulation software)*

3 Methodology of the Literature Review

A primary goal of the research method *literature review* is to generate new insights based on other primary works. Various general approaches can be distinguished that differ primarily in the way they try to incorporate quantitative data from identified articles. Meta-analyses aim to mathematically integrate the results of different studies. Systematic reviews focus on summarising quantitative studies regarding the effects of certain measures. Scoping reviews are intended to cover not just scientific literature but all relevant publications, for instance, to identify knowledge gaps or the extent of existing research (Sturma et al. 2016). The workgroup applied the latter method for its purposes.

The general process applied follows the methodology for scoping reviews proposed for use by Colquhoun et al. (2014). It has been described in Uhlig et al. (2018) and is summarised in Fig. 2. The depicted list of keywords is not applied automatically nor strictly but rather manually and for approximate matches in order to filter for relevant works. As of May 2021, a total of 207 publications from 29 journals and 47 conference proceedings as well as other publication channels (e.g. thesis works) have been identified and added to the scoping review's body of literature through the application of this methodology.

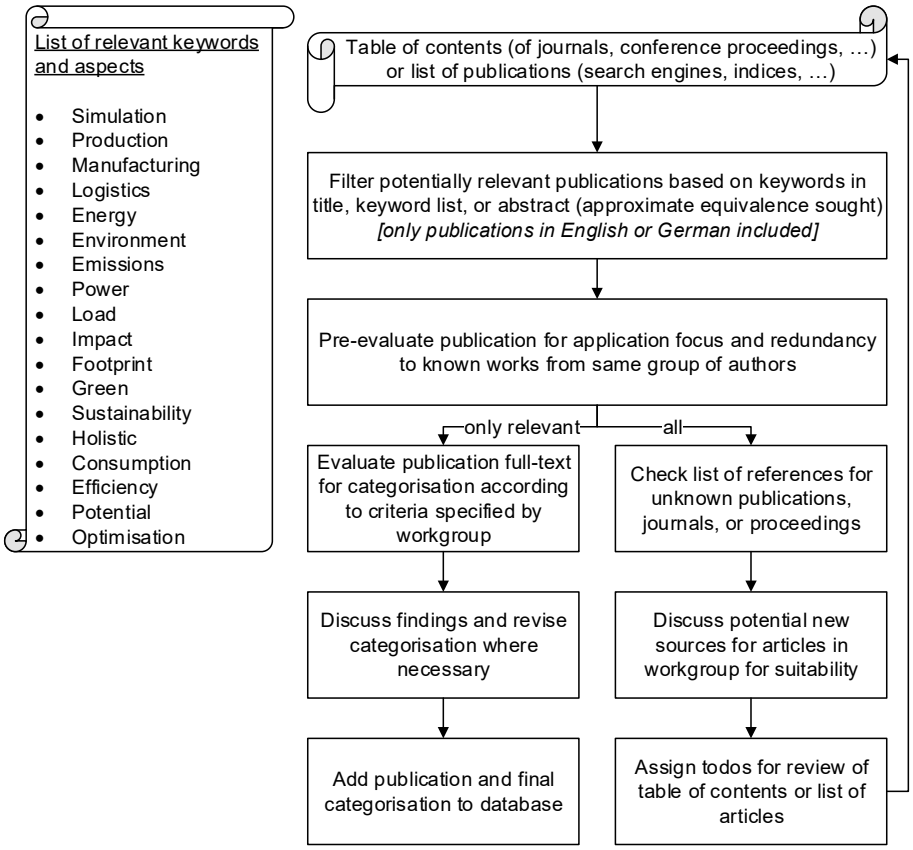

Figure 2: *Overview of process for scope review*

Three general options to facilitate the involvement of third-party actors exist. Firstly, the workgroup can be notified of journals, journal issues, conference proceedings, and further compendium works that might include potentially relevant publications. Secondly, possibly relevant publications can be brought to the attention of the work-group, directly. Lastly, fully evaluated publications (i.e. a suggestion for a publication and its classification according to the specified criteria) can be forwarded to the workgroup. They will be discussed in regular meetings before they are added to the database. It is foreseen that the public frontend of the online database will feature ways to support these options. Contributions are presently encouraged to be provided directly to members of the workgroup or through the website, once completed. The mandatory step *"discussion in the workgroup"* will serve to maintain consistency and suitability of added publications throughout the future extension of the database, following the scoping review methodology.

