SNE SIMULATION NOTES EUROPE

SNE Special Issue

Simulation in Production and Logistics: Impact of Energetic Factors

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Simulation Notes Europe (SNE) provides an international, high-quality forum for presentation of new ideas and approaches in simulation - from modelling to experiment analysis, from implementation to verification, from validation to identification, from numerics to visualisation - in context of the simulation process.

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Editorial

Dear Readers - *This SNE special issue 'Simulation in Production and Logistics - Impact of Energetic Factors', the second SNE issue of 2017, SNE 27(2), was suggested and compiled by ASIM, the simulation society in Germany, Switzerland, and Austria.*

The issue underlines the strategy of SNE to publish contributions on recent trends and developments in modelling and simulation in context with the full simulation process, and reflects the status of SNE as membership journal of EUROSIM, the Federation of European Simulation Societies, and the activities of the member societies

Sigrid Wenzel, head of ASIM's technical section 'Simulation in Production and Logistics' and her guest editorial board from the working group 'Consideration of Energetic Factors in Simulation in Production and Logistics' could motivate twenty-five experts to discuss a brand-new topic in seven contributions.

Along with this issue, we are happy to announce the relaunch of the new SNE website – www.sne-journal.org - with new design and new functionalities, as improved access for members of EUROSIM societies (see also new EUROSIM website – www.eurosim.info).

I would like to thank all authors for their contributions, and special thanks to the guest editorial board with S. Wenzel and her co-editors H. Pitsch, C. Pöge, M. Selmair, J. Stoldt, and T. Uhlig for this special issue, and thanks to the SNE Editorial Office for layout, typesetting, and for web programming for electronic SNE publication and for the new SNE web server.

Felix Breitenecker, SNE Editor-in-Chief, eic@sne-journal.org; felix.breitenecker@tuwien.ac.at

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office@sne-journal.org, eic@sne-journal.org

SNE Editorial Office, Andreas Körner
ARGESIM/Math. Modelling & Simulation Group,
TU Wien - Vienna Univ. of Technology /101,
Wiedner Hauptstrasse 8-10, 1040 Vienna , Austria

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Editor-in-Chief: Felix Breitenecker, Vienna Univ. of Technology, Math. Modelling and Simulation Group
Felix.Breitenecker@tuwien.ac.at, *eic@sne-journal.org*

Layout / Administration: A. Körner, A. Mathe, J. Tanzler, R. Leskovar, et al.; *office@sne-journal.org*

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Editorial SNE Special Issue 'Simulation in Production and Logistics - Impact of Energetic Factors'

Today, simulation-based planning and operating of production and logistics systems have to focus not only the conventional logistics key performance indicators like throughput, capacity utilization or stock of inventory, but also indicators like energy consumption and energy costs. Therefore, the ASIM section *Simulation in Production and Logistics* (SPL) has agreed to deal with energetic factors within production and logistics simulation studies in more detail and constituted an internal study group in 2014. This group discusses new approaches as well as new or extended applications. This special issue is one result of the study group.

The issue starts with the contribution of Marco Seewaldt, Joachim Nagel, Dieter Geckler and Uwe Bracht - *Energy-oriented Material Flow Simulation as a Contribution to Automotive Industry 4.0*. The authors present approaches to simulation-based improvements in energy and resource efficiency of automotive production processes. Using the simulation software Plant Simulation for the analysis of the potential energy savings they postulate the integration of existing approaches of material flow simulations with energy consumption aspects as a new contribution to the ongoing development of the tools and methods of Digital Factory and Industry 4.0.

The paper by Heiko Dunkelberg, Henning Meschede, Fabian Stöhr and Jens Hesselbach - *Assessment of Influencing Factors in Decentralized Energy Supply of Manufacturing Industries Using Probabilistic Methods* investigates a decentralized energy supply system for the plastic industry. The authors simulate the production schedules as well as the ambient temperature as probability density functions to generate various probabilistic scenarios. Their approach allows the determination of the resilience of decentralized energy concepts and an evaluation of the concept's sensitivity towards these two influencing parameters.

The third paper by Uwe Clausen and Moritz Poeting - *Allocation of Greenhouse Gas Emissions for Containers in Multimodal Transshipment Terminals Using Simulation* deals with a simulation approach to allocate and evaluate emissions of container handling procedures in multimodal container terminals. Using their approach, the authors would like to support container terminal operators to determine their emissions.

The paper *Simulation Study on Flexibilities in the Material and Energy Flows of an Open-pit Mine*, by Johannes Stoldt, Christin Fanghänel, Hans Rüdiger Lange, Andreas Schlegel, Thomas Woldt and Matthias Putz, presents a simulation study on an open-pit mine and seeks flexibilities for increasing the operator's overall energy efficiency. For this purpose, the material and energy flows are simulated simultaneously. An overview of considered indicators and executed experiments is given.

The paper of Maximilian Selmair, Marc Hanfeld, Thorsten Claus and Frank Herrmann - *Exploring Opportunities: Optimizing Production Planning by Factoring in Energy Procurement and Trading Options* discusses a material flow simulation study extended by an electricity price simulation and examines possible cost scenarios. The results suggest that the integration of energy trading and production planning is likely to result in a monetary advantage for the manufacturing industry.

Tim Peter and Sigrid Wenzel describe in their paper *Coupled Simulation of Energy and Material Flow Using Plant Simulation and MATLAB Simulink* the state of the art in integrating energy considerations into the simulation of production and logistics processes. They present different approaches to integrate energy analysis into simulation and point out a solution developed within a research project. Furthermore, they present a use case and some results of their simulation experiments.

The last paper *A Multimodeling Approach for the Simulation of Energy Consumption in Manufacturing*, by Thorsten Pawletta, Artur Schmidt and Peter Junglas, introduces a multimodeling approach for manufacturing systems and illustrates it by a prototypical example of a component based production line with an industrial furnace facility implemented in the MATLAB Simulink environment.

The members of the guest editorial board would like to thank Thorsten Claus, János Jósvai, Egon Müller, Markus Rabe, Oliver Rose, Andreas Schlegel, and Enrico Teich for assisting the reviewing process. Furthermore, we would like to express our gratitude to all authors for their cooperation and efforts, e.g. for sending revised versions – and last but not least thanks to the SNE Editorial Office for the support in compiling this special issue.

Holger Pitsch, INCONTROL Simulation Solutions, Wiesbaden, Germany

Carsten Pöge, Volkswagen AG, Wolfsburg, Germany

Maximilian Selmair, BMW AG, München, Germany

Johannes Stoldt, Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik IWU, Chemnitz, Germany

Tobias Uhlig, Universität der Bundeswehr, München, Germany

Sigrid Wenzel, University of Kassel, Kassel, Germany, Faculty of Mechanical Engineering, Dept. of Production Organization and Factory Planning; s.wenzel@uni-kassel.de

Energy-Oriented Material Flow Simulation as a Contribution to Automotive Industry 4.0

Marco Seewaldt[1*], Joachim Nagel[2**], Dieter Geckler[3], Uwe Bracht[4]

[1]Institut für Maschinelle Anlagentechnik und Betriebsfestigkeit, Technische Universität Clausthal, Leibnizstraße 32, 38678 Clausthal-Zellerfeld, Germany; **marco.seewaldt@imab.tu-clausthal.de*

[2]Volkswagen Aktiengesellschaft, AutoUni, Institut für Produktion, Logistik und Komponente, Hermann-Münch-Straße 1, 38440 Wolfsburg, D Germany; ***joachim.nagel@volkswagen.de*

[3]Volkswagen Aktiengesellschaft, Produktionsplanung Marke Volkswagen, Projekt Digitale Fabrik, Berliner Ring 2, 38440 Wolfsburg, Germany

[4]Institut für Maschinelle Anlagentechnik und Betriebsfestigkeit, Technische Universität Clausthal, Leibnizstraße 32, 38678 Clausthal-Zellerfeld, Germany

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Abstract. This article shows approaches to simulation-based improvements in energy and resource efficiency of automotive production processes. The concept of simulation oriented energy management enhances the quality of planning energy-efficient production systems. Moreover, it is an aim to reduce energy costs by improving the manufacturing management and control. The simulation software *Plant Simulation* (Siemens PLM) is used for the analysis of the potential energy savings. In the future, a connection with the real production control will become possible. Such self-optimizing production systems build the core of the much-discussed term 'Industry 4.0'.

Introduction

For years, energy factors gained in importance for industrial production planning processes and the operation of facilities [1, 2]. Volkswagen AG integrates the energy and resource consumption of production processes gradually as new parameters in the methods and software tools of the Digital Factory. A cooperation exists at the Technical University of Clausthal (TUC), Institute of Plant Engineering and Fatigue Analysis. One focus of the joint activities is the energy-oriented material flow simulation with the software tool *Plant Simulation* regarding the consumption of electrical energy and compressed air.

1 Potentials of Energy-Oriented Material Flow Simulations

The significant potential of energy-oriented material flow simulations results on the one hand from improvements of the production planning quality and on the other hand from the untapped opportunities of simulation-based energy management of production facilities. In the past the energy consumption of production processes has been statically estimated in the planning stage with a high level of inaccuracy without considering the dependencies on various energy sources. The usual safety margins often led to overdesigned infrastructure for electrical energy and compressed air, which is accompanied by extensive wastage.

In some brownfield factories, new technologies cause a lack of transparency of the energy consumption of the future production processes. This can lead to an insufficiently dimensioned energy production or use, which reduces the reliability of the new production facilities. This risk can be avoided by a simulation-based forecast of the consumption of all major forms of energy and resources.

Beyond a better prediction, new optimization potentials can be researched with valid energy-oriented simulation models. Differences in cycle times and system failures cause inefficient waiting times and offer many variation in the material flow, which can be identified by simulation. On this basis, energy efficiency measures can be implemented while remaining throughput neutrality.

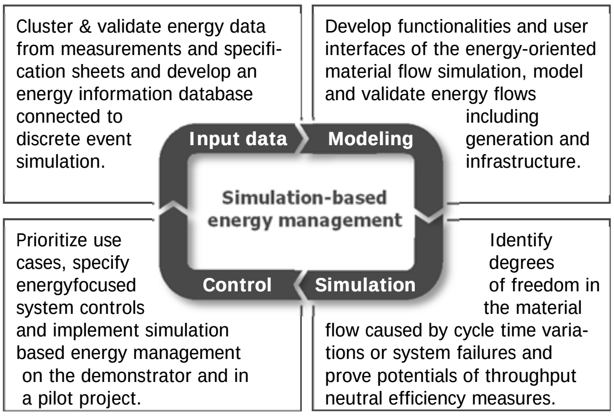

Figure 1: Fields of action of the simulation based energy management as closed loop system between physical and virtual production.

The influences of the material flow control actions on the energy consumption of production lines or entire factories can be analysed in detail. Then, decisions can be made and implemented accordingly. Systematic controls of buffer entry and storage exit strategies, which are essential for the production process, can be used foresighted into, identify periods in which power saving or standby modes are reasonable.

Results from these new measures and their evaluation promise great improvement potentials already in the planning phase of production facilities. In addition, Volkswagen pursues the vision 'Industry 4.0'. This strategy promotes the development of real time capable and intelligent networking of people, objects and systems taking advantage of all possibilities provided by current information technologies [3]. In view of the increased networking capability of production plants and the usage of sensor technologies horizontal on the shop floor and vertical in PC-based planning systems. New application areas of established software tools in the Digital Factory are conceivable [4]. Today, simulation studies in the automotive production are focussed on the factory planning process. In the future they might also provide reasonable assistance to optimize the ongoing production (Figure 1).

The efficiency potential of connected facilities by simulation-based energy-efficient and peak load controlled systems is currently not used, although appropriate communication protocols between shop floor and ERP levels have existed for years. A major barrier is the poor availability of essential simulation input data, which often still has to be measured by hand. Due to sensor technologies and connected devices this should cause no difficulties in the future.

2 Analysis of Potential Savings in the Production Areas of the Automotive Industry

The energy consumption of the automobile production causes about 20 % of CO_2 emissions throughout the life cycle of a Golf VII. Volkswagen emits about 25 % in-house while the rest falls to its suppliers. The supplier's share is 75 % because of their extremely energy intensive processes such as the production of steel, aluminium, plastics, paints, tires and windows.

The internal portion of Volkswagen is equally divided between the component manufacturing and the vehicle manufacturing. In the component manufacturing the business areas of foundry, gear drive and engine have very high energy consumptions. In the vehicle manufacturing it is the paint shop which has the highest needs. These main production areas thus offer high potentials for an energy-oriented material flow simulation (Figure 2).

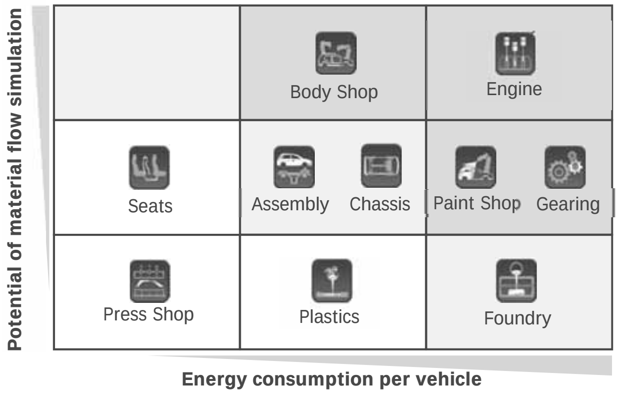

Figure 2: Potential analysis of the energy-oriented material flow simulation in the main production areas of Volkswagen AG.

However, from the perspective of the material flow they promise a different potential. The in-house material flow of a foundry has little impact on its energy consumption, while sufficient degrees of freedom for optimization can be observed in the production lines of the business fields of engine and gearing as well as in the paint shop.

Therefore, due to the complexity of the material flow in the body shop, this main production unit promises a high worthiness for simulation analysis, although the power consumption is relatively low in comparison to the complete production process of a vehicle.

Rather uninteresting for an energy-oriented material flow simulation is the press shop, which operates impressive large press lines, but their high energy consumption is compensated by an even higher productivity.

2.1 Holistic modelling of several energy sources and infrastructure levels

Before the simulative evaluation of concrete use cases it was necessary to develop further energy-oriented functionalities for the software tool Plant Simulation to model the energy flows including their generation and infrastructure. The most cost intensive energy sources in the automobile production are electrical energy and compressed air, thus corresponding use cases were selected. A distinction must be made between the infrastructure levels of the involved production facilities.

Following the successful implementation of the required functions on the level of a production line for crankshafts, the interaction between an air compressor and the high-pressure air cleaners which it supplies can be analyzed (Figure 3). The level of detail for modeling the power consumption of the compressor in relation to its internal control is as detailed as the compressed air consumers and the inducing material flow of the crankshafts. This allows an accurate dimensioning and selection of the compressors as well as a fine tuning of the internal compressor controller.

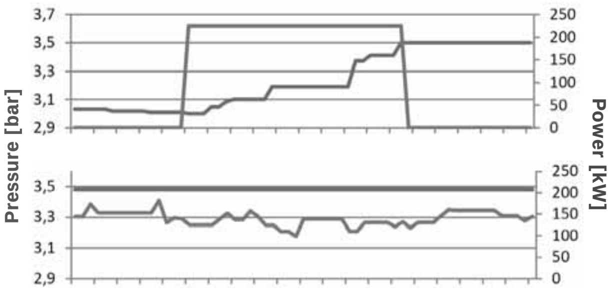

Figure 3: Pressure pattern and electrical power consumption of an air compressor plant with intermitted control (top) and continuous control (bottom).

At the level of an engine plant different control modes of an air compressor plant network can be examined by the same simulation objects. Moreover, typical problems of material flow studies can be skilfully linked with production analyses on energy-efficiency. While comparing the energy and resource consumption of a push production strategy with an alternate demand control strategy, the key figures of productivity as well as energy and resource consumptions can be reliably predicted.

2.2 Simulation based utilization of degrees of freedom in material flows

Based on the developed functionalities, degrees of freedom in the material flow can be identified and efficiency measures can be ensured. The output has to be secured because the productivity of a large-scale production is inviolable. But even in highly utilized production lines, both in component and in vehicle manufacturing, energy savings of about 3 % could be identified. Their implementation is not economical for existing production lines since the necessary control technology would have to be retrofitted.

As part of the redesign of production processes, these savings can be achieved without generating extra costs. The potential might be even higher when thinking of future fully automated small series production lines with a smaller degree of capacity utilization.

These potentials are generally based on degrees of freedom in the material flow of interlinked production lines whose plants generate unproductive waiting times, for example by different cycle times or system failures. Two types of effective control systems can be distinguished: The power saving control (Figure 4) and the peak load control (Figure 5).

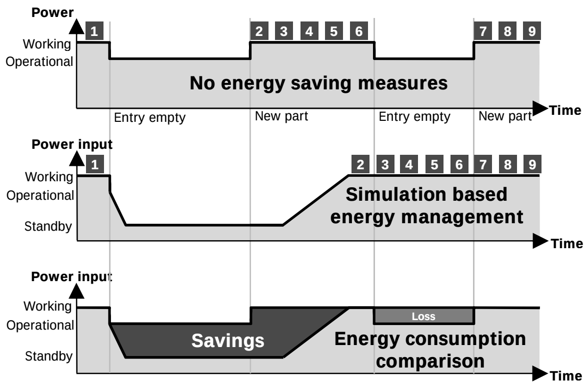

Figure 4: Potential of a power saving control system using the example of the electrical power input of a transfer line with standby-mode.

An energy saving controller tries to keep the standby breaks of a production as long as possible, without thereby generating a loss of throughput. So it is clear that such a control must not be applied to the bottleneck facility in a linked production line. After effectively shutting down, production lines typically require a start-up time, so more than one sensor at the entry and exit is needed to control the machines: The system must be able to foresee future waiting times to generate maximum energy savings [5] (Figure 4).

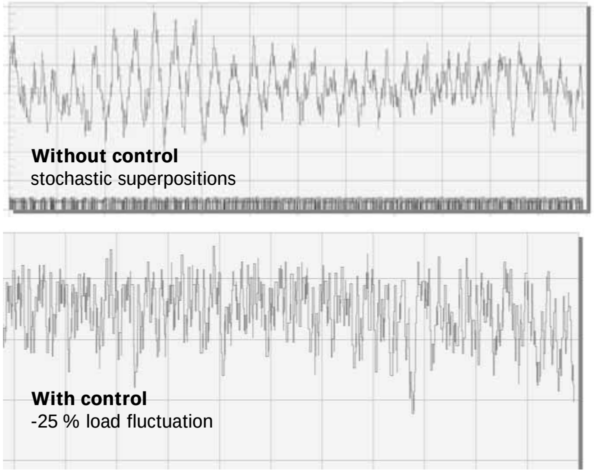

Figure 5: Savings of a peak load control using the example of the pressure profile of a crankshaft production with 20 high-pressure air cleaners.

While the power saving control causes a direct saving of electrical energy by the extension of standby breaks, the peak load control primarily aims at the process safety of a compressed air system. The target figure is not the consumption of compressed air but the load fluctuation in the compressed air network. Systems powered by compressed air often have a shorter cycle time than their corresponding production line, therefore simultaneity in the usage of compressed air can be avoided by specific delays without creating output quantity losses. Due to the secure avoiding of unfavourable stochastic superpositions of several machines, an otherwise necessary oversizing of the air compressors can be omitted. Once again savings in electrical energy consumption of air compressors can be achieved and operated in a more constant way (Figure 5).

3 Designing Decoupling Buffers in the Car Body Shop Considering Energetic Aspects

Interlinked manufacturing systems are decoupled by buffers to maintain the production. Continuous cycle time fluctuations are a crucial problem in the planning of particular clocked production plants when determining the optimal buffer size. These fluctuations and the failure of any single process can lead to the failure of the entire production system. The disturbances and failures cause a reduction of the overall system performance. The use of buffers to decouple the processes can reduce these impairments and improve the system output.

However, expenses arise for the space and the necessary technical equipment. In particular, decoupling buffers serve two main purposes: They reduce the idle time of the subsequent process by taking parts out of the buffer. Even in the case of a breakdown of the preceding section the production can be sustained. Conversely, parts can still be moved into the buffer if the succeeding production area is disturbed.

This also applies to the car body shop in the automotive industry. An entire vehicle body consists of several modules which are produced parallel to each other and assembled in the correct order (Figure 6).

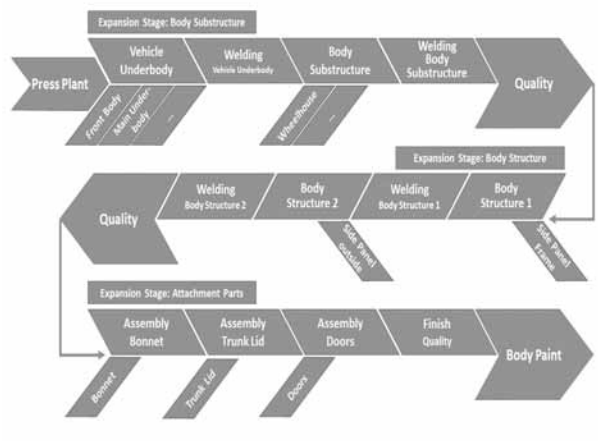

Figure 6: Sequence of a car body production [6].

