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Procedure model for efficient simulation studies which consider the flows of materials and energy simultaneously

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Abstract

The premise of this work is that more guidance is required for the application of the simultaneous simulation of material flows and energy flows. This assumption is supported by the findings of a systematic review which showed great diversity in earlier published case studies. Yet, other existing procedure models provide little advice regarding the manifestations of specific details of a simulation study. This paper presents a novel procedure model that is meant to increase the efficiency in simulation projects by providing detailed and consistent guidance for design choices in a simulation study. Selected results of its application are shown exemplarily.

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Keywords: Simulation, Energy efficiency, Decision making, Procedure model, Discrete event simulation

1. Introduction

Fuelled by economic pressure and societal change, the awareness of production companies for matters of energy and resource efficiency has risen in recent years. In response, engineers developed, implemented and tested a myriad of approaches to eliminate energy waste by means of technological and organisational improvements [1]. These efforts are usually expected to achieve an economic advantage quickly without adverse effects on the fulfilment of production targets.

The combined simulation of material and energy flows has become a tool of choice for investigating approaches, which concern production system planning or operational aspects (see reviews in [2,3]). A review of earlier published works on the subject shows that individual simulation studies vary significantly in their respective characteristics. This can be exemplified considering the consumption model (energy model) for electricity (ranging from operating state average demand to actor-based physical simulations) or the employed simulator's architecture (ranging from offline spreadsheet calculations to online coupling of multiple simulators).

Some general work on the structured implementation of simulation studies, which consider the flows of both materials and energy, has already been published [2–4]. However, it only offers limited insight on the relevant criteria for deciding which characteristics should be selected for investigating specific problems.

More guidance can be provided in the design and execution of efficient simulation studies for investigating the implementation of energy efficiency (EE) measures. Thus, a detailed procedure model is suggested to guide simulation engineers with respect to their particular task. In preparation to its introduction, section 2 clarifies some terminology used in this paper. The starting point for the procedure model was an extensive systematic review on the characteristics of case studies in the field, which have been published so far. Its quantified results as well as a critical review of existing procedure models are presented in section 3. A description of the proposed model and its steps is provided in section 4. At last, a brief example is introduced to clarify which details are considered and to illustrate the results of its application.

2. Terminology

Characteristics of a simulation study describe how specific aspects are designed in the execution of the study, e.g. which approach/method to experiment design was chosen.

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The **Characteristics vector** comprises all characteristics and defines the overall design of a study, i.e. includes the experiment design, the simulator architecture, the energy model and other characteristics' respective manifestation.

Case study is used, especially in the following section, in the sense of a singular execution of a simulation study to investigate a specific system with a certain aim. Accordingly, multiple investigations with different aims on the same system or vice versa are considered as multiple case studies.

3. Literature review

The premise of this paper is that the efficient application of simulation which simultaneously considers material flows and energy flows requires more guidance than current approaches can provide. The following section introduces a review of documented case studies (see section 2) to show the current diversity in such studies. Afterwards, existing procedure models are discussed and the need for action is outlined.

3.1. Systematic review of documented case studies

Recent years saw tremendous development in the field of simultaneous simulation of material flows and energy flows, much of which has been documented in specific case studies. To provide an overview on the aims of these simulation studies and their respective characteristics, an extensive literature review has been completed. In total, 75 publications from 2005 onward have been identified that presented 104 case studies (see section 2). These were classified regarding their primary goal, planning task, type of tool, energy-related target figures, energy models, and experiment design method. In the following, the results of this systematic review are discussed with selected citations. For purposes of conciseness, the entire list of reviewed papers had to be omitted here.

When material flow simulation is extended with energy, three different primary goals are relevant. 13 % of all case studies aimed to verify or validate that a certain change (see planning task below) could improve the system's energy efficiency. These put lower emphasis on quantifying the actual effects on the energy consumption (e.g. [5]). The majority of 74 % primarily tried to quantify the utilisation of energy-related target figures (e.g. [2,3,6–8]) and another 13 % aimed to optimise certain parameters/aspects (e.g. [9,10]).

Fig. 1 gives an overview on the planning tasks that were investigated using energy-enhanced simulation. Three basic groups of tasks could be identified: supply chain management, system design (SD), and production planning and control (PPC). The latter two have been differentiated further to give some insight on which particular aspect was adjusted to raise energy efficiency. From the numbers it becomes apparent that both SD and PPC have been investigated in about equal numbers, while only very few studies on supply chains (2 %) could be found. In most cases, the simulations focused on improved production control strategies (changes to the production flow; e.g. [2,4,5,10,11]) or efficient process or system design (selection and dimensioning of material flow system elements or similar; e.g. [2,3,6–8,12,13]).

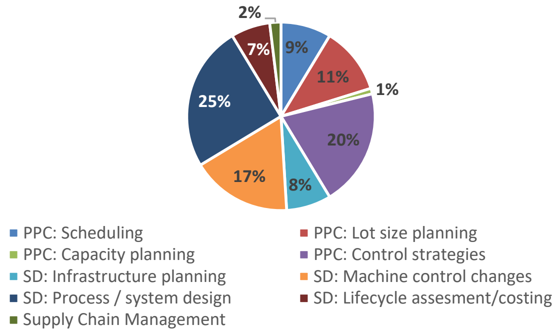

Fig. 1. Shares of use cases, which consider certain planning tasks.

At about 71 %, the vast majority of the case studies utilised discrete event simulation (DES; e.g. [3–6,9–11]). Tools that combine DES with continuous simulation approaches, such as AnyLogic®, were also used fairly frequently (16 %; e.g. [2,14,15]). Another 6 % employed only a solver or alternative simulation approaches and some 7 % of the documented case studies included no statement on the applied tools.

Documented solutions for enhancing material flow simulations with energy considerations differ primarily in which energy-related target figures are measured and in how the energy flows are modelled. In most cases, at 43 % each, electricity (e.g. [10,12,13]) or electricity along with other process media, such as compressed air, (e.g. [2,11,14]) were included in the investigation. 6 % of the case studies focused on a total energy equivalent (e.g. [8]) and further 6 % were primarily concerned with the CO_2 equivalent or similar lifecycle inventory indicators (e.g. [16]). Only 2 % used costs as the main target figure (e.g. [9,17]).

Fig. 2 shows the shares of case studies that applied the various identified energy models. The results show that most implementations used an average consumption for multiple operating states (OS) (e.g. [3,11]). Some works also utilised spline curves (e.g. [18]) or artificial models (e.g. [13]) abstracted from real measured profiles for selected OSs (especially for producing or warm-up/cool-down states). The use of continuous or physical models is also found in some case studies, most of which also employed combined simulation tools (e.g. [15]). Historic measurements or just time-shares of OSs are used in only a few case studies.

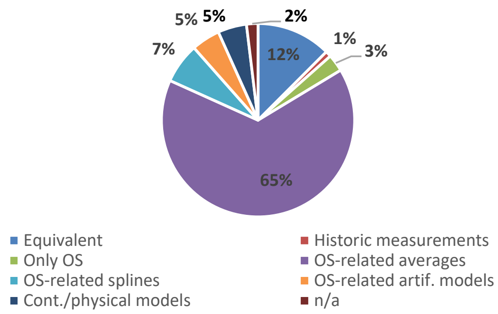

Fig. 2. Shares of use cases, which apply certain energy models.