4 Database and Website

In order to enable an efficient maintenance and exploitation of the knowledge that has been acquired by the workgroup, a web-based service is under development. This

section describes the envisaged general structure of the database, the planned access mechanisms, as well as the major technical characteristics.

4.1 Underlying Data Structure

The data are structured in a relational database model with the following basic entities:

- PAPER: title, language, source, year, abstract, administrative information (e.g. date generated, date changed).
- AUTHOR: first name and surname.
- INSTITUTION: name of institution (and department), city, country.
- CONTRIBUTOR: sequence number in author list.
- KEY: criteria to classify publications (cf. Wenzel et al. 2017) regarding energy-specific key performance indicators (KPI), process scope, production structures, production type, industrial sector, level of detail, integration architecture, simulation tool, and added input data.
- KEYWORD: key class (i.e. characteristics for each criterion for the classification of case studies; e.g. energy consumption per system or per system element over time for criterion energy KPI).

In addition to these basic entities, there are a number of relational entities, which comprise PAPER–CONTRIBUTOR, CONTRIBUTOR–AUTHOR, CONTRIBUTOR–INSTITUTION, PAPER-KEYWORD; and KEYWORD–KEY (Fig. 3). The list of keys is a fixed catalogue, and a change requires access to the underlying database. All keywords are related to exactly one of these keys, and each paper may be associated with several keywords, also allowing more than one keyword of the same key category.

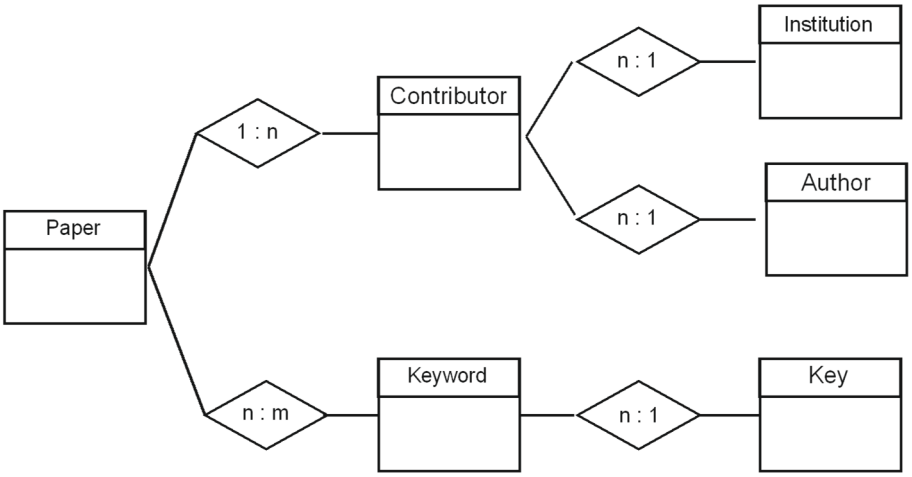

Figure 3: *Simplified Entity-Relationship Model of the database (cardinality in Chen-notation)*

4.2 Maintenance and Query Functionalities

The functionalities that are provided through the web interface can be differentiated into administration, maintenance of the data, and query. Administrative functions, like user right assignment or backup, are not discussed here. Maintenance functions enable privileged users to load any of the basic entity entries based on a unique identification (ID) code, which is automatically assigned to all entries. The entry (except the ID) can be changed in the interface and sent back to the database for permanent storage. Furthermore, relations can be added or edited. This function is supported in the user interface showing the content (e.g. the name of the key characteristic) instead of the ID (cf. Fig. 4). Furthermore, text-element-based filter functions will ease the search in large tables.