The production line of one module typically consists of three to five individual production cells which are linked by defined transfer points. In current production lines of the automotive industry not every production cell is decoupled by a buffer but on average every second production unit. These buffers are quite small and can contain four to eight parts. At the end of a module production area as well as between the process steps of the main production line much larger buffers are installed with a size of up to one hundred storage units.

3.1 Building the energy-oriented material flow simulation model

With the computer-aided tools and methods of the Digital Factory, in particular the material flow simulation, the output of a production plant is proved and thus also the quantity and the size of the buffers contained can be set [7]. However, for dimensioning the decoupling buffers so far only the target figures mentioned above were considered. A setup under energetic aspects, which makes more energy-efficient production processes possible, did not take place.

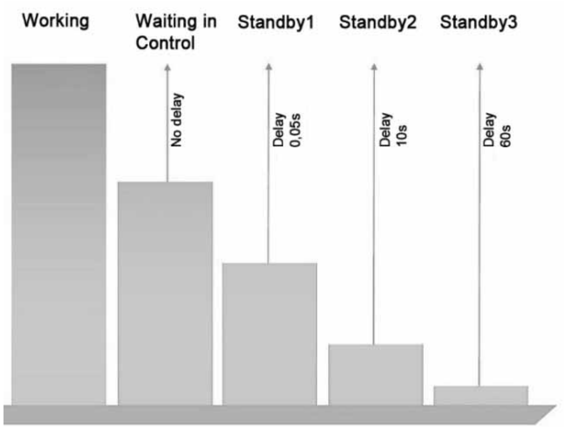

Figure 7: Energy states of an industrial robot [8].

Robots and machines in the body shop can operate more energy-efficient than it is usual today. An analysis of a current manufacturing facility showed that robots have an average of 30 % to 60 % idle times. Thus, a switch to standby or powering down at the right time can save electrical energy. Modern robots even have different standby modes which are associated with corresponding different time lengths to power up again (Figure).

Schacht [6], Brüggemann [9] and Meike [10] have proven that robots can save energy by decreasing the acceleration and the speed of movement for the same trajectory, but possibly at the expense of a longer cycle. The intensity of the acceleration has a significant impact on the total energy consumption [6, 9]. In conjunction with the reduction of speed, a local minimum of energy consumption can be observed [6, 9, 10]. Further energy-efficiency measures can be achieved by positioning the operating point (height, distance, home position) as well as the optimization of the trajectory in a "more natural and smoother" way [9].

As studies of Volkswagen AG and TUC have shown such material flow simulations are able to provide reliable energy consumption forecasts of production processes. In a second stage the usage of smart behaviour during bottlenecks due to system breakdowns will be analysed. The system can be switched to a slower but more energy-efficient operating mode and to standby. The subsidiary process and the subsequent process of the main production line were analysed with energy-oriented material flow simulations.

An initial check of each robot and machine has to clarify if it is allowed to be switched to power saving operating modes. For example, this is not allowed for trajectory-welding which must be carried out with a defined speed to meet the quality targets.

Also gluing stations may not be shut down because the glue would harden inside the station. By contrast, handling tasks or point-welding operations can be operated in several power saving modes.

These energy-oriented control options, standby and a slower but more energy-efficient operating mode, have to be implemented in an intelligent way under the premise of throughput neutrality. The following approaches have been entered into the control system:

- A cell is switched to standby if the upstream buffer is empty and it is waiting for a new part.
- If the following buffer is full and the subsequent production cell is disturbed, blocked or in standby mode, the current cell is switched to standby.
- The cell will begin to work in slow energy-efficient operating mode if the succeeding buffer reached a specific occupancy rate. It will work again at full speed, if a lower specific occupancy rate is reached.

For example, a cell with a subsequent buffer with the size of 6 parts switches the slow energy-efficient operating mode on if the buffer has stored 4 parts. It will resume work in full speed, only if 2 remaining parts are stored in the buffer. On the other hand, if the buffer works his way up to full occupancy the cell switches into standby and will be turned on again, accordingly again in the slower mode, if 2 parts are taken out by the following cell.

3.2 Results of the energy-oriented simulation studies

In the simulation studies the number of buffers, the buffer sizes and the limits for activating and deactivating the power saving modes vary. Simulation experiments without any intelligent energy state behaviour are used as reference for comparison. The maximum size of the decoupling buffers within the subassembly group is limited by the movement of the robots so that every storage place is within operating distance.

A reduction of the buffer sizes can be neglected since the buffers have already been dimensioned to achieve the intended throughput. Based on the research results of Schacht [6], Brüggeman [9] and Meike [10] the slower operating mode was set to 85 % energy consumption with a cycle time increased by 15 %. 12 observations per experiment were performed within 50 days plus 10 days to initialize the simulation runs.

Experiment	Throughput [units/50days]	Consumption [kWh]	Consumption per part [kWh]
Reference	57.459,83	279.197,91	4,859
4*/4/2***	57.015,50	260.043,92	4,561
4/4/1	57.183,67	253.529,24	4,433
5/5/3	57.577,42	260.241,04	4,521
5/5/2	57.543,42	253.622,14	4,407
5/5/1	57.603,25	253.136,54	4,394
5/4/2	57.562,00	250.479,10	4,351
5/4/1	57.633,25	249.838,91	4,335
5/3/1	57.638,58	249.061,58	4,321

Table 1: Simulation of a part of the body shop with energy-efficient strategies.
* Buffer Size, ** Slow on > =x, *** Normal mode on <= x

Overall more than 50 studies with different combinations of buffer sizes and upper and lower limits for the power saving modes were performed. Table 1 shows an extract of these results.

The first line shows the reference values without any changes of the buffers or benefits of energy-efficient controls. If the energy efficiency measures are switched on, an unchanged buffer size cannot achieve the same output. Nevertheless, in principle the energy efficient measures are working. For a decrease of 0.5 % output the energy consumption could be reduced by 8.8 %. However, with the increase of the buffer by only one unit, the energy consumption could be reduced up to 11 % with at least the same quantity of parts produced. It can be assumed that energy-efficient controls are more effective the longer they last.

4 Summary and Outlook

By the integration of existing approaches of material flow simulations with energy consumption aspects, the energy-oriented material flow simulation makes a new contribution to the ongoing development of the tools and methods of the Digital Factory. This can extend future planning processes of production facilities with the ability to dimension the technical building equipment more precisely. Through the application of power saving controls the energy consumption of production processes can be reduced while maintaining throughput neutrality. However, further research is needed to determine if the greater effort in planning and operating is cost-effective.

The prevailing pressure on productivity and costs in the automotive industry makes it difficult to test and implement innovative approaches towards a smart and more energy- and resource-efficient factory. However, given the ever increasing number of variants, customizing of individual products and further increasing energy prices, future applications are predictable.

The material flow simulation is currently almost exclusively used in the planning process. New problems arising during the operation of the plant are not analysed with existing simulation models, but are solved manually with best practice knowledge. The goal must be to utilize the simulation know-how in the current production and expand the collaboration between planning and operation of a plant. This can also help to raise awareness of the employees for a more energy-efficient production.

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Assessment of Influencing Factors in Decentralized Energy Supply of Manufacturing Industries Using Probabilistic Methods

Heiko Dunkelberg*, Henning Meschede, Fabian Stöhr, Jens Hesselbach

Department for Sustainable Products and Processes, Institute of Production Technology and Logistics, University of Kassel, Hesse, Germany; **dunkelberg@upp-kassel.de*

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Abstract. Plastics industry is the ninth largest electrical energy consuming sector in Germany. Currently, the production including the melting of plastic is electricity based although decentralized energy supply concepts using CHP units and thermal energy for melting and cooling exist. This research analyses the influencing factors 'production plan' and 'ambient temperature'. For both parameters, the influence on the decentralized energy concept and the status quo is compared. Therefore real data is used to parameterize probabilistic density functions. The system's behaviour by means of varying input profiles is evaluated using Monte-Carlo simulation. The results show that the influence of the production plan is stronger than the influence of the ambient temperature. Moreover the influence increases for the decentralized energy supply scenario.

Introduction

Considering the energy demand, plastics industry is the ninth largest electricity consuming sector in Germany [1]. The production process of injection moulded parts is very energy intensive.

Plastics industry is characterized by energy costs amounting to 1,8 % of their turnover [2]. The specific energy consumption is 0,78 MWh_{el}/t [3].

The German Association of the Plastics Converters (GKV) lists 2.800 plastic processing companies which exclusivly process plastics [4]. About one third of them are injection moulding companies. Including in-house moulders the number of companies which have their own injection moulding line is 2.300 [5].

In general, plastics processing companies use almost 100 % electricity to cope with their energy demand, excluding those companies which operate combined heat and power (CHP) systems.

Almost 50 % of the electricity is used either for the drive of the injection moulding machines or to apply clamping forces. Additional 15 % of electricity is needed for heating the plasticizing cylinder for melting the plastic as well as the hot runner system. The total energy demand for cooling is about 15 % while the system is usually separated in two cooling circuits. The first circle is used for cooling the molten plastic to 14 °C. In this case, compression chillers in combination with a dry cooler with winter relief are used. The other circle cools the machine drives and components. The temperature level is about 30 °C [6]. In Germany, dry coolers or cooling towers can be used all over the year. The remaining percentage of electricity is used for handling systems, lightning, the supply of compressed air and the drying of plastics. Depending on the material and produced product, the distribution of energy may change [7].

Current research activities focus on decentralized energy supply concepts for industries to reduce environmental impacts like greenhouse gas emissions. Schlüter describes the implementation of a trigeneration system in addition with thermal oil instead of electricity for heating the cylinders and melting plastics [6]. Dunkelberg et al. showed a thermal oil concept for extruders and its technical application as well as established the technical feasibility [8]. Wagner et al. evaluated energetically different scenarios of decentralized energy concepts in the plastic industry with focus on the link between production process and production hall [9].

The state-of-the-art design of new energy systems is based on standard load and temperature profiles.

Heat and cold generators as well as CHP plants are mostly designed in the same way by using load duration curves. Probabilistic variations of load or temperature around the years are seldom considered while extreme value scenarios like full production and highest temperature are performed. This leads to oversizing or non-optimal dimensioning.

In this research, a decentralized energy supply system for the plastic industry is investigated. To evaluate the feasibility of the concept, the production schedules as well as the ambient temperature are simulated as Probability Density Functions (PDF) to generate various probabilistic scenarios. This approach allows the determination of the resilience of decentralized energy concepts and an evaluation of the concept's sensitivity towards these two influencing parameters.

1 Methodology

1.1 Monte-Carlo Algorithm

In general Monte-Carlo methods are algorithms which use random inputs. They can be used to simulate complex stochastic models and generate data series with typical conditions and trends [10]. They are applied to different areas such as physics, economics, medicine and engineering.

The stochastic influences of technical and economic systems are often modelled by Probability Density Functions or Markov Chains. Pereira et al. analysed the Net Present Value (NPV) and produced energy cost of a photovoltaic (PV) system in Brazil based on PDF of total initial costs, interest rate and price per kWh sold to utility [11]. Nijhuis et al. used a Markov Chain approach to simulate residential occupancy figures as well as PDF of user behaviour and weather data to develop electricity load profiles [12]. Arun et al. investigated the optimal battery size for PV systems based on probabilistic electricity load profiles and a normally distributed PDF of solar radiation [13]. Further, Roy et al. developed a sizing curve for standalone wind-battery systems. Taken into account are the electricity load profile and the uncertainity of wind by Weibull PDF [14]. Sharafi and El Mekkawy used different PDF of weather data and load profiles to simulate a hybrid renewable energy supply of an apartment in Canada. Finally, they made a sensitivity analysis of various influence parameters [15].

1.2 Ambient temperature

A common procedure to generate synthetic weather data is to use Markov chain [16-19]. They are suitable to describe stochastic processes if a lot of historic data is available. An introduction into Markov chains and their application can be found in [20].

In this paper we introduce an approach using first order Markov chains to generate hourly ambient temperature time series. Based on historic weather data various transition probability matrices (TPM) are defined. They are divided by three categories: month, hourly amount of solar radiation and trend of solar radiation compared to the previous hour. The amount of solar radiation is combined in radiation classes of 100 W/m² each. A radiation of 0 W/m² forms its own class. The trend can be positive, negative or neutral. For a maximum solar radiation of 1.000 W/m² this results into 396 different TPM.

The column index of each TPM represents the temperature of the previous time step. Each element p_{nm} in a column stands for the cumulative probability of the current ambient temperature (ϑ_{amb}), represented by the rows. The principle setting of the TPM of temperature is shown in Figure 1.

$$\begin{array}{c} \\ \vartheta_{amb,1}^{t} \\ \vartheta_{amb,2}^{t} \\ \vartheta_{amb,3}^{t} \\ \vdots \\ \vartheta_{amb,n}^{t} \end{array} \begin{array}{c} \begin{array}{ccccc} \vartheta_{amb,1}^{t-1} & \vartheta_{amb,2}^{t-1} & \vartheta_{amb,3}^{t-1} & \cdots & \vartheta_{amb,m}^{t-1} \end{array} \\ \begin{bmatrix} p_{11} & p_{12} & p_{13} & & p_{1m} \\ p_{21} & p_{22} & p_{23} & \cdots & p_{1m} \\ p_{31} & p_{32} & p_{33} & & p_{1m} \\ & \vdots & & \ddots & \\ p_{n1} & p_{n2} & p_{n3} & \cdots & p_{nm} \end{bmatrix} \end{array}$$

Figure 1: Principle setting of TPM.

To generate the time series, the ambient temperature of the first hour is randomly chosen in the range of possible temperatures. Then, depending on the month, solar radiation class and trend, the corresponding TPM is selected.

With the temperature of the previous time step and randomly chosen probability, the TPM is used to generate the current ambient temperature. Finally, the time series gets corrected to reduce the variability. Therefore a simple moving average (SMA) is formed.

The pseudocode for the function $\vartheta_{\mathrm{amb}} = \mathrm{f}(\mathrm{G_h})$ is presented below:

```
for t = 1:simulation time
% determine month of the year (moy)
    moy = month(t)
% determine the solar rad. class (SRC)
% by using global radiation (G_h^t)
    SRC = G_h^t / 100
% determine solar radiation trend (SRT)
    if G_h^t - G_h^{t-1} > 0
            SRT = 1
    Else if G_h^t - G_h^{t-1} < 0
            SRT = -1
    else
            SRT = 0
    end
% find corresponding TPM
    TPM = TPM(moy, SRC, SRT)
% chose corr. column tpp of TPM
    tpp = TPM(ϑ_amb^{t-1})
% chose a random variable R = [0,1]
% determine ϑ_amb^t
    ϑ_amb^t = row(tpm = p_n) with p_n ≤ R & p_{n-1} > R
end

% perform SMA for reducing variability
for i=1: simulation time
    ϑ_amb^t = 1/5 ∑_{i=-2}^{2} ϑ_amb^{t+i}
end
```

Listing 1: Generation of probabilistic temperature profile.

To generate a synthetic time series of solar radiation an approach according to Duffie and Beckman [21] can be used.

1.3 Energy needs

For further simulations probabilistic parameter sets of the energy demand of injection moulding machines have been created. The energy demand of the machines depends on the temporal machine's state. There are four different machine states, which depend on different inputs and parameters like type of machine and melt or production programme:

- *Automatic mode*: The machine produces autonomously parts without interventions of the machine operators.
- *Manual mode:* The machine operator controls the machine. Cycle time and machine performance are specified by the operator. Compared to the automatic mode the performance is lower.
- *Alarm mode:* The machine has identified an error and is changed to the standby position. Important components are held at a certain temperature.
- *Offline mode:* The machine is switched off and does not produce.

The transition between the operating conditions of single machines has been analysed and shown by transition probabilities. The probabilistic parameter sets of the energy demands for power, heating and cold base on real data sheets of a medium sized plastics factory. Individual sets of sequences of states are generated for each machine. A part of the TPM of machines is shown in Figure 2.

	Long – runner					*... runner n*
	State 1	*State* 2	*State* 3	*State* 4	⋯	*State n*
State 1	0,18	0,80	0,04	0,00	⋯	TP_{1n}
State 2	0,65	0,90	1,00	0,97	⋯	TP_{2n}
State 3	1,00	0,96	1,00	0,97	⋯	TP_{3n}
State 4	1,00	1,00	1,00	1,00	⋯	TP_{4n}

Figure 2: Part of the TPM of machine states.

Similar machines have been classified into four different groups:

- *Long-runner*: The production time is longer than 80 % of the possible production time. The production is interrupted only by short alarm and offline times.
- *Short-runner*: The production time of the machine is shorter than 40 % of the possible production time.
- *Normal-runner-offline*: The production time is by nearly 60 %. Production is interrupted by few but long offline times.
- *Normal-runner-cycle*: The production time is by nearly 60 %. Production is interrupted by many short offline times.

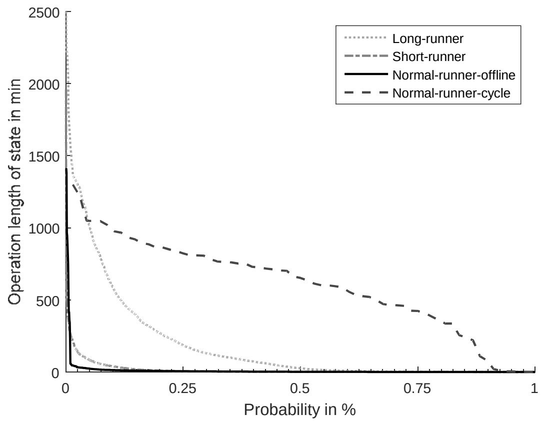

Figure 3: Runtime of the machine groups.

An exemplary description of probabilistic operation lengths for different types of machines is shown in Figure 3.

Furthermore, machines are classified into four different performance classes. The performance data results from measurements and describes the specific energy consumption and cooling needs of each machine. The process data are provided by a host-computer system.

For the parameter sets, probabilistic machine operation states are generated in accordance to the following procedure shown in Figure 4.

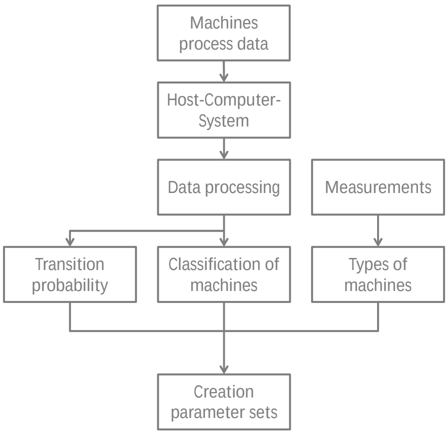

Figure 4: Procedure for creating parameter sets.

The operation states have been combined with the performances for the operation state and the machine type. As a result there are probabilistic load profiles. The pseudocode is presented below:

```
% determine number of active machines M
% of all installed machines M_set
    M = M_set ± 20 %
% initialize first state s_m^i with i = 0
    for m = 1:M
% while cumulated machine run time t_m
% shorter than simulation time t_s
        while t_m < t_s
% chose PDF of machine group and state
% chose a random variable
        R_1 = [0,1]
% determine duration of state d_m^i with
% corresponding PDF and random number
        d_m^i = PDF(R_1)
% find corr. TPM of actual state tpp
        tpp = TPM(s_m^i)
% chose a random variable
        R_2 = [0,1]
% determine new state of the machine s_m^{i+1}
        s_m^{i+1} = tpp(R_2)
% calculate energy demand vector E_m^i
% depending on state
        E_m^i = f(s_m^i, d_m^i)
        i = i+1
    end
end
```

Listing 2: Generation of probabilistic load profile.

2 Simulation Model

2.1 Description of the modules

Besides climatic and energetic input data, the simulation model consists of different modules for cooling and heating which are modelled as follows.

Dry cooler. The dry cooler (DC) uses the ambient temperature to cool down the circuit via fans. It is assumed that the installed capacity is sufficient for removing all the heat. Thus, the cooling output of the dry cooler only depends on the ambient temperature. If the ambient temperature is lower than the upper limit temperature of the dry cooler, the cooling output is equal to the cooling demand; otherwise the cooling output $\dot{Q}_{cool}$ is equal zero (equation 1):

$$6\dot{Q}_{cool,DC} = \begin{cases} \dot{Q}_{cool}, & \vartheta_{amb} < \vartheta_{max,DC} \\ 0, & \vartheta_{amb} \geq \vartheta_{max,DC} \end{cases} \quad (1)$$

The electric consumption of the dry cooler depends on the cooling output and the energy efficiency ratio (EER), which is set constant (equation 2):

$$P_{DC} = \dot{Q}_{cool,DC} / EER_{DC} \quad (2)$$

Compression chiller. The compression chiller cools down the circuit via vapour compression using electricity. Cooling output and power input are connected by the EER (equation 3):

$$P_{CCM} = \dot{Q}_{cool,CCM} / EER_{CCM} \quad (3)$$

According to Schlüter the EER can be calculated as a product of a basis EER, a factor depending on the ambient temperature and a factor depending on the cooling temperature [6]. In addition to this, a further factor is introduced to represent the dependence on the partial load performance (equation 4):

$$EER_{CCM} = EER_{basis} * \prod f_i \quad (4)$$

Trigeneration plant. The combined cooling, heating and power system (CCHP) uses a natural gas engine to generate electricity. The natural gas (NG) input depends on the partial load of the engine; the function is shown in Table 1.