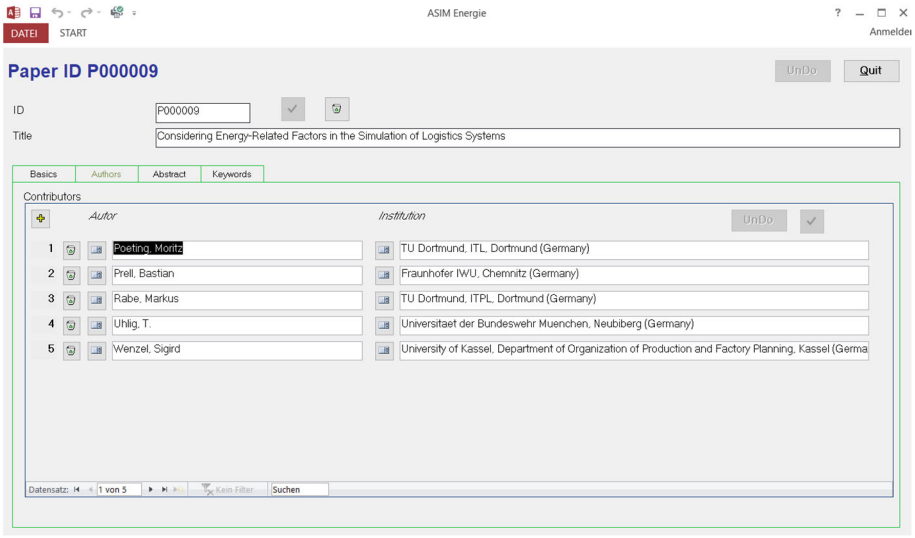

Figure 4: *Screenshot of the prototypical maintenance graphical user interface (GUI)*

In order to keep the development effort reasonable, a Microsoft Access interface is used for the maintenance functions. A later full implementation of these functions on the web server is possible (then, both mechanisms would work in parallel), if suitable resources are provided. For performance reasons, the data are cached in the local Access database and only cross-checked during editing operations and updated when changes are conducted in the local interface.

Query functions in the public interface work (i) through text elements of the entry or (ii) through keywords. In the first case, the user may enter any piece of text or a regular expression (RegEx), either in general or associated with one of the basic entities. Thus, searches can be limited to, e.g. titles or institutions. A search in the keywords or keys is not possible with this function. In the second case, the user will select a number of keywords. Multiple keywords for the same key are allowed, as well as a combination of keywords from different keys. In the first approach, all items will be found that

match any of the specified keywords. Depending on the usage, the workgroup might later consider more sophisticated mechanisms for the selection of items.

The result of a query is in the first step the number of items found. Depending on the user's rights, functions for downloading an overview or the resulting references, a bibliographic list in bibTex format, or the full available information can be generated.

4.3 Technical Characteristics and Roles

In order to enable a low-barrier access, the complete system will be web-based and deployed on the web server of the ASIM Simulation in Production and Logistics Conference (ASIM 2021). The data are held in a mySQL database, with the interface coded in PHP7, applying standard HTTP POST mechanisms for the data transfer (Fig. 5).

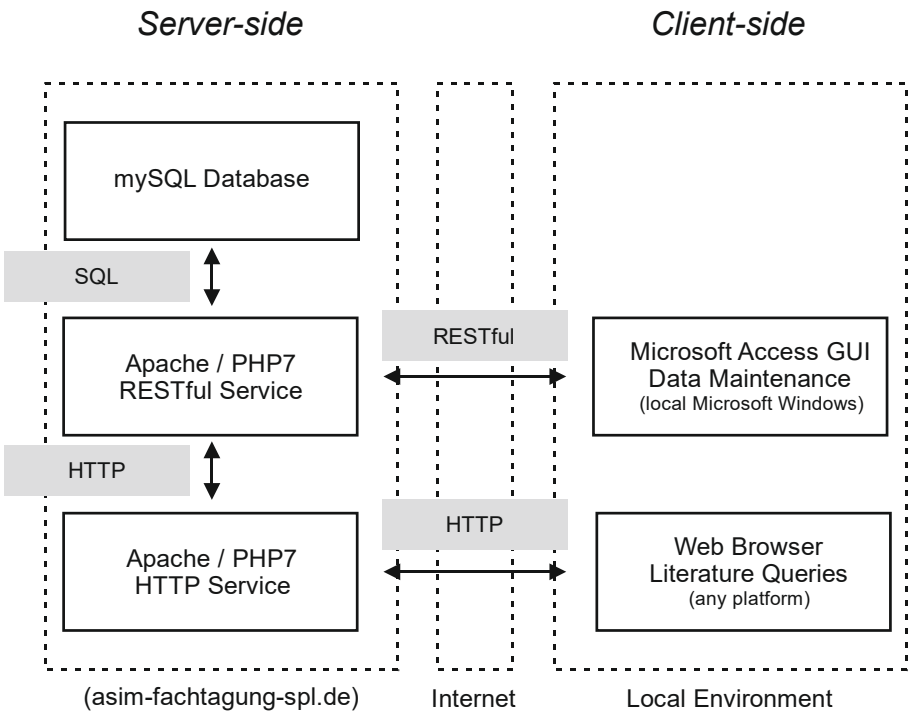

Figure 5: *General architecture and deployment of the application*

In detail, there is a RESTful service implemented as a shell for the database. The RESTful service comprises standard functions for adding, replacing, or deleting basic entries and further functions to relate such entries, e.g. to relate an author to a paper or to an institution. These services are conceptualised as integrity-guaranteeing, i.e. changes are only permitted if the database's integrity is not violated by the operation. The same RESTful service will also conduct the authorization approval activities, checking the user's permission for specific activities on the database.

In the first preliminary version, the access to the complete page will be restricted by a suitable username and password for authorised workgroup members as beta users. In a second stage, specific differentiated user rights will be assigned. The envisaged user groups are:

- EDITOR, authorised to change the content and add new information, as well as to accept contributed information.
- CONTRIBUTOR, authorised to propose changes to the database that are visible to editors, but not to the public.
- REQUESTER; authorised to query the database by text items or keywords, and to access the full information available, including full references and abstracts.
- GENERAL, authorised to query some overview information, e.g. the institutions that can be associated with specific keywords. The categories of the open information are not yet decided.
- MANAGER, authorised to add or delete users and user rights.
- ADMIN, comprising all rights described above plus the right to conduct changes in the database without consistency approval, thus allowing for corrective actions in the case of technical failures.

Obviously, there will be a user access control for most of these roles. While roles like EDITOR or MANAGER will require the permission of the workgroup, the rules for some other rules will have to be decided. For practical reasons, at least CONTRIBUTORs might be requested to register with their institution and email address. Also, REQUESTERs could be asked to make themselves known before full access is granted, in order to give the workgroup a chance to get in touch with them and to monitor the interest in their work. This seems to be a fair approach given that the workgroup publishes its knowledge in such an open way.

It should be noted that – through the implementation as a RESTful service – there is an application programming interface (API) that could also be used by any evaluation software, independently of the user interfaces that are described in this paper.

5 Summary

This paper gives a short overview on the main work and the results of the "Workgroup on the Investigation of Energy-related Influences in SPL". The literature overview, which has been created in the workgroup since 2014, was structured via keywords, so that all contributions could be classified systematically albeit manually and analysed laboriously so far. In order to make the extensive results more usable and internationally visible, to be able to easily add further relevant third-party literature, and to provide efficient features for data analyses, a database has been designed. This database is currently in the realisation phase. The implemented database schema was briefly presented herein. The backend functions have already been realised using Microsoft Access.

Future work will focus on the implementation of data query and maintenance functions in a web frontend as well as the establishment of an organisational evaluation process for new third-party contributions within the workgroup. Furthermore, it is planned to carry out and publish more analyses of the recorded publications using the database. The long-term goal is an international visibility of the database including a sustainable and simple organizational concept. The access to the database will be

available on the website of the ASIM Section "Simulation in Production and Logistics" under the URL http://asim-fachtagung-spl.de/asimenergy.

Acknowledgement

We would like to thank the members of the ASIM Section's Simulation in Production and Logistics (SPL) workgroup on the Investigation of Energy-related Influences in SPL for their support over many years in researching and evaluating relevant publications as well as in making the database usable and applicable.

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