	Part load			
	0 %	50 %	75 %	100 %
Fuel consumption	0 %	59 %	80 %	100 %

Table 1: Fuel consumption in part load in percent of full load value.

Furthermore the CCHP unit provides heat; either by the exhaust gas or by the cooling cycle of the engine. Moreover, the plant produces cooling via absorption chilling. Hereby, a part of the heat is converted into cooling. The functional description of the EER of the absorption chiller is taken from Schlüter [6]. Following the determination of the EER of the compression chiller, the EER of the absorption chiller depends on the ambient temperature, on the cooling temperature and moreover on the re-cooling temperature. The re-cooling temperature is calculated by the following equation with a constant efficiency η (equation 5):

$$\vartheta_{f,out} = \vartheta_{f,in} - \eta(\vartheta_{f,in} - \vartheta_{amb}) \quad (5)$$

where $\vartheta_{f,out}$ is the fluid outlet temperature and $\vartheta_{f,in}$ the fluid inlet temperature in °C.

Burner. The burner uses natural gas to provide heat. The natural gas amount is calculated by a constant efficiency (equation 6):

$$\dot{m}_{NG,burner} = \dot{Q}_{heat,burner} / \eta_{burner} \quad (6)$$

where $\dot{m}_{NG,burner}$ is the mass flow of natural gas in kg/hr, $\dot{Q}_{heat,burner}$ the thermal output in W and η_{burner} the burner's efficiency.

2.2 Analysed scenarios

Two different stages of decentralized energy supply scenarios are modelled using Matlab / Simulink. For simulation reasons, the signal routing shown in the following figures is opposing the energy flow. The first system describes the state of the art of energy supply for plastic industries and is shown in Figure 5.

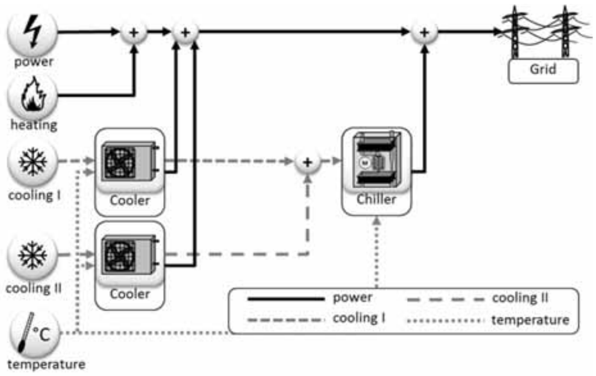

Figure 5: Signal routing Matlab Simulink model state of the art of energy supply in plastic industries.

The system consists of the injection moulding machines, demanding different forms of energy: heat for the melting, electricity for the drive, cooling for the tool and cooling for the drive. The heat for the melting is generated electrically. Due to this the heat demand is converted into an electricity demand.

The drive cooling is achieved using a dry cooler. In case of ambient temperatures higher than 11 °C the system is not able to cool down the circuit and a compression chiller provides the cooling. The cooling for the drive is realized by a further dry cooler. Above an ambient temperature of 30 °C the cooling has to be realized by the compression chiller, too.

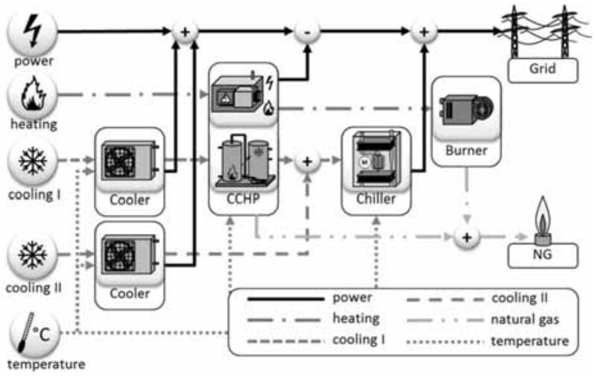

Figure 6: Signal routing Matlab Simulink model full decentralized energy supply in the plastic industries.

Instead of the electric heating of the melting process a thermal oil system is integrated in this second system (Figure 6). The thermal oil system is explained in detail in Schlüter [6]. Furthermore, a CCHP system is added which performs according to the cooling demand of the injection moulding machines.

The generated electricity is used for the drives whereas the heat of the exhaust gas is partly used for heating thermal oil to satisfy the heat demand. Together with the heat of the engine cooling circuit the other part of the exhaust gas heat drives an absorption chiller to satisfy the cooling demand of the melt in cases of ambient temperatures higher than 11°C. The compression chiller is still included as a back-up system. Furthermore, a natural gas burner is integrated in the thermal oil system in cases of less heat generation by the CCHP system. Finally the system is bidirectionally linked to the grid.

2.3 System configuration

The design of the energy supply is based on a companies' thermal and electrical load profiles. A data set for 40 injection moulding machines is generated according to the approach shown in Figure 4. Two exemplary sets of parameters are considerd and simulated. Set 1 includes only machines of type "Long-runner". It represents a factory with high machine running times which is typical for a custom moulder which produces technical components for the automotive industry. Machines of different types are simulated in set 2. It represents the industry average and corresponds to the investigated company. The distribution is shown in Table 2 and 3.

In accordance with the state-of-the-art, the CCHP system is designed using standard weather data and a standard load profile for the energy consumption. The performance of the CCHP is led by the cooling demand which has to be covered by the absorption chiller, i.e. the total cooling demand reduced by the cooling performance of the dry coolers.

	Long runner	Short runner	Normal offline	Normal cycle
Type 1	10	0	0	0
Type 2	5	0	0	0
Type 3	10	0	0	0
Type 4	15	0	0	0

Table 2: Number of machines for the system configuration dataset 1.

The state-of-the-art design uses standard weather data to determine the resulting cooling load. With regards to economic feasibility, the minimal full load hours of the absorption chiller are set to 4000 hr/y. The CHP unit is designed to the resulting heat load.

This leads to a CHP fuel input of 400 kW. The resulting absorption chilling machine (ACM) performance is approx. 120 kW_{th}. The thermal output for the thermal oil is set to 15 % of the fuel use. The gas burner is designed to ensure the remaining heat power for the thermal oil. The dry cooler and the compression chilling machine (CCM) are able to satisfy the total cooling load.

	Long runner	Short runner	Normal offline	Normal cycle
Type 1	10	0	0	0
Type 2	0	5	0	0
Type 3	0	0	5	5
Type 4	10	0	0	5

Table 3: Number of machines for the system configuration dataset 2.

2.4 Implementation of the simulation

To determine the influence of probabilistic distributed load and temperature profiles to the simulation results, the scenario analysis is divided into sub-scenarios. For this purpose the load as well as the temperature profiles have been fixed.

For this reason the parameters' influences are analysed and compared to each other. All possible combinations have been simulated. The analysed combinations are shown below:

a. fixed load profile and fixed temperature profile
b. variable load profile and fixed temperature profile
c. fixed load profile and variable temperature profile
d. variable load profile and variable temperature profile

Because of the dependence of the ambient temperature, three representative months are chosen to evaluate the results in winter and summer as well as in a transition period.

3 Results

Comparing the mentioned sub-scenarios b. and c., the results show that the influence of a variable load profile is more sensitive than a variable temperature profile. For this reason, only the sub-scenarios c. and d. are presented in the following.

3.1 Status quo scenarios

The results of the simulation runs of the status quo system using dataset 1 (only long runners) are presented in the following figures. Each figure consists of four histograms, each presenting one of the following indicators:

1. *Machines:* Electricity consumption of machines
2. *Grid:* Electricity consumption from public grid
3. *CCM:* Electricity consumption of *CCM*
4. *Primary energy:* Primary energy consumption of whole system

For the same sub-scenario, the histogram of the electricity consumption of the machines is not changing. Figure shows exemplary the distributions of the indicators for the summer season with fixed load and variable temperature while Figure 8 shows those for summer season with variable load and variable temperature.

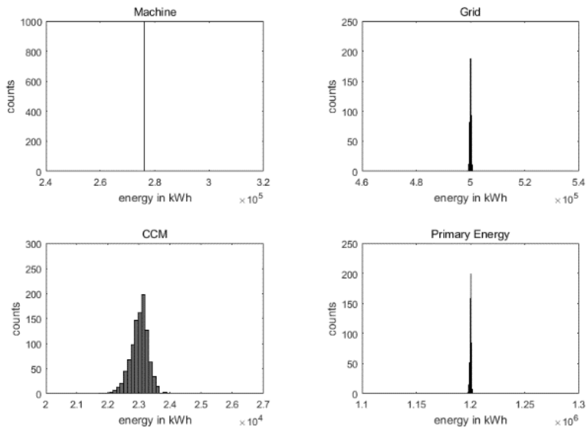

Figure 7: Distribution of indicators for summer season with fixed load and variable temperature.

It is apparent that the distribution range of each indicator becomes wider in the scenarios with variable load profile. Regarding the primary energy consumption, the range increases from 4.700 kWh to 156.200 kWh while the mean value is nearly the same (1.200.000 kWh respectively 1.208.000 kWh). This behaviour underlines the strong influence of the probabilistic distributed load profile to the simulation results.

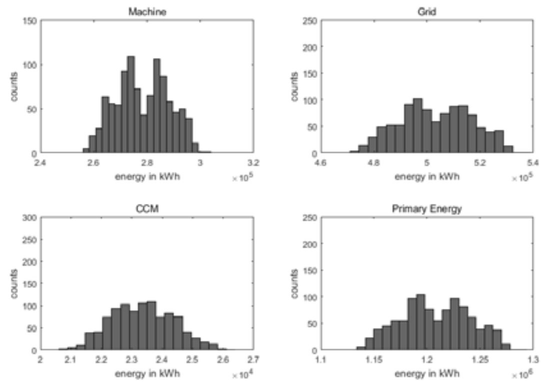

Figure 8: Distribution of indicators for summer season with variable load and variable temperature.

3.2 Decentralized energy supply scenarios

The following shows the results from the simulation runs of the decentralized energy supply with the dataset 1 (only long-runners). To evaluate the system's behaviour and the parameters' influence, six energetic indicators are used for benchmarking:

1. *Machines:* Electricity consumption of machines
2. *CCHP:* Electricity generation of CHP unit
3. *Grid:* Electricity consumption from public grid
4. *ACM:* Electricity consumption of ACM
5. *CCM:* Electricity consumption of CCM
6. *Primary energy:* Primary energy consumption of whole system

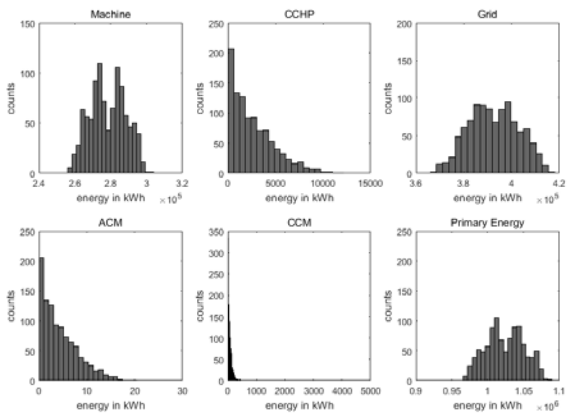

Figure 9: Distribution of indicators for winter season with variable load and variable temperature.

The results of chosen sub-scenarios are shown in figures consisting of six histograms, each representing one indicator. For the same sub-scenario, the histogram of the electricity consumption of the machines is not changing. Figure 9 shows exemplary the distributions of the indicators for the winter season with variable load and variable temperature while Figure 10 shows those for summer season with variable load and variable temperature.

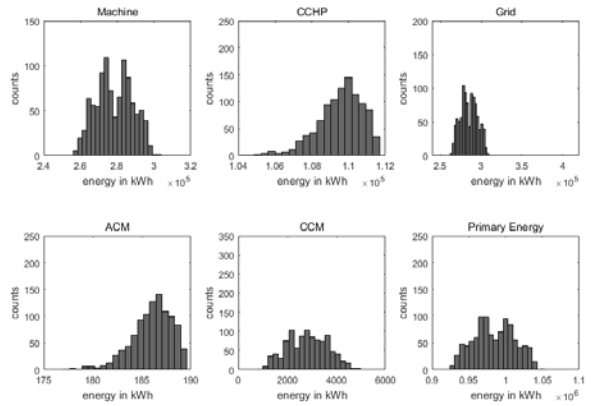

Figure 10: Distribution of indicators for summer season with variable load and variable temperature.

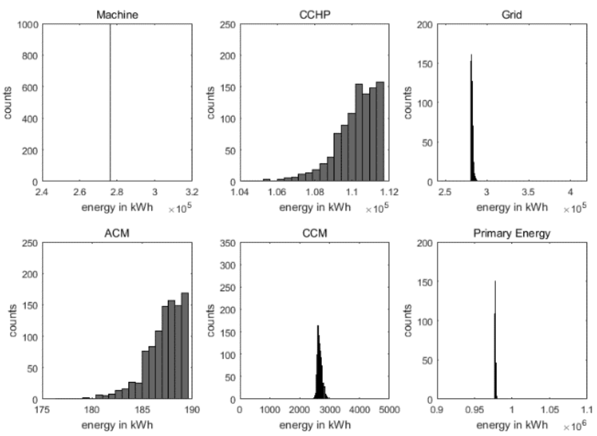

Figure 11: Distribution of indicators for summer season with fixed load and variable temperature.

In all simulated scenarios it is obvious that during the winter season the electricity consumption from public grid is at the highest level compared to the other periods, although the electricity consumption for the compression chiller is at its lowest level close to zero.

The comparison of the primary energy consumption of both seasons underlines that from a holistic and systemic point of view, in such a system the utilisation of the CHP unit instead of the operation of dry coolers is preferred because of the reduced electricity consumption from the grid. Furthermore, the comparison between both scenarios shows that in any case the decentralized system has significant primary energy savings. The primary energy factor for electricity is 2.4 and for gas 1.1 [22]. Especially the factor for electricity might change with higher share of renewable energies in the grid.

Comparing the distribution of indicators for summer season with variable load and variable temperature with those of summer season with fixed load (shown in Figure 11) allows the evaluation of the sensitivity of the influencing parameters.

The mean value of the CHP unit's electricity generation shifts slightly to the right. The same happens with the mean value of the absorption chiller's electricity consumption. This behaviour underlines that the full load hours of both systems increase by using a fixed load profile. Regarding the design process of the CHP unit shows that the utilization of standard load profiles can lead to an oversizing of the system. That means that the ACM and the CHP as well may not work at the optimum operating point.

Considering the three indicators electricity consumption from the grid, electricity consumption of the compression chiller and primary energy consumption of the whole system, the comparison of Figure 10 and Figure 11 illustrates that the range of these indicators become smaller while the mean values are nearly the same. In detail, for the single indicators the width of the range changes from 130.700 kWh to 2.810 kWh (primary energy), 4.059 kWh to 490 kWh (compression chiller) and 47.930 kWh to 7.480 kWh (consumption from public grid). This behaviour shows that the influence of probabilistic load profile is higher than the influence of probabilistic temperature data.

Comparing the simulation results of dataset 2 with dataset 1 it is obvious that there is an influence by the machines types to the results. The distribution is similarly to the distribution of dataset 1. It can be seen that the mean of the distribution is shifted and the width of range is smaller. For example for summer seasons the mean changes from 984.700 kWh to 961.000 kWh (primary energy). The width of range changes from 130.000 kWh to 94.300 kWh (primary energy).

4 Conclusion

The influence of probabilistic data on decentralized energy supply systems for the plastic industry depends on the parameter and the season. The highest influence is in the summer season. Furthermore, a probabilistic distributed load profile affects the result stronger than varying temperature profiles. In comparison to the results of the status quo system the influence of the parameters in the simulation of the decentralized system is stronger. For example, the change of width of the primary energy consumption from sub-scenario fixed load and variable temperature to both variable profiles is 33,23 % for the status quo but 46,51 % for the decentralized system.

The investigation shows also that the state-of-the-art design process of such energy systems allows good and fast results. Nevertheless, the Monte-Carlo simulation underlines that the designed configuration is oversized in some cases. Furthermore, in respect to extreme value scenarios, the Monte-Carlo simulation indicates the probability of such events and that these scenarios occur very rarely for short a time period.

On going research focuses on the transferability to other sectors with different influencing factors is examined. It is also considered how the presented approach can be applied for large scale energy systems with more than one consumer.

Furthermore, the data provided by measurements and the computer host system could be replaced by a previous simulation models. To get the PDF of the energy needs this model has to consider probabilistic inputs, too.

5 Acknowledgments

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Allocation of Greenhouse Gas Emissions for Containers in Multimodal Transshipment Terminals using Simulation

Uwe Clausen*, Moritz Poeting

Institute of Transport Logistics, TU Dortmund Unversity, Leonhard-Euler-Str. 2, 44227 Dortmund, Germany;
*clausen@itl.tu-dortmund.de

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Abstract. The assessment of emissions caused by logistics operations in general and their allocation to individual customers in particular are major challenges for logistics service providers. Presently, numerous standards and guidelines exist (e.g. ISO 14064-1, ISO 14065, DIN EN 14040, DIN EN 14044, DIN EN 16258, PAS 2050) for the calculation of Greenhouse Gas (GHG) emissions caused by logistics processes. To support container terminal operators to determine their emissions, we use simulation to allocate overall emissions in a container terminal to a single container handling. To approach this goal, at first this paper describes the measurement of energy consumption from the handling equipment. After that, the paper shows the simulation approach to allocate the emissions.

Introduction

The climate change and its numerous negative influences to the development of weather are ascribed to the emission of greenhouse gases (GHG), especially carbon dioxide (CO_2). Those are identified as climate-damaging. To reduce these emissions and to counteract to the climate change national and international arrangements are made.

Since the global emission is growing continuously, Germany reduced its emissions in total to the target values which were assigned in the Kyoto protocol. Umweltbundesamt states that the transportation sector reduced its emissions since 1990 by 5.1 %.

The overall GHG-emissions of Germany's economy sectors were reduced by 21 %. In contrast to transportations, manufacturing reduced its emissions by 34.9 % in the same time as well as private households by 33.1 % and the energy sector by 14.8 % [22]. Those numbers show the minor ratio of transportations concerning the reduction of CO_2-emission. If only transportation is considered the emission is even increased by 13 % regarding 1995 to 2010 [21].

Transportation is a substantial sector regarding the GHG-emissions and got a ratio of 20 %. Only the energy sector got a higher impact to the total GHG-emission. So, realization of successful arrangements becomes essential. The increasing GHG-emission caused by transportation is not only obvious in Germany. It is also globally identifiable. Statistics, published by the Organization for Economic Cooperation and Development show that the total amount of GHG-emission declines from 1990 to 2007 by 2 % but on the other hand they increased by 45 % in the transportations sector [17]. Also, the European Comission verifies this trend. Even though greenhouse gas emissions from transportation started to decrease in 2008, they still exeeded the target emission from the 2011 Transport white paper target by 67 % in 2012 [9].

A reason for the difficulties to reduce GHG-emissions concerning the transportation sector is the continuing growth of transport volume. Especially the freight traffic via road grew in recent times while simultaneously other modes of transport lowered their volume of ton kilometers.

This claims an analysis of Bundesverband Güterkraftverkehr Logistik und Entsorgung (BGL) e.V., illustrated in Figure 1. The analysis shows the distribution of ton kilometers concerning the modal split in freight transportation.

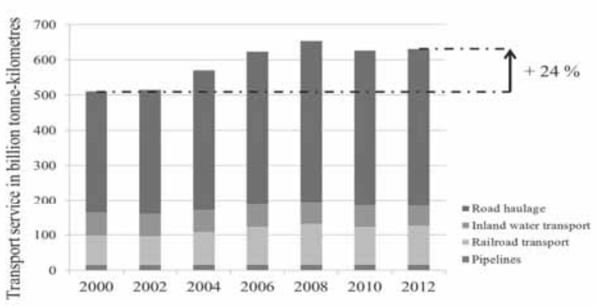


Figure 1: Modal Split.

Remarkable is that road transportation showed an allover volume share of 70.5 % ton kilometers. This is a plus of 24 % in comparison to the modal split share in 2000 [1]. This leads to higher increase of GHG-emission caused by the transportation sector. A chance to counteract that trend is to shift road transportation to other modalities. This is called modal shift.

Modal shift aims at reducing the amount of road transportation and replace it with rail or barge transport. The main concept includes continuous transport using different modes of transportation in a single load unit from source to sink. But unnoted which kind of modality is chosen for transportation it will cause GHG-emission.

It is necessary to allocate emissions caused by operations along the transportation chain. This is already possible for individual transportation modes. The emissions of related handling operations are usually estimated on the total consumption data of the whole facility. Information of handling emissions of loading units is insufficient. Regarding these circumstances, a detailed calculation of emission data is required to be able to allocate CO_2-emissions for handling operations in multimodal container terminals.

In this article an approach is presented to evaluate GHG-emissions of container handling procedures in multimodal container terminals precisely.

1 Related Works

1.1 Allocation of GHG-emissions

Balancing GHG Emissions (which means CO_2, CH4, N2O, HFC's, PFC's, SF6) is called CARBON FOOTPRINT and is part of the ecological balance sheet.

This ecological balance sheet is an instrument which allows calculating emissions of different products (goods and services) to make them comparable. The Norms [5, 6] contain principles and examination framework for environmental accounting as well as methodological requirements for performing environmental accounting measures. The ecological balance sheet refers to environmental aspects and environmental effects which occur during product life cycle, originating from raw material about production, application, waste treatment to final disposal. According to the used method for impact assessment there can be considered up to fourteen impact categories. One of these categories is GHG-capability.

Detrimental in developing an ecological balance sheet is that even simple systems require a large data base which causes remarkable acquisition effort. Therefore, systems need to be simplified to minimize data needs. Though results do not reproduce an accurate image of the current situation, logistics carbon footprint can be determined for a product (good and service) as well for companies, a location, an organization or various transport services. Several methods, norms, guidelines and studies [13, 16, 20] exist which set branchspecific basic conditions for assessing logistic processes and systems.

A norm for calculation and reporting of energy consumption and GHG-emissions of transport services (freight and passenger transport) has been initiated by the European Commitee for Standardisation (CEN) in 2008 [6]. The norm contains a standardized procedure for determining GHG-emissions for every of transport (road, rail, water and air traffic) along the entire supply chain (from shippers to forwarding agent and freight carrier up to subcontractors) and furthermore guidelines for standardized documentary. Additionally, it contains recommendations for determination of an adequate database. At least the user is free to choose individual measured values, vehicle / route specific average or fleet values of transport service provider and defaults of database, although results differ in degree of detail.

However, those standards do not contain administrative or supportive operations (e.g. production planning- and control process, maintenance, disposal) and stationary processes, like internal handling operations, so that essential elements are not included in balance results.

Basically, GHG-emissions of stationary logistic processes at multimodal logistic hubs are caused by following factors:

- Power consumption of handling facilities, terminals, storage areas or offices
- Heat energy consumption
- Further used energy sources (e.g. gas, diesel fuel) for additional equipment like Reach Stackers, other terminal crafts or forklift trucks.

Since stationary processes were explicitly excluded in the currently existing standard EN 16258, in accordance with the Greenhouse Gas Protocol, the direct GHG emissions which occur through combustion of fuels as well as through occupation of electricity and heat are determined by using formula (1).

$$GHG = EC \cdot EF \qquad (1)$$
$$EC: Energy\ Consumption$$
$$EF: Emission\ Factor$$

Due to missing valid energy consumption data of multimodal handling terminals calculation is needed to be based on approved sources and estimations of energy consumption. Standards, guidelines, literature, manufacturer information and company details may be considered. However, sources do not provide consumption values for every single functional unit and existing information exclude terrain conditions or terminal layout within consumption data. This contribution points out in which way energy consumption values are allocated on loading unit level by using energetic simulation based on selective measurements energetic simulation in combined transport simulation is a preferred instrument for examination and evaluation of operations in course of time within multimodal handling terminals [8, 14, 15].

1.2 Simulation of energy consumption in multimodal transport

Simulation solutions for holistic depiction of multimodal terminals have been developed by authors of previous articles. Those simulation solutions, based on material flow oriented simulation software *Enterprise Dynamics*, contain solutions for detailed planning of terminal systems as well as a low-level detailed solution for draft planning of multimodal handling terminals.

Those solutions contain modules for depiction of multimodal terminals and mathematical heuristics for optimal control of handling equipment, allocation of loading points and yard-management [3, 4, 10, 11, 12] or simulative descriptions of Carbon Footprints in supply chains or great logistic networks [18, 19].

As shown in those papers, current existing research projects and solution approaches in case of energetic simulation focus transport and exclude handling facilities or consider them only on abstract level.

Regarding the fact that stationary processes cause 25 % of total CO_2-emissions in transportation an approach for detailed consumption analysis on loading unit level is required [13]. Current available simulation solutions are not able to determine GHG-emissions of handling processes. Several simulation approaches considering consumption values for single handling equipment such as floor conveyors. Since these approaches do not include different ambient conditions like topographical characteristics as well as empty or loaded run, this paper considers integration of those aspects to simulation environments for multimodal handling terminals.

2 Solution Approach

The presented project is based on a former developed method kit to evaluate GHG-emissions for various transportation modalities. In this project research is focused on the emissions of handling operations in multimodal container terminals. Therefore, five work packages are defined. To meet a high level of accurateness simulation is used to evaluate emission data for different terminal layouts. The estimated values are the system load for the simulation independent CO_2-method kit which is developed in *Microsoft Excel*.

The approach contains a current state analysis. In this step the multimodal container terminals of the industry project partners are analysed concerning layout, modal split and handled loading units. Furthermore, throughput, utilization and seasonal deviations are calculated individually. Depending on the modes of transport the container terminal can be divided into various functional areas according to the connected modalities. This paper focuses on bimodal and trimodal terminal layouts. Figure 2 illustrates all functional areas in a schematic layout.

At second the evaluation of consumption values of various handling equipment of container terminals is concerned. In this case specialist literature is studied and data of manufacturers of handling equipment are collected. Furthermore, all data and information are validated and complemented.

Therefore, measurements are done which record the consumption for an exemplary early shift. Those measurements take place at the multimodal container terminal facilities of project partners.

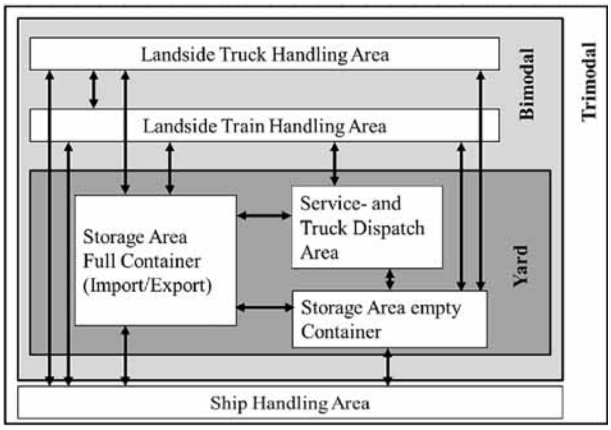


Figure 2: Functional areas of a container terminal.

In the following, consumption affecting factors are determined by deductive analysis. The objective is to higher knowledge about all relevant factors or technical specifications which influence the energy consumption of specific handling equipment. Various discussions during the project about the results lead to the ability to identify emission causing factors of handling operations in terminal layouts. The evaluated results are categorized and furthermore presented to all project partners to evaluate relevant influencing factors.

In recent times the Institute of Transport Logistics developed a tool to run simulations for handling facilities within combined transportation chains. This tool is focussed on simulation and is complemented by a module which allows the evaluation of GHG-emissions. This is an event-driven and module based simulation which maps multimodal container terminals including all stochastic interdependencies of different functional areas in an experimental model. For that purpose, various, appropriate to all evaluated emission causing factors, facility models are analysed by scenario technique. On this way system load for each scenario is generated. Based on those and by help of a key performance indicator catalogue the GHG-emissions are possible to allocate accurately for each loading unit.

The results of all described working steps are gathered in one module for multimodal logistics hubs. This is an advancement of the already existing determination tool for GHG-emissions among the entire transportation chain of containers.

With help of this module it is also possible to evaluate the GHG-emission of a specific terminal layout by filling in all relevant KPI's. The decision to choose *Microsoft Excel* to develop that method kit is obvious since the first version of this GHG-emission method kit was based on it and *Microsoft Excel* is the most common program, even in small companies, which don't have to invest a lot to gain benefits from such a method kit.

3 Integration of Measured Values into the Simulation Environment

Due to a missing reliable database for energy consumption values of container handling instruments, first of all such a database is meant to be developed. For that purpose, numerous measurements are made at various handling facilities which use different models of gantry and quay cranes of different ages. Those measured values are data load for crane modules in a container terminal simulation. Furthermore, within all measurements a detailed process analysis is realized which is synchronized to the energy consumption analysis to allocate consumption values to single process steps. A whole handling cycle consists of process steps which are shown in Figure 3.

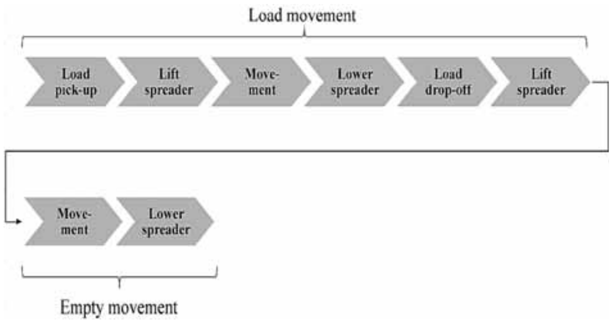


Figure 3: The processes of crane operation.

The illustrated process chain starts with an empty run to reach the next loading unit which requires handling. After positioning above of the loading unit, the spreader is lowered. By closing twist-locks or grippers the crane picks up the loading unit and lifts, to move it to its dedicated position. Once the crane arrived at the loading unit final position it lowers the spreader and reopen spreader or grippers to drop off the loading unit. Finally, the crane lifts the spreader again and is now available for another handling process.

The measured effective power is allocated to all process steps on a secondly basis and can be integrated in all events in the crane module of the simulation environment. The determination of all GHG- emissions during the transshipment process requires a simulation tool that reflects all subprocesses in an appropriate level of detail.

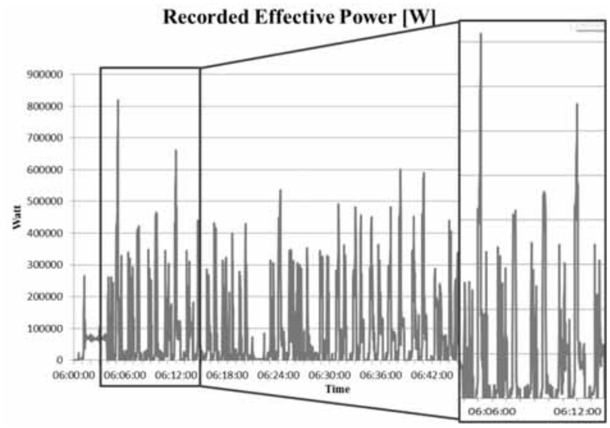


Figure 4: Record of Consumption.

TerminalSim is applicable in that case. It is based on *Enterprise Dynamics* [12]. TerminalSim is a Low-Level-of-Detail simulation solution for container terminals which contains parameterized modules which are able to map all functional areas of multimodal handling facilities. *TerminalSim* is integrated to a standard data base connection to provide quick modelling and analysis of different simulation scenario. This allows parameterizing automatically, executing and evaluating each scenario. All crane modules in *TerminalSim* are expanded by all results of energy consumption measurements [2]. Those values demonstrate differences for energy consumption of cranes regarding their construction year (Figure 4). New and modern cranes with or without energy recovery have lower energy consumption as cranes with an age between one and ten years. Cranes which are older than ten years show the highest values of energy consumption.

To get an idea of the emission causing factors in multimodal container terminals it is essential to seek after all parameters of the cycles in the recorded shifts. Basically, it is the aim to get results for energy consumption data per loading unit. In this context, the parameters of all loading units should be classified to identify emissions of loading units with different technical specifications, weights or handling durations.

Definition of weight classes. Therefore, all loading units are classified to different weight classes to group them and in case to show allocation of emission for each weight class. To be able to analyse all loading units regarding their weights, classes are defined. On that basis all loading units can be assigned to on weight class. Those weight classes are named by the type of loading unit plus the number for the individual weight class.

Type	Name
20 feet	20‘
40 feet	40‘
45 feet	45‘
High-Cube	HC‘

Weight	Name
empty	CT + 1
0 < t <= 10	CT + 2
10 < t <= 20	CT + 3
20 < t	CT + 4

Figure 5: Container classification.

Figure 5 gives a schematic overview about the definition of classes. Furthermore, those classifications also exist for trailers. In case of trailers, handling in terminals the classification of the loading units regarding their weight is similar and the weight classes remain.

- Example: a 20 feet sized container which carries 21 tons is defined in container class 204

Definition of distance classes. Furthermore, the covered distance for each handled loading unit is focussed to identify possible influence to GHG-emission. Therefore, the covered distances of loaded and empty tours are important for the analysis. Similar to the weight classification also those distances are grouped to distance classes which are able to be examined regarding their GHG-emission.

Relation	Distance class
Distance loaded	EL
Distance empty	El
Distance Cycle	Eg

Distance	Class
< 20 m	ET +1
20 m < x < 60 m	ET +2
60 m < x < 100 m	ET +3
> 100 m	ET +4

Figure 6: Distance classification.

In contrast to the weight classes it is beneficial to specify the distances of each handling cycle more detailed. Basically, the total distance of a single handling operation can be separated into a distance covered with load or without load. Within the analysis both components are defined as separate class (Figure 6). Class *“EL”* represents the covered distance with load and in contrast to that *“El”* represents the distance which is need to covered empty.

This detailed classification is essential, since both distances can differ a lot in one full cycle. It is possible that a resource covers a huge distance loaded and just a very small distance unloaded because the next loading unit is waiting right next to the previous drop-off position. Of course, the situation can occur vice versa. Since the distance is surely an emission causing factor it is part of this analysis to identify if there is a difference in loaded and unloaded movements.

Analysis of energy consumption. Before evaluating the average energy consumption to achieve a statement regarding the GHG-emission of handling operations in multimodal container terminals the key figures which describe the measuring span should be evaluated. Based on those data the average consumption can be identified.

To get this measuring span every terminal is analysed concerning

- Amount of container classes
- Distance classes per loading unit
- Total consumption and consumption per type of loading unit
- Consumption depending on covered distance and weight.

Amount of container classes. For each container terminal where measurements were done statistics state the distribution of the different kinds of unit loads. Those data give a quick overview of the container or trailer mix which is representable for daily operation. In Figure 6, a sample is developed to show how the mix of loading units was mapped.

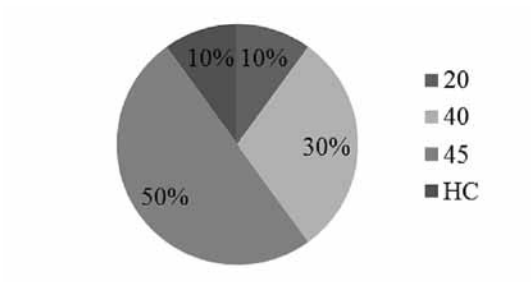


Figure 6: Share of container classes (example).

All those basic parameters about the mix of loading units need to be analyzed in detail. Since a point of concern is the average consumption depending on the weight of a loading unit it is also essential to know the distribution according to the defined weight classes.

Those overviews allow evaluating the representative-ness of the recorded consumption values. By considering the size of all single samples, it is possible to identify outliers or average values. Figure 7 shows a sample distribution in a specified container weight class.

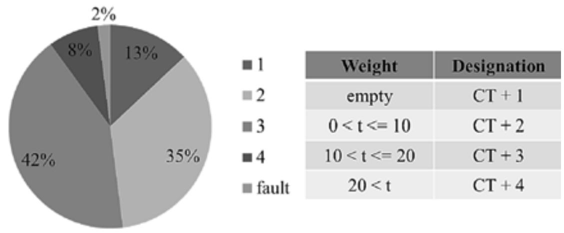


Figure 7: Share of container.

Distance classification. To evaluate more consumption causing factors a point of concern is furthermore the covered distance while handling operations in multimodal container terminals.

After discussions with project partners and operators of container terminals, the distance of the handling operations was identified as possible factor. Taking this into account, an analysis based on the covered distance is meant to turn assumption to statement.

For that reason, each kind of loading unit is also considered according to their individual distance. The distances of the cycles are grouped to specific classes, such as the weight classifications (Figure **8**). Furthermore, useful classes were defined to get a detailed insight to the distance depending energy consumption.

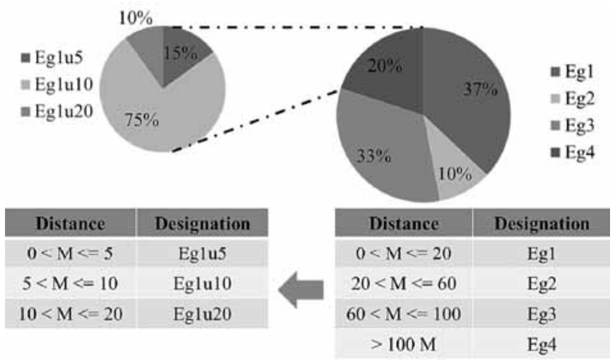


Figure 8: Distance classes.

4 Allocation of Energy Consumption with Simulation

In the course of this paper, total consumption of multi-modal handling facilities are aimed to be allocated on loading unit level by considering dependence of different parameters. This is realized using simulation methods.

For this purpose, specific simulation models, based on identified parameters, are developed. Those models are useful to derive consumption values for different handling situations. This is essential, since process analysis is done only for exemplary early shifts and those values do not represent general conclusions regarding handling volume and loading unit structure.

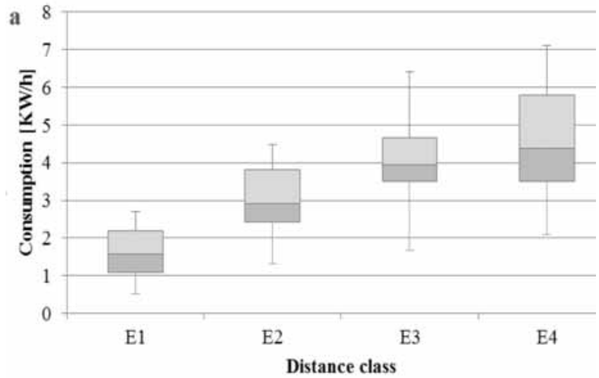
To ensure provision of long term oriented (> 1 year) consumption values, simulation is needed to display consumption by simultaneous allocation on loading unit level.

Content of this article are results of the first analyzed terminal. The considered terminal is equipped with a gantry crane and various reach stackers for trimodal handling operations. The handling area got a length of 420m and is 135m wide. This area is completely covered by a gantry crane. Furthermore, the area consists of a quay side handling area for container vessels, a container depot, 4 tracks for trains which cover 350m length and loading areas for trucks. All handlings from landside to seaside area and vice versa are done by the gantry crane. In opposition loading and unloading of trains hat the railroad tracks are advised to the reach stackers. The crane only supports the reach stacker units only in case of free capacities or meeting acceptance.

The terminal handles TEU 150.000 per annum. Here, the contribution focusses the handlings proceeded by the gantry crane. Reach stackers are included in this project at later stage. Duration handling operations of the gantry crane, backing-in times of trains and trucks are captured as well as provisioning time of trains and the time of arrival and departure of every ship during one week of employees of the terminal. Based on these measurements, stochastic distribution functions were defined and implemented to the simulation model as element for time consumption.

Based on historical values a data set of 2014 is considered to include seasonal effects in simulation. In the next phase 50 simulation runs are executed. By discussion with experts, at the handling facilities location, the results were validated.

Simulations as well as measurements state no influence to energy consumption by the weight of loading units in handling operations. A remarkable influencing factor is the handling distance of loading units. The result of analysis shows a high influence of moving distance to energy consumption of gantry cranes. To get those results more detailed, distance classes are defined according to an ABC-analysis approach. Figure 9 show results of different distance classes. Consumption is increasing according to distance.



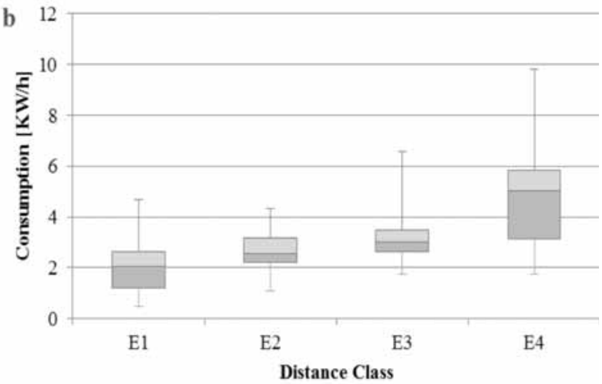


Figure 9: Consumption per Distance class for 20-Feet-Container (a) and 40-Feet-Container (b).

- Class E1 - up to 20m
- Class E2 - 21m to 60m
- Class E3 - 61m to 100m
- Class E4 - more than 100m

Based on the results of simulation and furthermore by including environmental influences and especially relocations, following consumption values were identified (Table 1).

Container	Ø-time	Ø-KWh	Ø-€/KWh	Ø-KG CO_2/KWh	Ø-distance[m]
20“ empty	0:02:58	3.65	0.40	1.56	88.84
40“ empty	0:02:47	3.09	0.34	1.32	66.68
20“ light	0:03:00	4.02	0.44	1.72	124.14
40“ light	0:03:30	3.48	0.38	1.49	84.60
20“ medium	0:02:50	3.14	0.35	1.34	180.35
40“ medium	0:05:51	3.63	0.40	1.55	72.06
20“ heavy	0:03:00	4.19	0.46	1.79	95.23
40“ heavy	0:02:42	3.82	0.42	1.63	123.99

Table 1: Allocated energy consumption on container-level.

On average a single container handling cost € 0.40 and emits 1.55 kg CO_2 which corresponds to the ecological balance sheet. This proofs the simulation approach as valid. By use of this presented method it is now possible to allocate more precisely emission values for single types of loading units. This provides numerous advantages for terminal operators in case of marketing, optimization or differentiated accounting activities.

5 Conclusion

Within this research project power consumption and influencing factors on multimodal transhipment terminals have been identified. The results showed that handling distances are the most influencing factors regarding energy consumption. Hence, to save energy and costs it is necessary to reduce handling distances. Secondly, the results showed that relocations are an important factor that should be reduced. Each relocation action is causing additional energy consumption.

In further steps, the results will be expanded to cover additional resource consumption values and terminal layouts. Furthermore, nonspecific terminal resources e.g. lighting systems will be added.

The results are being integrated in the *Microsoft Excel* based CO_2-allocation tool and extend the existing CO_2-method kit to empower sme logistic service provider to determine GHG-emissions of handling operations in multimodal container terminals.

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Simulation Study on Flexibilities in the Material and Energy Flows of an Open-pit Mine

Johannes Stoldt[1*], Christin Fanghänel[1], Hans Rüdiger Lange[2], Andreas Schlegel[1], Thomas Woldt[3], Matthias Putz[1]

[1]Fraunhofer Institute for Machine Tools and Forming Technology IWU, Reichenhainer Strasse 88, 09126 Chemnitz, Germany; *johannes.stoldt@iwu.fraunhofer.de

[2]Innovationsregion Lausitz GmbH, Goethestraße 1, 03046 Cottbus, Germany

[3]Vattenfall Europe Generation AG, Vom-Stein-Straße 39, 03050 Cottbus, Germany

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Abstract. The progressing introduction of renewable energy sources (RES) in the energy system creates an increasingly difficult market environment for traditional utility companies. While their fossil-fueled power plants are important to secure the supply of electricity, the associated operations are costly and energy intensive.

This paper presents a simulation study on an open-pit mine (OPM), where flexibilities are sought for increasing the operator's overall energy efficiency. For this purpose, the OPM's material flows and energy flows are simulated simultaneously. Drawing from discrete production systems in a "cross-learning" approach possibilities for and adjustments to the process control are investigated. Preliminary results show that some opportunities to increase efficiency exist but still require more scrutiny.

Introduction

Climate change as well as rising prices for natural resources along with the limited availability of the latter prompted the EU to implement the "2020 climate and energy package." The intention of this piece of legislation is to drastically improve energy efficiency, increase the share of renewable energy sources (RES) and lower the emission of greenhouse gases [1]. Due to this package and other national political changes (e.g. Germany's nuclear power phase-out) the share of RES is steadily rising. Such changes bring about fundamental changes to the market, most importantly volatility in energy supply. Yet, in all of the 27 EU member states together, lignite (coal) is still an important primary energy source with a share of about 1/10th (as of 2012) [2].

This share is even greater in Germany (≈ 1/4th) and Greece (≈ 1/2) [2]. These numbers show how significant lignite-fired power plants (LFPP) still are in energy systems which rely increasingly on RES. This is especially true in periods when the natural availability of RES is limited.

The lignite required for the LFPP is procured from energy intensive open-pit mines (OPM). This dependence and the associated costs are an important issue for OPM operators – traditional utility companies. Technical and physical efficiency potentials have been nearly exhausted by an ongoing process of incremental improvements. Thus, the next lever, which could be used, is the control over the interaction of individual elements in the LFPP-OPM-system. To this end, available and exploitable flexibilities have to be identified first.

Vattenfall has made a point of implementing various measures to increase flexibility in the production as well as the load management in their OPM operations [3]. Thus, the underlying knowledge of the system can serve as the starting point for further analysis.

By means of discrete event simulation (DES), the work presented in this paper aimed to identify and assess available flexibilities in a specific OPM. A premise to this work was that mining operations could be regarded as both suppliers and consumers in the energy system. Hence, time-related improvement measures were deemed the most promising in terms of improving costs and process quality.

In the following, the concept of the simulation study is discussed in detail. Section 2 introduces an analysis of the system and Section 3 presents the implementation of the DES model. Finally, an overview of considered indicators and executed experiments is provided.

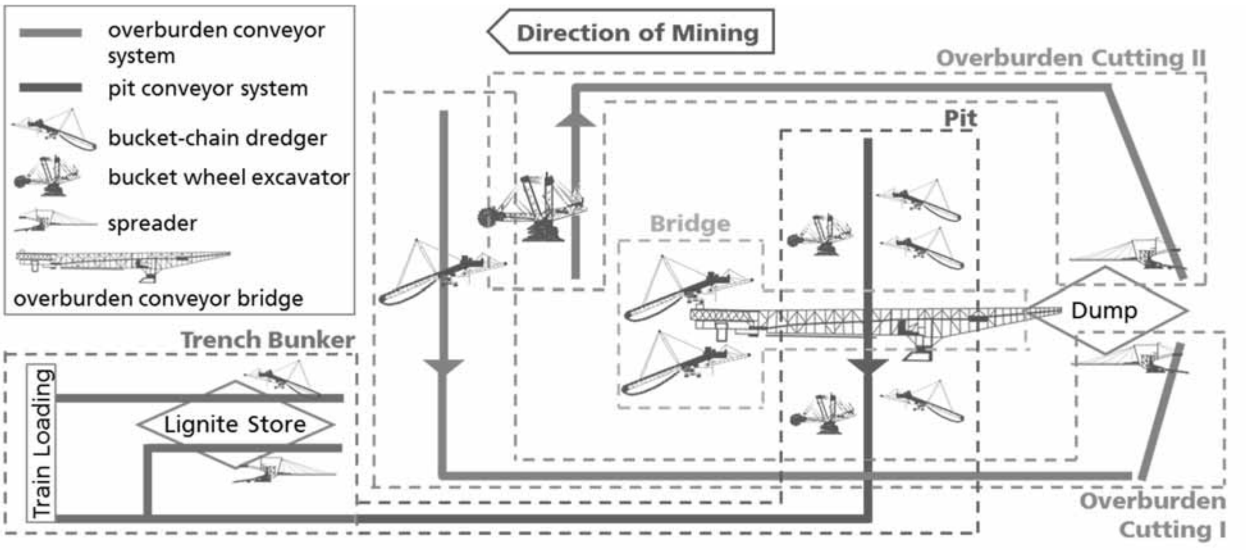

Figure 1: Layout and production process of Welzow-Süd open-pit mine.

1 Concept of the Study

DES was the enabler in this study to analyze the complex dynamics of the selected OPM using a deterministic model. In particular, the interrelations between various flexibilities and existing influences (e.g., personnel deployment, just-in-time lignite deliver, energy procurement, maintenance tasks, breakdowns, or weather risks) were to be evaluated. Eventually, the knowledge gained will serve to derive new control strategies for the OPM, which exploit available flexibility. Some previous papers discussed the use of DES for earthwork and mining processes as well as fleet management in such operations [4-7]. [8] reports on a simulation study in which a mining process was modelled mathematically but with little regard the short-term interactions of different pieces of equipment. A similar study with a greater focus on energy consumption is presented in [9]. The study presented here is new in that it regards the flow of material and energy in equipment over time in a single model.

Besides the possibility to also use probabilistic models in the future, DES was selected because an OPM can be likened, in many regards, to a clocked production line usually found in the automotive industry. For instance, most operating data is collected in a discretized manner so that the management view on the system is comparable (e.g. m³/h instead of units/h). Similarly, lignite can only be delivered if all prerequisites (e.g. functionality of all coupled machines as well as previous excavation of overburden) are fulfilled.

DES, to close again, is very well established for studies of automotive production systems. Coming from this likeness, a "cross-learning" approach between the automotive sector and the energy sector was followed. A fundamental research question was, if approaches proven successful in fostering energy efficiency in discrete production systems (e.g. [10,11]) could be applied in continuous systems. The tools of choice for this work were *Siemens Tecnomatix Plant Simulation* and Fraunhofer IWU's *eniBRIC*, a self-developed extension for the earlier (cf. Section 3.4).

2 System Characterization

For the purpose of this study, the OPM Welzow-Süd in Brandenburg, Germany, was selected. The following sections present the production process of this site as well as an overview on its utilization of energy.

2.1 Lignite production in Welzow-Süd

Like most OPMs, Welzow-Süd primarily utilizes continuous equipment technology. Matter above the lignite, so called overburden, is removed in three subsequent levels, loaded onto belt conveyors and transported to the other side of the excavation where it is dumped again [12] (cf. Figure 1). Once direct access is possible, lignite is excavated and transported either to the trench bunker for later loading or immediately to the train loading bays [12]. The OPM's progress, i.e. the direction of mining, is determined by prior geological analyses.

For each ton of lignite extracted from Welzow-Süd approx. 6 m³ of overburden need to be moved. According to the ratio of about 6 m³ per ton, 110 Mm³ of overburden a year are moved to produce 20 Mt of lignite.

The direct dump system used for the third and last layer of overburden (cf. [12]; see middle of Figure 1) is a particularity of the Welzow-Süd OPM. It uses an overburden conveyor bridge to transport excavated matter to the opposite side of the pit in a highly performant and cost efficient manner. In order to exploit this potential to the fullest, the maximization of the bridge group's (bridge and two bucket-chain dredgers) utilization is a primary aim during operation.

Previous layers of overburden are removed by the overburden cutting groups I and II, respectively. Each of these consists of a bucket chain dredger or a bucket wheel excavator, a series of conveyors and a spreader. The latter is responsible for dumping the overburden evenly.

Two bucket wheel excavators along with three bucket chain dredgers mine the lignite in the pit. These machines feed onto a single line of belt conveyors and, thus, are operated selectively according to the quality of the coal found in the seam. Hence, only lignite of constant quality is transported to the trench bunker at any given time. Concurrent mining of different qualities is strictly avoided so that some excavators will need to pause.

Lignite from the pit will either be loaded onto trains immediately or stored on different heaps (sorted according to the quality) in the trench bunker for later loading. In total, up to 170.000 t of lignite can be stored and, to maintain security of supply, a minimum of 90.000 t should never be undercut. As trains are loaded throughout the week but the OPM only operated on business days, all loading on the weekend will drain the lignite heaps. In case the operating pit cannot keep up with the demand, trains will also be loaded from the bunker.

Each of the groups of equipment, i.e. each production area, can be regarded as a largely independent production line. These are operated predominantly independent from one another, which manifests, for instance, in the different shift schedules they have. Yet, a number of restrictions between the various areas exist. Generally speaking, overburden I maintains a minimum lead on overburden II, which maintains a lead on the bridge group, which maintains a lead on the pit. The bridge group, in particular, prioritizes specific areas under which lignite of a certain quality resides, based on demand estimations and the store development.

Keeping these restrictions in mind, some flexibility exists in the way lignite is exposed. Particularly the areas overburden I and II may prove useful in this regard. However, this potential is not used at this point because operators prefer to maximize the operation time of equipment. The rational therein is that future losses from equipment failures (or similar interruptions) need to be mitigated in advance.

An analysis of the equipment utilization statistics of the dredger as well as the excavator in the overburden cutting groups shows promise for load management approaches. Planned stops currently account for up to 20 % of the overall production time. Load management approaches, such as those investigated for car body shops (e.g. [13, 14]), may be suitable to improve the energy efficiency in operation. The following list summarizes some previously identified mechanisms suited for this purpose and their respective characteristics:

- Quick shutdown: high impact, immediate effect, disrupting operation
- Modulation of production efforts: low impact, immediate effect, currently only manually, dependent on the current operating state
- Controlled ramp up/down: significant impact, reaction time approx. 30 minutes
- Shift rescheduling: long lead times required

2.2 An OPM's role in the energy market

Annually, Welzow-Süd usually consumes between 300 and 350 GWh of electricity. The overburden cutting areas account for half of that, with another 30 % being used by the bridge group and some 20 % by the pit, the trench bunker and indirect areas (e.g. surface drainage). An exemplary overview of some system elements or areas is provided in Table 1 (average hourly consumption of active equipment during production).

Besides the operating time, the geology of the OPM has a major influence on the energy and material flows. The properties of excavated matter – e.g., humidity, density, etc. – influence both mining and transport processes. Accordingly, adjustments to the process parameters, such as the conveying speed, may be a necessary corrective action during operation. Consequently, the material flow intensity and the energy demand would change. Correlations of a similar kind can also be found for other equipment in the system.

Elements (selection)	Ø-electricity consumption [MWh per h]
Bucket wheel excavator (OC II)	3.7
Overburden conveyor (OC II)	13.77
Spreader (OC II)	2.71
Bucket-chain dredger	4.31
Overburden conveyer bridge	8.04
Bucket wheel excavator (pit)	0.9

Table 1: Hourly electricity consumption.

Just considering the conveyors, their energy consumption is dependent on the currently transported mass, the conveying speed, the length and the gradients of the various belt sections. In normal operation, especially the mass is the predominant influence, which causes variable load profiles. During ramp up and ramp down (when the conveyer fills up or empties), this effect is especially high. Inhomogeneity of the excavated matter will also have an effect. The conveyor layout changes less frequently, usually when significant progress in the direction of mining was made. In case of the overburden conveyor belts, a length of up to 14 km is possible and those linking the pit to the trench bunker may climb up to 80 m high.

Following the above remarks, it is evident that an OPM is a significant consumer in the energy markets. At the same time, it serves as a primary source for LFPP, which generates about a quarter of Germany's overall electricity supply. This double role and the fact that both OPM and LFPP are operated by the same company, pose a dilemma. When electricity is scarce, the electricity prices as well as the demand for lignite can be expected to rise. This, again, prompts for greater production of lignite and reduced energy demand from the OPM at the same time. The latter would decrease the (internal) energy costs of the mining operation. Furthermore, released capacity could be offered to external customers at a high price.

Four fundamental energy market mechanisms currently exist for planning and marketing the energy demand in advance or for reacting to fluctuations on a short-term basis. These influence, how flexibilities in an OPM could be exploited in a value-adding way. From long-term to short-term they are:

- Day-ahead marketing: lead time > 12 h; solvent market; hourly products
- Intraday trading: lead time down to 1 h and under; quarter-hourly products
- Imbalance energy: minimization of volume delta reduces costs for balancing energy; ongoing with a quarter-hourly horizon
- Operating reserve: pre-qualifying; provision (binding); detailed regulation; requirements of technical controllability to meet dynamic control demand

The OPM's double role can also be contemplated from a sustainability angle. In this respect, it can be stated that the eco-efficiency of lignite production can be increased when times with high availability of RES are favored. Yet, this would increase the output when the LFPP's demand is actually waning.

To find the best course of action, the most appropriate operation strategies to follow in this complex environment, simultaneous simulation of the flows of material and energy was deemed the most promising approach. In particular, the most effective levers for exploiting available flexibilities in the mining process needed to be determined and their effects quantified.

3 Simulation Model

Once the scope of the project as well as its goals were clearly defined, the procedure model presented in the standard VDI 3633 Part 1 [15] was followed for to perform the simulation study. The following sections present the main results up to the mode implementation.

3.1 System borders and level of abstraction

Given the complexity of the system the definition of system borders was of great importance. These define which elements and flows should be simulated as well as where information, material, etc. needs to be exchanged with the environment. For the study of Welzow-Süd only those elements which have a part in the flows of lignite, overburden or electric energy were considered. This includes the geologic profile, excavators/dredgers, conveyors, spreaders and train loading. Indirect areas, such as revegetation, water management, etc. were dismissed as their energy demand and impact on operations was insignificant compared to that of the direct areas.

While train loading marks the outbound border of the model, the demand of the LFPP was still considered. More specifically, the LFPP acted as a company-internal customer, which generates production jobs for the OPM. These jobs, i.e. the demand for lignite, also translate into requirements regarding the removal of overburden.

Following the discussion in Section 2.2 it is evident that the structure of the lignite deposit and especially layers of matter above the seam have a tremendous effect on the energy consumption. Accordingly, the correlations between extracted matter (both lignite and overburden) and the production progress needed to be included in the model. Thus, the extraction sites demark the inbound border of the system. As modelling the actual geographical profile was considered too difficult and would have required excessive effort, they were abstracted to series of different types of matter.

The general level of abstraction for this study was defined to be equipment, i.e. excavators, conveyors, etc. Hence, the behavior of individual actors in the equipment was not considered in either the flow of materials or energy. Electricity sources and energy distribution equipment were disregarded, too.

3.2 Data analysis

In order to quantify and model the behavior of individual pieces of equipment and the system in general, an extensive analysis of pre-existing operating data was carried out. The basis for this work were production reports, production logs, error logs, train protocols, service protocols, energy consumption reports, etc. In effect, a realistic picture of the OPM could be obtained.

Yet, the available data were provided in inconsistent resolutions, sometimes using varying units of measurement, from different sources for the various system elements. To accommodate for the apparent differences, in-depth analysis and substantial pre-processing had to be performed.

Special emphasis was put on the identification of energy-related operating states and their respective electricity consumption behavior. The results thereof showed that between three to five operating states suffice to model the various pieces of equipment. These are generally “off”, “disrupted” and “operational”. In addition to these, selected pieces also have “moving”, “switching cutting setup” (from above to below or vice versa), “start-up” or “overburden cutting” (as opposed to lignite cutting for excavators in the pit).

Especially the operational state but also the start-up state are related to the excavated or transported matter. The underlying correlations were also determined in the data analysis and described using simple linear regression curves. This type of regression was used as it yielded a high coefficient of determination for the analyzed data. On the one hand, other tested regression functions did not improve the accuracy considerably and, on the other hand, a simplified consumption model was preferred. The reason for the latter was that the overall modelling approach is rather abstract so that regressions that are more complex would suggest a level of precision in the model that was never targeted.

The calculations for the determination of the regression curves for excavators were based on the time series of lignite and overburden and the electricity consumption profiles of individual pieces of equipment. While information on the excavated matter could be extracted from production logs of a reference period, the content of conveyors had to be reconstructed. This was possible by means of the excavator behavior, the production logs and the error logs. The coefficients of determination R^2 for individual regression curves lay in the range of approx. 0.70 to 0.95, depending on the type of input data that could be used (see before).

The production logs primarily consist of minutely data of how much matter of which type was excavated. Analysis showed that three fundamentally different types of both lignite and overburden, each, were processed in the OPM. Furthermore, the raw data varies greatly (due to technologic reasons), so 5-minute averages were used throughout the study. The error log holds information on the beginning and end of equipment disruptions as well as the respective reason.

Information from both logs was used to execute preliminary simulation runs, from which the content profiles of conveyors and spreaders could be discerned. These were then overlaid with the energy consumption profile to calculate the missing regression curves.

3.3 Model implementation

All system elements were modelled in a single frame (*Plant Simulation* sub model). To improve the recognition value of the model (Figure 2), the layout of the individual elements principally recreates that of the actual OPM. Since the excavation sites were only modelled as time series, their respective objects only use static symbols.

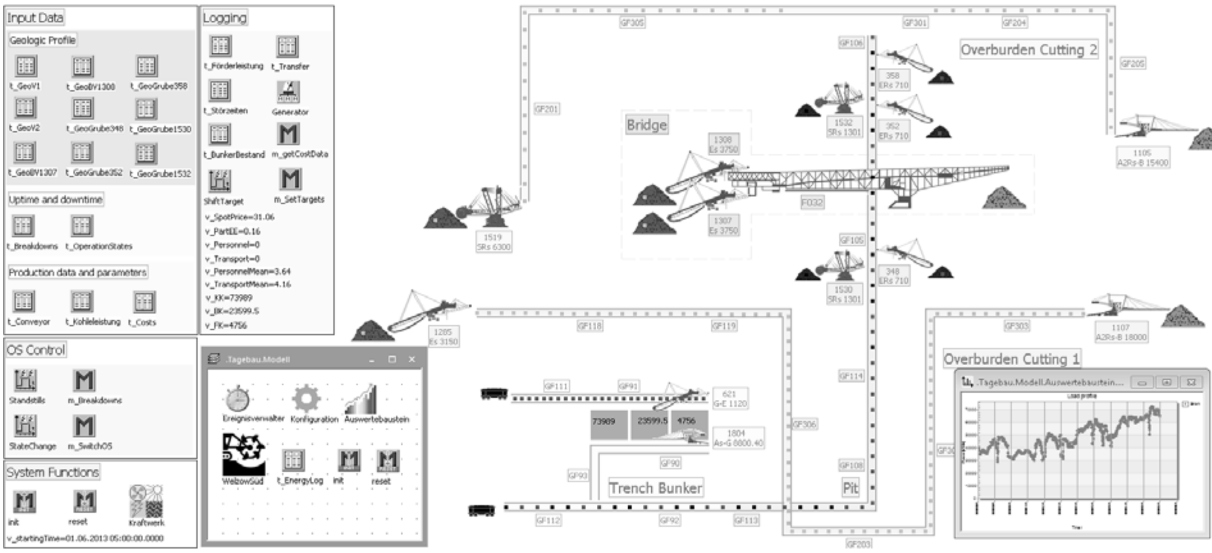

Figure 2: Screenshot of the simulation model with simulated load profile in lower right corner.

Hence, their progress is not reflected in the visualization during runtime. Similarly, the representation of other equipment changes neither in length/ shape (conveyors) nor in position (conveyors, excavators and spreaders) in accordance with the progress. Throughout the implementation, *Plant Simulation's* object-oriented modelling abilities have been utilized to reuse user-defined procedures and data structures. Accordingly, a basic class for matter (moveable unit; MU) was created, which contains specific attributes such as volume, power consumption, energy costs, etc. From this, lignite and overburden classes (3 of each) were derived. Upon instantiation by an excavation site (source) according to the predefined time series, they are initialized with specific attributes (e.g. volume of the 5-minute package). During simulation, other attributes are updated when necessary (cf. also Section 4.1).

Similarly, the excavators were based on a single excavator class, which is fundamentally a demounting station followed by a separation buffer (capacity 1, dwell time 30 s). It receives 5-minute packages, splits them into 30-seconds packages (increasing the resolution for the energy demand calculation in following objects) and outputs one every 30 s. Additionally, the excavator class includes the *eniBRIC* class to model the flow of energy (cf. Section 3.4). Derivatives of the base class have been created for selected groups of excavators according to the respective identified operating states. Thus, *eniBRICs* basic configuration could be preset specifically for these groups in the class library before the various excavators were instantiated.

The correct energy demand is set during runtime by means of user-defined procedures which are called when a new 5-minute package is processed.

Conveyors (including the bridge) and spreaders were also first implemented in a base class. Fundamentally, they are length-oriented conveyor objects (as opposed to the point-oriented objects used for excavators). In order to model the respective energy consumption, *eniBRIC* has been added as a sub class. During runtime, user-defined procedures calculate the conveyor content whenever it changes (MU entering/exiting) and then determine the new energy demand based on regression curves (cf. Section 3.2). The latter is then used to update the *eniBRIC* instance's current level of consumption. In the simulation model, the various conveyor sections, the bridge and the spreaders were instantiated and linked to one another as well as to the excavators (cf. Figure 2).

In addition to the elements of the material flow and the energy flow, the sequence logic was implemented in the model. It consists primarily of user-defined procedures and data/information objects. The latter are imported to the simulation upon model initialization and include, for instance, spot market prices, cost rates for personnel and transport, information on non-operating periods, lignite orders from the LFPP, etc. Once a simulation run commences, procedures are triggered based on these data to change the system elements' operating state according to the imported time series. Thus, breakdowns, shift breaks, etc. are simulated according to the available logs and protocols from the analyzed reference period (cf. Section 3.2).

While this implementation was very well suited to validate the model conformity, prospective simulation experiments would require less deterministic sequence logic. Hence, the user-defined procedures were designed to also work with probabilistic inputs, e.g. for dealing with random equipment disruptions.

3.4 Integration of eniBRIC

While *Plant Simulation* versions 11 and onward provide basic functionality for simulating the flow of energy, these are arguably limited unless extended through user-defined procedures. The *eniBRIC* library (cf. [16,17]), on the other hand, was developed to be flexibly applied regardless the number of operating states or considered energy carriers.

As described in the previous section, one instance of *eniBRIC* is created for each instance of a material flow element. The respective configurations consist of the three to five operating states identified in the data analysis. For each of these, a specific demand was specified, as was the ability to realize a material flow in the respective state.

The consumption of excavators, conveyors and spreaders were determined to be variable, depending on the properties of excavated or transported matter. Hence, the operational state of the corresponding elements has been duplicated (e.g. operational 1 and 2) to be able to switch between different states that allow material to be processed. This was necessary to accommodate for *eniBRIC's* inherent control logic and was controlled via procedures that are called when the element contents change.

Within the model, only electricity was regarded. Since *eniBRIC* requires a source of energy for each energy carrier parameterized, an electricity source had to be instantiated. In the context of this model, this could be considered the connection to the utilities. Energy sources are, in essence, regular *eniBRIC* instances without additional material flow objects. During simulation, energy drains (i.e. material flow equipment) retrieve the location of the respective source from a preconfigured matrix in *eniBRIC's* configuration module.

Data collection and visualization during runtime is made possible by means of the evaluation module. It gathers information of the energy-related operating state transitions and the corresponding energy demand profiles. Most in-depth analysis for the experiments presented in Section 4.2, however, were performed on data exported from this module's instance in the model.

3.5 Model tuning, verification and validation

As mentioned before, the entire system was modelled based on data provided for a reference period (1 month). To verify the model's general correctness and validate its fundamental ability to study available flexibilities, the models performance was compared to that of the actual system. In particular, the variance and the cumulated error of the system output indicators as well as the energy consumption profiles were checked.

Figure 3 depicts an exemplary graph, which was used to visually ascertain the variance between reality and model. Similar comparisons have been made for the entire system, other areas of the OPM (e.g. overburden cutting I, etc.) and even individual pieces of equipment.

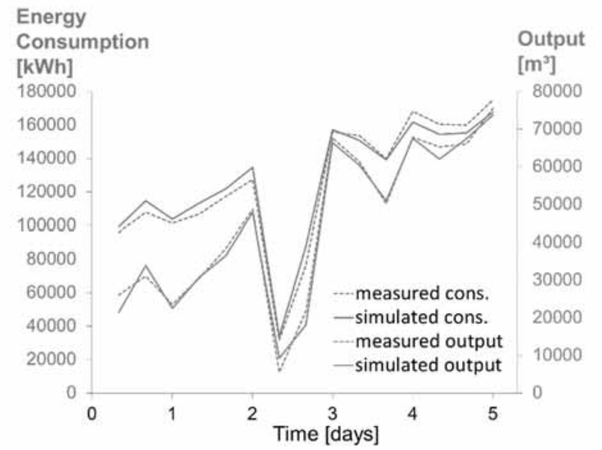

Figure 3: Comparison of energy consumption [kWh] and output [m³] for overburden cutting II.

Initial results showed some more divergence between the real system's behavior and the model. Further tweaks of the model parameterization were then applied in an iterative process in order to refine the results considerably.

A typical verification and validation procedure as proposed in state of the art literature (e. g. [15]) was applied to the model with its eventual parameterization. The final variance of the entire system's energy consumption, volume of moved overburden and lignite production was eventually determined to be ≈ 0.3 %, ≈ 0.0 % and ≈ 1.1 %, respectively. Similarly, the cumulated errors for these indicators were determined to be ≈ 0.7 %, ≈ 0.8 % and ≈ 0.6 %.

4 Simulation Experiments and Results

The previous section illustrated how a valid model of the OPM was created. It was used for first simulation experiments in order to identify exploitable flexibilities. To ascertain these accurately, various indicators were defined, which are described in the following section. Afterwards, some preliminary results are presented.

4.1 Relevant indicators

In order to investigate, for example, flexibilities in the electricity market or in the lignite demand several global indicators were defined. Particularly, the following were determined to be of interest:

- Variance of the electricity price from the average,
- Primary energy factor of consumed electricity based on the German electricity mix,
- Deviation of targeted to actual output of lignite,
- Utilization of lignite production capacity, and
- Variance of costs for personnel and transportation.

Other possible indicators can be, for instance, the share of electricity costs on the overall operating costs, the distribution of specific energy costs (over time or overhead/lignite) or the utilization ratio of the trench bunker. To provide the necessary inputs for computing any of these indicators, both real data, which are partly input information of the model, and simulation data are combined. The resulting time series of indicators mark the starting point for the analysis of potentially influenceable production processes and related effects resulting from their exploitation.

In addition to the above indicators, the simulation model can generate statistics for each processed volume package. This includes the following specific indicators:

- Time of extraction,
- Specific personnel and transport costs,
- Specific throughput time,
- Specific power consumption,
- Specific energy costs, and
- Specific primary energy utilization.

At the time of a package's creation in the simulation, the time of extraction as well as personnel and transport costs (as products of the package's tonnage and specific cost rates) are determined. The specific throughput time is calculated when packages leave the system and may be used as pointers to identify process disturbances. The specific power consumption refers to a single volume package. It is calculated considering the volume-dependent power demand of the different system elements (cf. Section 3.3).

Accordingly, the relevant attribute of an MU is updated whenever the energy consumption of a material flow object changes or the MU exits one of the former. The specific energy costs and the primary energy utilization are based on the specific power consumption and, thus, are updated in the same manner. They are calculated by multiplying the specific consumption with the spot market prices and the percentage of non-renewably sourced electricity, respectively. Both scalars were regarded as time-dependent.

4.2 Discussion of experiments

Multiple simulation experiments were performed to identify available flexibilities. These generated different data sets for the global indicators as well as for the specific indicators. The experimental design followed an expert-knowledge-driven approach, where input information was varied in accordance with suggestions from the project team.

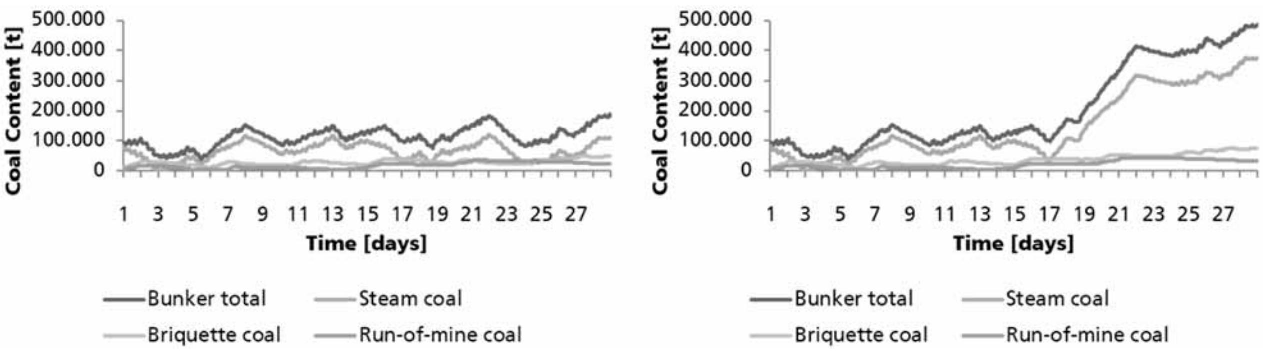

Figure 4: Trench bunker content in reference scenario (status quo; left) and with reduced lignite demand of LFPP (right) over time.

Thus, a number of distinct scenarios were defined. Deterministic simulation runs were performed for these and analyzed qualitatively as well as quantitatively. Examples for such experiments are:

- Altered electricity price curve,
- Reduction of lignite demand, and
- Reduced frequency of breakdowns.

An altered electricity price curve directly affects the energy costs of the production system. The amplitude of this change is quite significant. It is therefore important that the results are analyzed to derive more cost-efficient operation strategies. The scenario 'reduction of lignite demand' investigates, for example, how an unplanned increase in production of renewable energy sources influences the system. A change like this would diminish the demand for electricity generation at the LFPP and, thus, delay the latter's orders for lignite. In such a case, the trench bunker starts to fill up to its capacity if production continues unchanged. Figure 4 depicts the content of the trench bunker for the status quo (reference scenario) as well as for the demand reduction scenario, as simulated. On the other hand, the energy mix in this time is environmentally friendly due to reduced reliance on fossil fuels. Accordingly, operation strategies should be defined to balance the trench bunkers content and the company's economic, as well as ecologic targets. The approach presented in [18] may serve as a starting point for this.

Decreasing production or shifting it – preferably to periods which promise greater energy efficiency – are possible courses of action to prevent excessive stocking of lignite. These require stable processes, i.e. a reduced number and total length of breakdowns, to ensure that operation is possible when intended. For both decreasing and shifting production, the determination of thresholds for controlling the OPM processes is a necessity. The simulation results of the scenario 'Reduced frequency of breakdowns' provided initial insights on this. Furthermore, greater energy efficiency from the company's point of view in this context can mean either less primary energy per ton of lignite or more profit in marketing LFPP capacity. In the latter, the OPM operation would be shifted to times of lower electricity prices or make use of demand response to sell the generated energy at the highest price possible.

These above experiments were performed and results are currently analyzed by mining experts. Their eventual goal is to identify exploitable flexibilities and define strategies to optimize the process control accordingly. Especially plan revisions during the day and short-term load reductions are promising because they may allow for intraday trading at the spot markets. Improvements on the input data and additional experiments are planned to investigate this more thoroughly in the future.

5 Conclusion

Lignite-fired power plants (LFPP) along with open-pit mines (OPM) are the backbone of many national energy systems. In Germany, around 1/4th of the electricity is sourced from LFPPs. As OPMs are very energy intensive, operators aim to improve their energy efficiency. For this purpose, the here-presented study applied a "cross-learning" approach to identify suitable flexibilities by likening the OPM to a discrete production system (e.g. a car body production line). It was modelled using *Plant Simulation* and *eniBRIC* (a self-developed extension to the earlier) to simulate both the material flow and the energy flow simultaneously.

Initially, the prime targets of the simulation study and the system borders have been defined. Subsequently, an in-depth data analysis based on real data from the OPM Welzow-Süd was performed. The results thereof went into parameterizing the model. During the implementation, all continuous flows of matter were discretized over time, i.e. equidistant volume packages of varying size. The energy demand of the regarded system elements was modelled as either operating state averages or using regression curves. After successful validation of the deterministic model, initial experiments were designed and performed.

Preliminary results showed how the system behaves when operation conditions change, particularly when renewable sources suddenly provide excess energy. Further experiments showed how adjustments in the operation schedules of equipment (e.g. by reducing failure times) would affect the system's main performance indicators.

All of these results are currently being scrutinized by mining experts to identify suitable approaches for exploiting identified flexibilities. The results of this work will need to be tested in the simulation model. Applying probabilistic parameterizations to simulate machine failures and extraction rates may also allow for assisting simulations during the operation phase.

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Exploring Opportunities: Optimizing Production Planning by Factoring in Energy Procurement and Trading Options

Maximilian Selmair[1*], Marc Hanfeld[2], Thorsten Claus[1], Frank Herrmann[3]

[1] International Institute Zittau, Central Academic Unit of Dresden Technical University, 02763 Zittau, Germany
maximilian.selmair@mailbox.tu-dresden.de

[2] Wintershall Holding GmbH, 34119 Kassel, Germany

[3] Ostbayerische Technische Hochschule, 93025 Regensburg, Germany

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Abstract. Motivated by the increasing share of renewable energy in the markets for energy commodities, this study has evaluated the potential for optimizing production planning by taking into account disposable options for procuring energy, in this case electricity. For this purpose, a material flow simulation study extended by an electricity price simulation has been executed to examine possible cost scenarios. Our findings support the notion of a potential for further research in new optimization models involving energy procurement as well as energy trading options.

1 Introduction

The nuclear phase-out, planned to have been accomplished by 2022, leads Germany to its pioneering role in expanding renewable energies. Along with the liberalization of the European energy markets, new opportunities of energy procurement have been established. Considering the remarkable volatility of the electricity market due to the increasing solar- and wind power feed-in along with individual pricing structures, the application of such opportunities imposes a flexibilization of production [1]. Thus, the authors saw the need to develop new approaches for production planning.

Based on the executed simulation study, the dependencies between production planning and energy costs are demonstrated. The results suggest that the integration of energy trading and production planning is likely to result in a monetary advantage for the manufacturing industry.

In the following sections, an investigation by means of simulation, a detailed discussion of the associated results and perspectives for future research are provided.

2 Related Literature

Energy-efficient production planning has become an increasingly important issue in recent years. For Germany in particular, the scheduled shutdown of nuclear power plants has raised awareness regarding resource efficient production.

Research in the field of energy efficiency and energy oriented production planning has become increasingly important in the past decade. Motivated by scarce resources, flexible energy prices and the fluctuating supply of renewable energy, there are several contributions for energy-oriented production control such as [1-13].

As not every production facility is suitable for this kind of energy orientated production planning, Kabelitz et al. [14] developed a method to evaluate the energetic flexibility of production systems.

Another way to exploit the fluctuating supply of renewable energy is the integration of energy storages. Atabay et al. [15] provided a mathematical calculation for determining the size of energy storages required, depending on the energy demand and the expected energy tariff. A case study performed in two very different companies demonstrates the application of this method.

One outstanding example for knowledge transfer between theory and practice is a project named *Green Factory Bavaria* which is co-operated by the Fraunhofer Society [16].

By providing several research, demonstration and learning platforms, the project assists the manufacturing industry in increasing their level of resource efficiency. Technical solutions as well as methodical approaches are part of the knowledge transfer from applied research to the manufacturing industry.

However, approaches taking into account financial possibilities in energy procurement for the purpose of optimizing production planning have not been developed yet. The following section describes the authors' proposal of such an approach.

3 Problem Definition

In recent years, the energy market's structure has been changed by liberalization, energy transition and digitalization. The formation of wholesale markets for energy and the developing competition provides opportunities to trade amounts of energy among market participants. This also enables non-energy companies to benefit from the energy trading opportunities. The trading of energy can be organized by institutional exchanges (e.g. European Energy Exchange EEX or Intercontinental Exchange ICE) or may be based on bilateral negotiations. Manufacturing companies, whose production processes are very energy intensive, can obtain their energy requirements directly or indirectly via an upstream supplier by trading standardized products in the markets for electricity and gas.

These standardized products that can be traded on the spot and futures markets include baseload volumes of various maturities. The following contract types can be differentiated:

- hourly contracts
- daily contracts
- monthly contracts
- quarterly contracts
- seasonal contracts
- yearly contracts

For instance, within an hourly contract a constant load will be delivered for a fixed price (e.g. 1 MWh/h for 25 €/MWh). The commodity electricity can be divided into baseload- and peak load contracts. The same is applicable for monthly contracts, where a constant load is supplied for all hours of a month – just as for the quarters, seasons and years. The prices for the different contract types are subjected to price variations at the respective trading times.

The different products are being traded in different maturities. For example, on the electricity market of the EEX it is only possible to trade contracts with delivery of single hours of a given day on that particular day (intraday trading); the trading of daily deliveries is only possible on the day prior. Monthly contracts are traded a few months prior to their delivery.

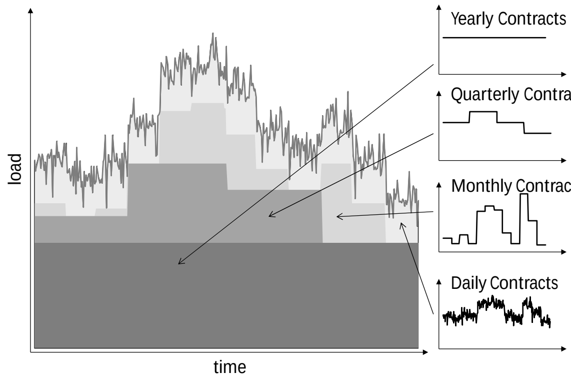

Figure 1: Structuring of a load profile using standardized energy trading products.

The same applies respectively for quarterly, seasonal and yearly contracts. In practice, the scheduled purchase of energy is based on historical load profiles. The principle that underlies the structure of an exemplary load profile with the above mentioned standardized products is illustrated in Figure 1.

Interdependencies between production planning and energy trading can be identified [15, 17]. One possibility to influence the energy costs is an advantageous combination of the standard trading products and the best moment to buy commodity products. In other words: When the prices are high, a low demand is advisable and vice versa. Therefore, it will be an advantage to place high-demand-periods in low-price-periods.

Nevertheless, manufacturing companies that participate in energy trading markets are faced with cost associated risks. These risks result from the markets' price volatility and have to be supervised. In this discussion, we define the cost risk as the deviation between the planned budget and actual costs. Therefore, a high variance of the energy demand would lead to greater cost risks. If a high degree of capacity utilization of the production is achieved in the early stages of planning, the resulting load profile can almost completely be structured by forward based contracts.

Thus, it is possible to secure energy prices in advance and – due to the absence of (unplanned) short term load variations – to avoid the selling / buying of short term (hourly) contracts and to reduce the cost risk. The following figure illustrates these relationships.

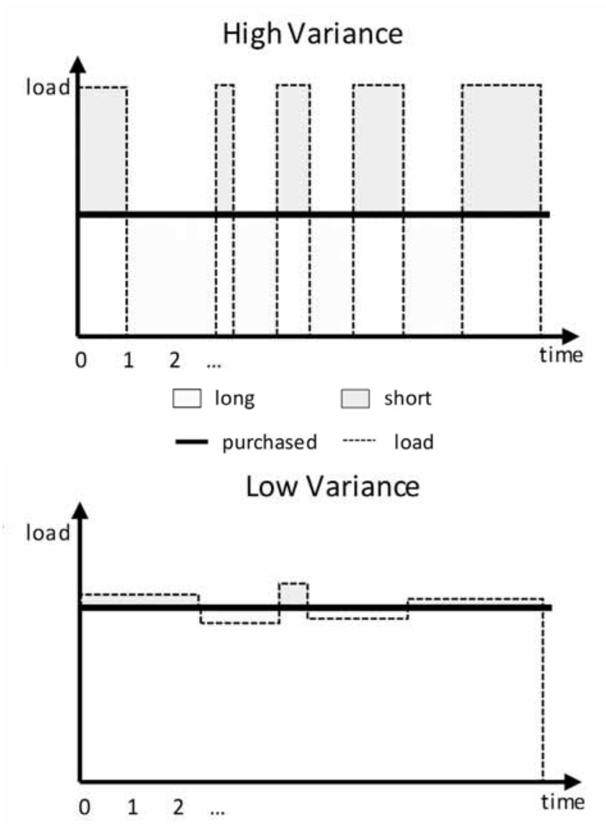

Figure 2: Dependence of load profile variance and energy purchasing.

T	Scen 1 [€/UoM]	Scen 2 [€/UoM]	Scen 3 [€/UoM]
0	30.00	30.00	30.00
1	31.49	29.64	41.84
2	24.51	24.96	46.33
3	29.26	24.97	49.02
4	25.60	29.93	41.68
5	16.50	28.72	50.82
6	16.25	21.56	50.88

Table 1: Price scenarios.

The first chart of Figure 2 depicts the fictitious case of a production plan with a high variance load profile. This case results in high load fluctuations. If a forward contract was to be purchased at $t = 0$, time periods with shortages and with surplus quantities would result. At the beginning of the planning period, the exact prices for selling surplus or buying shortfall quantities are unknown. Consequently, a cost risk results.

The second chart describes low variance. If the energy procurement is planned on the basis of this load profile, only small deviations remain, which can be evened out by means of short term trading products. This results in a lower cost risk in comparison to the scenario in the first chart.

The numerical example below illustrates the problem regarding the dependency of costs for energy and production planning. The above-mentioned cases are the basis for the following: (1) The production plan results in high variance of the energy load profile and (2) low variance of the energy load profile. The planning period amounts to 6 TU (time units). At the beginning of the planning period ($t = 0$), a baseload contract for these 6 TU is worth 30 €/UoM (Units of Measurement) (delivery across all 6 TU). Purchasing a baseload contract for this period is only possible in $t = 0$. Table 1 provides three price scenarios that represent possible price trends when purchasing short-term contracts.

Table 2 displays case (1) with high variance. For demonstration purposes, it is assumed that 3 UoM must be produced in total and each product UoM requires 1 UoM of energy. Thus, in $t = 0$ it is only possible to purchase a baseload contract for the next 6 TU. In this example, the baseload contract is determined by 0.5 UoM. In this case, the initial production plan specifies the production of 1 UoM in periods $t = \{1,4,5\}$ respectively. Due to the purchasing of energy with a load of 0.5 UoM in $t = 0$, in $t = \{2,3,6\}$, surplus quantities occur. These quantities are sold on the market at the prices mentioned in Table 1. Consequently, shortages arise in $t = \{1,4,5\}$ that need to be procured at prices which also listed in Table 1 The distribution of costs displayed below in Table 2 results from the scenario of the planning point in $t = 0$.

Based on this example, the energy costs are subject to variations. Depending on the price development, the costs range from € 84,05 to € 98,39.

t	Load [UoM]	Purchase [UoM]	+ long / - short [UoM]	Scen 1 [€]	Scen 2 [€]	Scen 3 [€]
1	1	0.5	-0.5	-30.75	-29.82	-35.92
2	0	0.5	0.5	-2.75	-2.52	8.16
3	0	0.5	0.5	-0.37	-2.51	9.51
4	1	0.5	-0.5	-27.80	-29.96	-35.84
5	1	0.5	-0.5	-23.25	-29.36	-40.41
6	0	0.5	0.5	-6.88	-4.22	10.44
			Σ	**-91.80**	**-98.39**	**-84.06**

Table 2: Cost distribution for a high-variance-load-profile.

t	Load [UoM]	Purchase [UoM]	+ long / - short [UoM]	Scen 1 [€]	Scen 2 [€]	Scen 3 [€]
1	0.5	0.5	0	-15.00	-15.00	-15.00
2	0.5	0.5	0	-15.00	-15.00	-15.00
3	0.5	0.5	0	-15.00	-15.00	-15.00
4	0.5	0.5	0	-15.00	-15.00	-15.00
5	0.5	0.5	0	-15.00	-15.00	-15.00
6	0.5	0.5	0	-15.00	-15.00	-15.00
			Σ	**-90.00**	**-90.00**	**-90.00**

Table 3: Cost distribution for a low-variance-load-profile.

In the following section, the scenario for case (2) is discussed. The initial production plan results in an even distribution of the 3 UoM over the 6 TU. This results in a load profile of 0.5 UoM/TU, which is purchased as a baseload contract in $t = 0$, results (see Table 3). Thus, the load variations in the planning period as well as the necessity to sell/buy surplus/shortfall quantities are reduced to a minimum.

Therefore, the load profile can be covered entirely by purchasing the baseload contract in $t = 0$ and the price of 30 €/UoM can be secured. The overall costs for purchasing energy amounts € 90 in every of the three price scenarios (see Table 3). In this case, there are no cost variations and the costs in every price scenario are the same.

As illustrated in the above-mentioned example cases, it is likely that an integrated view of production planning and energy purchasing will influence energy costs. On the one hand, the forward markets' opportunities for securing energy prices, and on the other hand, the trading of short-term contracts on the spot market provides a potential for optimizing the flexibility of the production process and for reducing the costs for energy.

The main target of this contribution is the implementation of a simulation study. Therewith, the impact of an integrated view of production planning in combination with the opportunities of energy trading on the expense situations of companies can be conjectured. Finally, the optimization potential is identified and the determinants of the optimization problem are specified.

4 Simulation Study

This section describes the details of the parameters utilized in the simulation study. Figure 3 illustrates the resulting energy cost distribution as a result of merging a material flow simulation and an electricity price simulation. Both mentioned simulations are independent of one another.

Material Flow Simulation. The requirement for this part of the simulation was to determine a complete energy consumption pattern for a fictitious production system. For this purpose, a job shop production system with a total number of nine machines was designed. In order to examine different consumption patterns, it was decided to apply different priority rules when scheduling this production system. Such heuristic methods are used in industrial practice to avoid time-consuming constraint-based approaches. Although these methods have nothing in common with energy saving methods, they can be used to obtain different energy patterns.

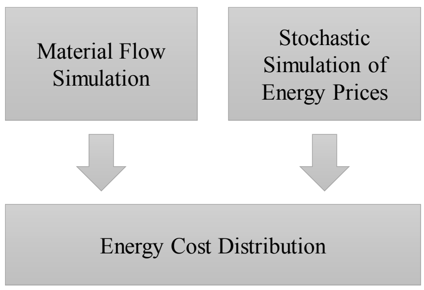

Figure 3: Proceeding of the simulation study.

Commonly applied rules are as follows [18]:

- FIFO: First-In-First-Out
- LIFO: Last-In-First-Out
- SJF: Shortest Job First
- LJF: Longest Job First
- SRPT: Shortest Remaining Processing Time
- LRPT: Longest Remaining Processing Time
- EDD: Earliest Due Date

With a flow simulation model designed in Tecnomatix *Plant Simulation 13*, these seven rules for the same volume of orders were applied to generate different consumption patterns. As the total consumption of the production system is the point of interest, the energy patterns of all machines are identical:

- Ramp Up: 10 kW/h
- Setup: 7 kW/h
- Processing: 35 kW/h
- Standby: 6 kW/h
- Ramp Down: 7 kW/h

The case study includes a total amount of 810 jobs. Every job is linked to a working schedule specified by one of four possible products that is to be produced. This sequence can be inferred from Figure 4. All durations are stated in minutes.

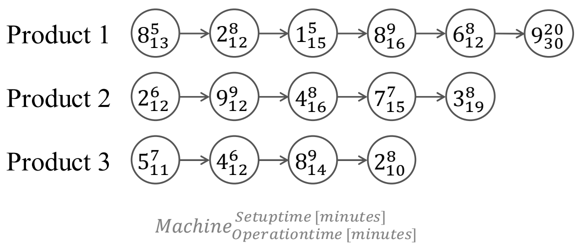

Figure 4: Sequence, setup time and operation time for each product.

The order quantity of each job is an evenly distributed number between 2 and 6. Depending on the applied priority rule, processing these jobs will take between 33 and 36 days. This algorithm to create all 810 jobs is given in the pseudocode shown next.

```
for iPer = 1 to 27 loop
  for iCnt = 1 to 10 loop
    for iPro = 1 to 3 loop
      Product = "P"+iPro
      Amount = Uniform(2,7)
      ReleaseDate = iPer
      DueDate = Uniform(iPer+1,iPer+5)
    next
  next
next
```

Listing 1: Algorithm for job-compiling.

The algorithm generates jobs for 27 periods (first loop). Every period contains 10 jobs (second loop) for each product (third loop).

Price Simulation. The Ornstein-Uhlenbeck-Process was used to model and simulate the stochastic behavior of electricity price developments. This approach is in line with [19] as a base model for commodity prices:

$$dS = \kappa(\mu - S)dt + \sigma dZ \qquad (1)$$

Parameters are described as follows:

- S: Electricity Spot Price
- κ: Mean Reversion Factor
- μ: Mean (e.g. price of forward contracts)
- dZ: Brownian Motion
- σ: Standard deviation of the price returns
- dt: Time increment

As the historical spot prices for electricity contain negative prices, the logarithm of the prices discussed by Schwartz [19] is not applicable. Therefore, the naive discretized approach, mentioned in [20], was applied when simulating the electricity spot prices:

$$S_t = S_{t-1} + \kappa(\mu - S_{t-1}) \vartriangle t + \sigma dZ_t \qquad (2)$$

The process simulation was based on the following parameter values:

- $S_{t=0}$: 24.21
- κ: 0.0736
- μ: 25
- σ: 4.7051
- $\vartriangle t$: 1

Using the model mentioned above, 1,000 price paths for a period from 01/05/2016 0:00 till 05/06/2016 20:00 was simulated. The simulated price paths are negative in some cases. That is, in these periods a company would receive money when obtaining energy from the supplier.

For the purpose of simplification and reproducibility of the results, we refrained from using a more complex model. For an extended spot price model see [17].

5 Results

In this section, closer look at the results of the above described simulations and the resulting energy cost distribution is presented. A different load profile was generated for each applied priority rule, as visualized in Figure 5. The combination of these load profiles with 1,000 random price paths leads to Figure 6. Here, the cost distributions for every applied priority rule are evaluated.

It is noticeable that all distributions are different regarding their expected value and spread. Thus, in this case study, some priority rules such as LRPT or FIFO lead to lower expected energy costs than others. Another important indicator is the spread of the cost distribution. The wider the distribution, the higher is the uncertainty and thus the resulting cost risk. Therefore, the EDD rule provides the narrowest distribution and thus the lowest uncertainty. Depending on the market's energy prices, the costs for obtaining energy can deviate more from the expected value if the distribution is widespread. All cost distributions are described detailed with estimated costs, minimum, maximum, spread and an exemplary historical value in Table 4.

The various distributions, especially their deviations, provide a potential for using energy procurement and trading options to minimize energy costs in industrial manufacturing. The application of seven different priority rules for scheduling the production system of our case study leads to different and random procurement times.

As can be seen in Figure 6 and read in more detail in Table 4, the resulting costs and also the resulting cost uncertainty differs between all cases. This implies a cost sensitivity regarding a) the combination of contracts in the forward market, which can be bought at the beginning ($t = 0$) and should be adjusted during the production period depending on the price development for the tradeable forward contract and b) the reaction of short term price movements on the spot market.

Using this potential requires a suitable planning approach and should be object of further research.

Priority Rule	Expected Costs [€]	Min [€]	Max [€]	Spread [€]	Hist.* [€]
FIFO	3.753	3.500	4.014	514	3.757
LIFO	3.863	3.662	4.061	400	3.873
SJF	3.748	3.389	4.120	731	3.671
LJF	3.841	3.709	3.977	268	3.830
SRPT	3.854	3.694	4.037	343	3.878
LRPT	3.660	3.381	3.944	563	3.608
EDD	3.823	3.690	3.984	293	3.781

* historical value from 01/05/2016

Table 4: Description of all cost distribution.

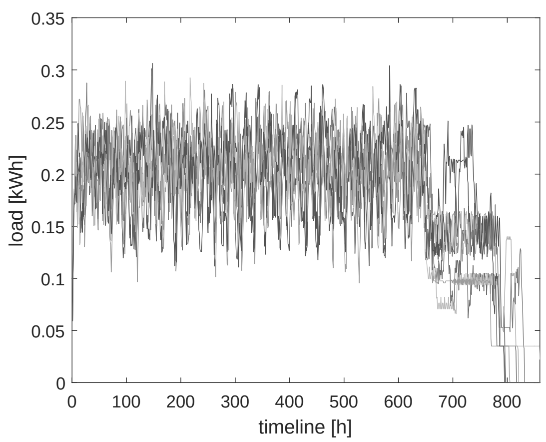

Figure 5: Load profile for applied priority rules.

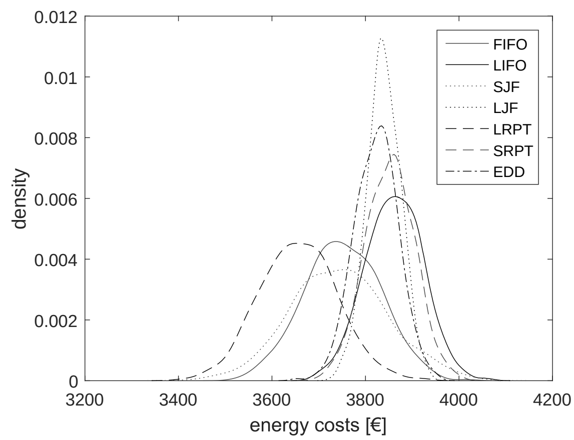

Figure 6: Energy cost distributions for applied priority rules.

6 Conclusion and Future Work

In this investigation, potential for augmenting the optimization of production planning by factoring in energy procurement and trading options was identified. Provided that a company's production offers enough flexibility, short-term reactions to changing market situations are possible. By means of our simulation study, our results are demonstrating different energy costs distributions for a variety of schedules generated by applying common priority rules. Consequently, a potential for optimization is apparent.

Therefore, an optimization model that focuses on saving energy costs in periods in which the production schedule is flexible will be our objective for further research. While planning continuously, the model should re-plan the whole planning horizon after each period to consider short-term as well as long-term energy price changes. Thus, an inclusion to the hierarchical production planning concept provided by Hax and Meal [21] seems appropriate to the authors.

Finally, we want to highlight that this research project does not focus on a higher energy efficiency and will not save energy in particular. Rather, it should help to reduce energy costs and decrease the cost risk for companies without fixed energy prices by means of an integrated consideration of energy procurement and trading options.

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Coupled Simulation of Energy and Material Flow using Plant Simulation and MATLAB Simulink

Tim Peter*, Sigrid Wenzel

Department of Organization of Production and Factory Planning, University of Kassel, Kurt-Wolters-Straße 3, 34125 Kassel, Germany; **tim.peter@uni-kassel.de*

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Abstract. This paper describes the state of the art in integrating energy considerations into the simulation of production and logistic processes. It presents different approaches to integrating energy analysis into simulation. Furthermore, we discuss a solution developed within the research project *SimEnergy*, a use case for application and the results of the project. We explain how the developed solution was improved after the project had shown that it delivers comparable results to the original approach. We use the obtained results to develop a simplified model in *Plant Simulation* and compare the results to the coupled simulation solution. Furthermore, we analyze the impact of the temperatures chosen for restarting the machines in the output of the production line. A second use case demonstrates the differences between a coupled model and a simulation in *Plant Simulation,* if the timing of a temperature-based failure is important for the simulation results. We conclude with a presentation of prospects for further research.

Introduction

With the growing importance of energy consumption in the production of goods, the consideration of energy influences during the planning phase has also gained relevance. This is also noticeable in the research field of simulation-based planning. Various works discuss different solutions in terms of how energy aspects can be integrated into the simulation of material flows. Within a research project titled *SimEnergy* the Department of Organization of Production and Factory Planning at the University of Kassel developed a solution for simulation-based planning and evaluation of energy efficiency for production systems in the automotive industry in collaboration with the simulation service providers SimPlan AG and Limon GmbH and the application partner Volkswagen AG. This paper provides an overview of the state of the art in combined simulation of energy and material flows, describes the technical solution developed in the *SimEnergy* project and discusses further developments regarding the technical solution and some results of the simulation experiments. The paper concludes with further prospects for research and development.

1 Combined Simulation of Material and Energy Flow

When planning new production lines, companies use energy efficient technologies and procedures as a matter of course, but consideration of energy aspects when planning production or logistic systems is still subject to research [1]. Static approaches, such as the energy value stream analysis, [2] are not capable of taking into account dynamic interactions or stochastic distributions. With both being major requirements for a secure planning, simulation is a useful tool for the securing of planning results [3, 4]. Simulation is used not only in production and material flow planning but also when designing technical building services for cooling, heating or providing process energy [5, 6]. Some use cases require consideration of the material key performance indicators on the one hand and of energy key performance indicators on the other as well as the occurring dependencies between both. This is why researchers have developed several approaches using simulation for combined energy and material flow planning. These approaches differ in their methodology and in the simulation tools used:

- Discrete event simulation with additional simulation objects or tools for evaluation of energy key performance indicators of the model [7].
- Discrete event simulation with Excel-based evaluation of energy key performance indicators after simulating [8, 9].
- Two separate coupled models: discrete event simulation for the material flow simulation and continuous simulation for the energy simulation [10–12].
- Simulation using a tool that supports discrete event simulation as well as continuous simulation in one model [13].
- Continuous simulation for both energy and material flow [14].

The first approach calculates energy usage based on the material flow simulation. Each machine state (working, standby or idle) is coupled with an energy consumption level. They either integrate the energy consumption objects directly into the discrete event model or outsource it into a separate database that runs parallel to the simulation. While the material flow simulation directly influences the energy consumption, it is not influenced by energy key performance indicators (e.g. current energy consumption) itself. These approaches do not simulate the energy or physical models separately.

The second approach is similar to the first. However, it does not perform the calculations for energy usage live but following the simulation run. The user has to export the results to a calculation software (e.g. Excel) and perform the necessary operations there. While less effort is required for modeling and developing the required simulation objects, evaluation of the results is more time-consuming. Again, there is no possibility to simulate effects of energy key performance indicators on the material flow system.

If bidirectional dependencies between energy aspects and material flow have to be evaluated online, only the last three approaches will offer a suitable solution. While combining both models in one tool (e.g. *AnyLogic*) requires less effort than building two separate models, the simulation user needs to have knowledge about material flow modeling as well as a detailed understanding of physical and thermodynamic processes depending on the level of detail in the models. Using two separate specialized tools provides advantages, because experts of the respective fields are already familiar with them and use them in a non-coupled way in their day-to-day business.

If a solution provides an interface for communication between models, the simulation experts can focus on building their respective models as they would normally do. Enhanced by the required elements for communication, those models can be used for a combined, coupled simulation of bidirectional dependencies between the material flow model and the physical energy model.

In the *SimEnergy* project, the team decided to use *Plant Simulation* by Siemens Tecnomatix as a discrete event simulation tool for simulating the material flow in production and logistics and *MATLAB Simulink* by Mathworks for simulating the thermodynamic physical processes. On the one hand, the application partner is an automotive company and *Plant Simulation* is the most common tool used for the simulation of material flows for production planning and logistics in the automotive industry in Germany [15]. *MATLAB Simulink*, on the other hand, dominates the market for continuous simulation of physical processes [16]. This is why a combination of the two tools seemed reasonable for implementing a coupled simulation of energy and material flow for the given use case.

As it has already been described, the different solutions for simulation of material flows and energy processes differ not only in the effort required for modeling and analysis, but also in the effort required for acquiring data. The more specialised and detailed the models, the more necessary data with a higher level of detail. If physical processes are simulated to gain energy key performance indicators regarding the temperature in the factory, data about the heat emissions of the machines, the insulation of the building and air circulation is required, which would not be necessary, if the aim is to calculate energy usage depending on the machine states over time. One can, however, expect a higher level of detail in the results. Depending on the use case and on the objective of the simulation studies you should choose a suitable approach. What a simulation using two specialised, coupled models could look like and whether or not it provides additional value to the user will be discussed in the following sections.

2 SimEnergy Solution

The following section presents the simulation approach developed in the project *SimEnergy*, describes the application in a use case and discusses the results.

2.1 Technical solution

The technical solution developed in the *SimEnergy* project consists of a direct online-coupling of the two simulation tools *Plant Simulation* and *MATLAB Simulink*. The *Plant Simulation* model contains the production and logistic model with all machines, conveyor belts, buffers, etc. It uses TCP/IP-sockets for network communication. The *Simulink* model contains all energy systems, such as cooling tower, pumps, pipes, heat exchangers, etc., that are needed to model the heating and cooling of the machines and the supporting infrastructure. All required assets are modeled in one large *Simulink* model, some of which are grouped into subsystems. The user has to export the *Simulink* model as C-Code, to compile it into a *.dll-file and to embed it into a specially developed wrapper application. The wrapper application runs the model *.dll-file and handles the data exchange via TCP/IP for the *Simulink* model.

SimAssist, a tool developed by SimPlan, acts as a communication platform. A specially developed add-in provides functions for network communication between the *Plant Simulation* model and the *MATLAB* wrapper application and for synchronization of the simulation time. This is necessary because *Plant Simulation* is a discrete event simulation tool, while *Simulink* is a continuous one. Time-synchronization is achieved by simulating in fixed time steps, which also are data exchange intervals. The *SimAssist* tool ensures that both simulation models are at the same simulation time step. Figure 1 visualizes the described architecture.

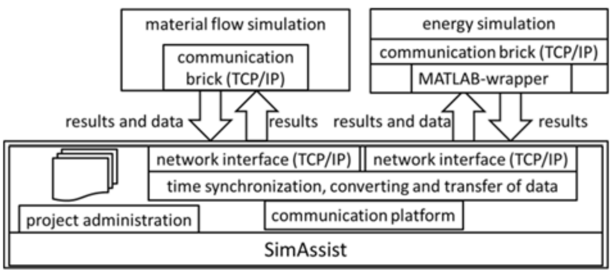

Figure 1: *SimEnergy* System architecture.

The *SimAssist* tool also handles the converting of data into different data types. This is necessary because *Plant Simulation* can only send and receive string data types, while *Simulink* requires numerical data types (e.g. real or integer).

The *Plant Simulation* model transfers the state of machines (working, idle and failed) to the *Simulink* model, which then calculates the temperatures accordingly. If the calculated temperature exceeds a critical value, the *Simulink* model transfers a message to the *Plant Simulation* model that the machine has to be set to 'failed'. If the simulation models contain more than one process, which requires data transfer, the models will combine all data into one string, which is transferred afterwards. This is the case when several machines exchange their states and influence the thermal model. The receiving model resolves the string into its components and transfers the data to the respective blocks in the model.

2.2 Application

The project team validated this approach by applying it to a use case in the automotive industry. The team chose the use case by means of two criteria: Firstly, whether the use case provides a clear connection between energy and material flow that justifies a coupled simulation, and secondly, whether there is enough input data available to build the two required models. The chosen production line consists of several interlinked machines for turning, washing and grinding of gearbox parts. A serially connected water pipe connects all electric cabinets of the machines and provides cooling water for them. On hot summer days, the electronics reach a critical temperature when the machines are at full load. Therefore, the machines have to be switched off. The interaction between the energy and the material flow exists firstly in the dependency between the temperature and the load of the machines (material flow influences temperature), and secondly, in the powering down of the machines when a critical temperature is reached (temperature influences material flow).

2.3 Results

Using the models, the project team executed several simulation runs. The user adjusted the critical temperature value for powering down in each simulation run to test the effects on the throughput of the production line. The simulation experiments illustrate that the solution provides valid results and that the coupling between *Plant Simulation* and *Simulink* works as designed. The correlation between the temperatures for powering down and the throughput of the production line is comprehensible [11].

3 Further Developments

While the *SimEnergy* solution provides an executable model-coupling platform with additional functionality for project management and export of results, it turns out to have several drawbacks. The biggest issue is the need to convert the *Simulink* model into a *.dll first so that it depends on a wrapper application to work properly. Furthermore, observing the animation of the model during the simulation run is impossible when converting it to a *.dll-file. Observing the animation of the model, however, is an important validation technique [3]. Besides, the user can only change the parameters of the simulation if this option is already prepared in the models beforehand and changes have to be made in the *SimAssist* software. Further changes require modifying the original model and a newly compiled *.dll-file. These three considerations led to the need to simplify the solution. The Department of Organization of Production and Factory Planning at the University of Kassel continued the development after the end of the project in 2015 by coupling the two simulation tools directly, abandoning all middleware. The next chapter describes the resulting solution.

3.1 Technical solution

As already described, there are three major problems which originally led to the development of a solution using *SimAssist* and a *MATLAB* wrapper application as middleware:

- The need for data type conversion between the models.
- The need for time-synchronization between a discrete event simulation tool and a continuous one.
- The need to resolve string data type network messages that contain data for several simulation blocks.

The authors solved the first issue by analyzing the possibilities that the simulation software provides and by extensive testing. Sending data from *Plant Simulation* to *Simulink* leads to the realization that the string data type, sent by *Plant Simulation*, is interpreted as ASCII Code in *Simulink*. Thus, when sending a figure one (1, e.g. for machine is working) or zero (0, e.g. for machine is idle) the 'TCP/IP receive block' in *Simulink* receives a 49 (for 1) or 48 (for 0) respectively. A simple mathematical operation in the model of subtracting 48 from the received value delivers the original message.

Information whether the machine is operating (1) or idle (0) is already enough for calculating its heat emissions. If more machine states are relevant they can also be expressed using numbers, like '3' for standby. Programmed methods in *Plant Simulation* retrieve the state of the machine and encode it into a single digit number.

Another problem that led to the original solution in the research project is the fact that the 'TCP/IP send' block in *Simulink* sends numerical data types, which *Plant Simulation* cannot interpret. After analysing the available blocks in *Simulink*, the authors decided that the 'to instrument' block is usable for communication with devices over network that require a string data type. *Plant Simulation* is able to interpret the messages sent by the 'to instrument' block and programmed methods convert the messages to integer variables.

Depending on the received value, machines can be marked as out-of-order, as idle or as working, thus simulating temperature caused failures. Figure 2 shows the newly developed architecture for directly coupled simulation models.

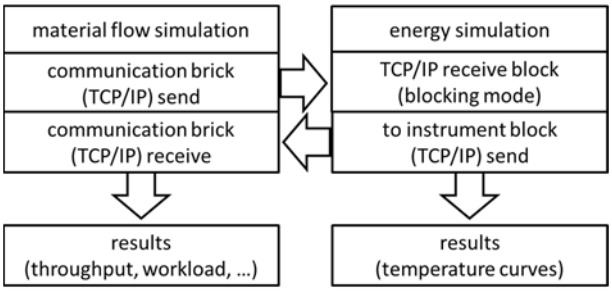

Figure 2: Architecture for directly coupled simulation models.

We transferred input data, such as the table containing the outside temperature during the day, which influences the cooling capacity of the cooling tower in the physical *Simulink* model, from the *Plant Simulation* model, where it was originally stored, directly into the *Simulink* model, eliminating the need to transfer that data, as it has no relevance for the material flow model.

Within the *SimEnergy* solution, the *SimAssist* software is responsible for time-synchronization between models. Now that we have developed a solution that no longer makes use of the SimAssist software, a new solution for time-synchronization has to be developed. In *Simulink*, we set the 'TCP/IP receive' block to 'blocking mode' so that the simulation continues to the next time step once data is received.

To prevent the *Plant Simulation* model from running ahead, we implement the sending sockets and the corresponding methods to stop the simulation time once data is sent. The simulation time continues once the model receives data from the *Simulink* model. The timer, which controls the time steps in which data is sent, is set to the same simulation time step as the *Simulink* 'TCP/IP receive' block. That means that both simulation models run alternately. The *Simulink* model is still a continuous simulation within each time step. However, when the time step is reached, it pauses until it receives new input data from the *Plant Simulation* model. This solution leads to both models running synchronously in fixed time steps. The received value is used for calculations within the entire time step. Consequently, changes in the machine states occurring in between two time steps have no effect on the *Simulink* model.

To further avoid the need to send several data encoded in one string, which leads to decoding problems, each machine connects to the respective blocks in the energy model by a separate socket block using different TCP/IP-ports. While this works well for now, it might get confusing for complex models.

To test this newly developed solution the team has modified the original models built by the simulation service providers in the *SimEnergy* project so that they use the new communication method. The results are positive: The runtime of the coupled models is comparable to using the SimAssist software. Time-synchronization worked well and both models run in fixed exchange intervals. The user reads the results directly from the models and is able to export the data to Excel for further processing. To simplify this process we write methods that store relevant data in tables and variables.

3.2 Experiments and results

As already mentioned in the introduction of this paper, it is questionable whether the increased workload for building two coupled simulation models provides any additional benefit for the user. One possible simplified solution would be to use a single *Plant Simulation* model and simulate the energy aspects using approximations. To compare both solutions, the authors ran coupled simulations first. The coupled solution delivered the following temperature curves with a critical temperature of 40° C and a restart temperature of 36° C.

In Figure 3 the curves M1 to M3 show the temperatures for the three examined machines.

T_Out shows the outside temperature during the day. Only M3 is subject to temperature caused powering off. The other machines are also affected because of the resulting blocking of the conveyor belt. The coupled *Plant Simulation* model shows the logistic key performance indicators like throughput in 24 hours and availability of the machines. M3 has temperature related failure rates of 18.54 % of the total operating time.

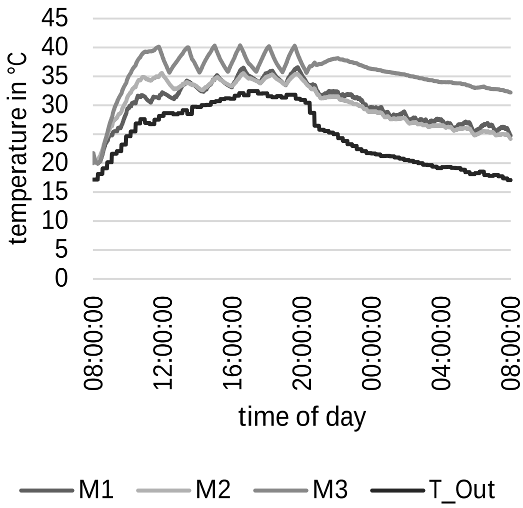

Figure 3: Temperature curves for the machines 1 to 3.

Table 1 shows the output of the three different products produced on this line for 24 hours of simulation time. As there are no random variables in the models and no parameters were changed, all three simulation runs deliver the same output numbers. We can also conclude that there are no randomly occurring issues with data exchange.

	drain_1 output	drain_2 output	drain_3 output	sum
run 1	688	549	467	1,704
run 2	688	549	467	1,704
run 3	688	549	467	1,704

Table 1: Output of three different product types in the coupled simulation model.

To test whether the same simulation results can be achieved by using a *Plant Simulation* model alone without coupling it with another model, we approximate the model behavior in *Plant Simulation*. The failure rate of 18.54 %, which resulted from the coupled simulation, is now used as availability in the machine block in *Plant Simulation*.

The block of machine 3 is parameterized with an availability of 81 % (rounded from 100 % - 18.54 % = 81.46 %) and a MTTR (mean time to repair) for cooling down of 10 minutes.

This time the simulation results depend on the random number seed. The failure rate and duration of machine 3 is the only parameter influenced by the random number seed. The residual model remains unchanged from the coupled experiment. We conducted five simulation runs with different seed values to obtain secure results. Table 2 shows the output numbers of each product type and the resulting average over the five simulation runs.

	drain_1 output	drain_2 output	drain_3 output	sum
run 1	674	543	474	1,691
run 2	658	492	430	1,580
run 3	696	575	485	1,756
run 4	706	582	496	1,784
run 5	695	571	489	1,755
average	685.8	552.6	474.8	1,713.2

Table 2: Output of three different product types in single Plant Simulation model.

As expected, the average output numbers are similar to the results of the coupled simulation.

3.3 Influence of on and off temperatures on output

According the Fourier's law, the heat flux density is proportional to the temperature gradient. When heat is only transported in one direction, the heat flow is described as in formula 1:

$$\dot{Q} = -\lambda * A * \frac{d\vartheta}{dx} \tag{1}$$

$\dot{Q}$ represents the heat flow, λ the thermal conductivity, A the surface, $d\vartheta$ the temperature difference and dx the thickness of the wall [17].

In our model, all variables apart from the temperature difference are constant or can be assumed to be constant during the simulation runs. That means that the effect of cooling the electric cabinet is biggest if the difference between the temperature of the cabinet and the temperature of the cooling water is as high as possible.

The longer the duration in which the machine is switched off, the smaller the benefit from the cooling because of the decreasing temperature difference. Thus, short intervals are desirable when switching the machine off for cooling.

We performed several experiments to examine these effects and their impact on the throughput of the material flow model. Table 3 shows the results of the experiments with 40° C as temperature for switching off (T_off) and 36° C, 38° C and 39° C for switching on (T_on).

T_off (°C)	T_on (°C)	output combined	failure rate	number of failures
40	36	1,704	18.54 %	6
40	38	1,774	15.43 %	10
40	39	1,811	13.75 %	13

Table 3: Results depending on the on/off temperatures.

As expected, we can see that with higher temperatures for switching on, the output of the production line increases and failure time decreases. However, the line had to be stopped more often with an increasing T_on. In conclusion, the output becomes higher for more frequent, but shorter off-times. The optimal operating situation is when the line never reaches the critical temperature. Thus, the operator should slow down production to such an extent that the machines approach critical temperature but never reach it.

3.4 Conclusion

Based on Chapter 3.2 we come to the conclusion that simple approximations in the material flow simulation lead to similar results in logistic key performance indicators. But it has to be remembered that the availability value for machine 3, which is the basis for the approximation, could only be obtained by using coupled simulation. Another possible way to obtain the required data is to measure the failure rates in the real-world system. If the system is still in the planning phase and no real machines are available, measuring is not an option. In this case, a coupled physics simulation of energy and material provides additional information to the simulation user and the additional effort might be justified depending on the use case.

Coupled simulation might also be useful for determining the optimal operating point for a production line if it depends on physical processes. However, in practice this may be difficult as the ideal operating speed depends on many variables like outside temperature or the load of all machines in the production line, which cannot be accurately forecasted. Furthermore, we neglected start-up times for machines in this scenario. Long start-up times will lead to preference of longer on/off intervals.

4 Second Use Case

The first use case from the *SimEnergy* project has only small differences in output values. Due to the relatively constant production of parts, the exact time of an occurring failure is not relevant to the output of the production line. To analyze the behavior of a system where the exact time of the failure (or any other event) matters, we define another u e case for our simulation.

4.1 Model description

To define a situation where the time of an event matters for the results of the simulation we built a model consisting of a soldering oven. It runs at a certain temperature, which is provided by a heater in the oven. Parts enter the oven on special workpiece carriers, which are transported on a conveyor belt and move slowly through the oven. At the end of the oven, they are separated into good and defective parts depending on the time spent in the oven. Figure 4 shows the conceptual model of the material flow model implemented in *Plant Simulation*.

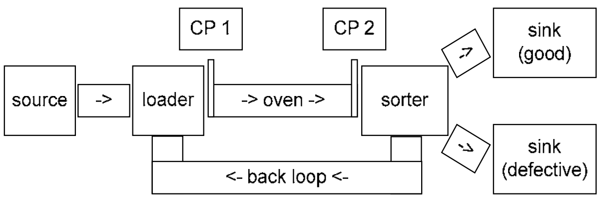

Figure 4: Conceptual model of the material flow.

The source generates the parts and a conveyor belt moves them to the loader where they are loaded onto the workpiece carriers. At checkpoint 1 (CP 1), the timestamp when they enter the oven is saved. After leaving the oven at checkpoint 2 (CP 2), the timestamp of exiting the oven is saved.

We use those values to calculate the time of stay in the oven for each part. At the sorter, we remove the parts from the workpiece carrier, which we put on a back loop to provide it for new parts at the loader. Depending on the time of stay in the oven, we separate parts into good parts and defective ones.

The *Simulink* model contains the model of the oven and its internal heating process and the heat loss via convection and radiation as well as the heat loss caused by the cold parts entering the oven. This heat loss depends on the material flow into the oven, which directly depends on the throughput. The *Plant Simulation* model collects throughput data for each time step (60 seconds) and transmits this aggregated value to the *Simulink* model, where the mass flow is calculated by multiplying the part count with the mass of the parts. The part temperature on entering the oven is considered constant. If the oven reaches a defined temperature, the *Simulink* model transmits a message to the *Plant Simulation* model that the oven is now ready. The production starts by the time the temperature of the oven has declined until it reaches the critical temperature. In this case, the *Simulink* model transmits a message to switch the oven to a 'failure' state. The production stops until the oven has heated up enough to continue production.

This time we entered random variables into our material flow model. The arrival time at the source is exponentially distributed and the working time at the loader is normally distributed. Parts do not arrive constantly at the source but in batches of 50. That means that there are times with production when a batch is in production and idle times. This way, we intended to examine the influence of the failure time on the throughput of the system and the throughput time of each part.

4.2 Experiments and results

At first, we performed coupled simulation runs. As the material flow model contains random variables this time we run five replications with a simulation time of 24 hours and look at the resulting values for throughput, throughput times and failures. Table 4 shows the average results for the coupled simulation experiment with five simulation runs with different seed values for the random variables.

key performance indicators	coupled simulation results
amount defective parts	212.2
amount good parts	1,438.6
total amount parts	1,650.8
maximum throughput time (hh:mm:ss)	00:14:38
minimum throughput time (hh:mm:ss)	00:03:40
average throughput time (hh:mm:ss)	00:05:15
failure rate (in percent)	15.56
absolute amount of failures	19.8
average time per failure (hh:mm:ss)	00:11:01

Table 4: Average results for the coupled simulation runs.

To compare the results of the coupled simulation with a simplified simulation in *Plant Simulation* as we did with the original *SimEnergy* models, we implemented the failure rate for the oven now into the *Plant Simulation* model as a failure profile with 84.44 % availability and a MTTR of 11 minutes as they result from the coupled simulation run. We set the 'failures relate to' setting to 'working time' because the oven can only fail due to critical temperature when it is working. Table 5 shows the results of the simplified failure behavior in the *Plant Simulation* model.

For the *Plant Simulation* experiment we performed 10 simulation runs. The average value for the 10 runs is shown in Table 5. As we can see, some values differ only slightly from the coupled simulation experiment. The differences are quite significant for some other key performance indicators. The higher maximum throughput time is caused by the unlikely event of two failures happening right after each other. In this case the throughput time of one part is considerably higher than in the coupled simulation model where two failures happening right after each other is impossible due to the nature of the heating and cooling model in *Simulink*. However, if some parts are affected by two failures, this also means that in total fewer parts are affected by failure thus reducing the total amount of defective parts. Failure rates in percent and the absolute amount of failures are smaller because in *Plant Simulation* failure rates only relate to working times. Thus, the failure times in relation to the total simulation time are reduced. Minimum throughput time remains constant. 3:40 min is the shortest time for a part to pass through the oven caused by the moving speed of the conveyor in the oven.

key performance indicators	coupled simulation	only *Plant Simulation*	difference
amount defective parts	212.2	103	51.46 %
amount good parts	1,438.6	1,568.8	-9.05 %
total amount parts	1,650.8	1,671.8	-1.27 %
maximum throughput time (hh:mm:ss)	00:14:38	00:29:42	-102.96 %
minimum throughput time (hh:mm:ss)	00:03:40	00:03:40	0.00 %
average throughput time (hh:mm:ss)	00:05:15	00:04:40	11.11 %
failure rate (in percent)	15.56 %	7.99 %	48.64 %
absolute amount of failures	19.8	11.1	43.94 %
average time per failure (hh:mm:ss)	00:11:01	00:09:54	10.16 %

Table 5: Comparison of simulation results.

4.3 Conclusion

In this second example we defined a scenario where the exact time of a failure is important for the simulation results as it influences the amount of defective parts and the throughput times. The approximation in *Plant Simulation* without coupling the model now delivers less accurate results compared to the coupled simulation. The thermodynamic processes of heating the oven and the cooling from the entering mass flow determine the exact time for temperature related failure. This behavior cannot be simulated accurately in *Plant Simulation* alone. Furthermore, to approximate the failure behavior we need data from the coupled model: The percentage of failure time and the average duration of failure. This data cannot be acquired without a coupled simulation because it depends on the material flow itself. Material flow key performance indicators like throughput and product type define the cooling of the oven and the temperature in the oven influences the material flow. Thus, both models depend on each other to deliver accurate results.

5 Prospects for Further Research

As the results for a coupled simulation approach using *Plant Simulation* and *Simulink* look promising, we are further developing this approach. Other use cases from theory and practice will provide further opportunities for testing whether the additional effort required for a coupled simulation delivers more accurate results than a simplified approximation in a single material flow model. Additionally, we will develop a guideline to support simulation users or service providers deciding which simulation approach under which circumstances will be the best one. For this purpose we will define criteria to identify interconnections between energy influences on the one hand and production and logistics on the other, which lead to the necessity of a coupled simulation.

6 Acknowledgments

The project "SimEnergy – simulation-based planning and evaluating of energy efficiency for production systems in the automotive industry" (Simulationsgestützte Planung und Bewertung der Energieeffizienz für Produktionssysteme in der Automobilindustrie) was funded by the Hessen Agentur (HA-Projekt-Nr.: 369/13-08) from 04/2013 to 03/2015.

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A Multimodeling Approach for the Simulation of Energy Consumption in Manufacturing

Thorsten Pawletta[1*], Artur Schmidt[1], Peter Junglas[2]

[1]Research Group Computational Engineering & Automation, Wismar University of Applied Sciences, Philipp-Müller-Straße 14, 23966 Wismar, Germany; *thorsten.pawletta@hs-wismar.de

[2]PHWT Vechta/Diepholz/Oldenburg, Rombergstraße 40, 49377 Vechta, Germany

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Abstract. In the design of manufacturing systems the consideration of resource usage, especially energy consumption, is getting more attention. However, the inclusion of all relevant physical processes in a unified modeling approach is a non-trivial task, if detailed analyses are required. The commonly used modeling approach for manufacturing systems is the discrete event modeling technique. However, models of physical processes are often continuous in nature and are modeled using ordinary differential equations or differential algebraic equations. Indeed, the investigation of such physical processes in manufacturing systems often demands a more specific consideration of process control operations, which are favorably modeled using state machines. To combine those different paradigms a multimodeling approach for manufacturing systems is proposed. The approach is illustrated by the example of a production line with an industrial furnace facility.

Introduction

The modeling and simulation of manufacturing systems has been a subject of study for several decades. According to [1], the typical modeling approach is discrete event modeling in this domain. This fact is reflected in the popular simulation tools applied in this field today. However, the situation has recently been changing, because of new aspects that have been taken into account and increasing requirements for accuracy.

One of these aspects is the time-dependent energy consumption of single-process operations, process chains or an overall production system, which becomes important in context with the increasing influence by renewable energy sources and the associated volatile energy availability and energy prices. Approaches for single-process operations, such as in [2], are focused on the energy consumption of single machine operations. They are often based on differential algebraic equations. However, approaches for investigating several machines coupled to a process chain use more abstract models mostly based on discrete event methods, such as in [3, 4]. Today most approaches related to energy processes in manufacturing are only focused on the simulation of energy consumption. In [5] it is emphasized that the energy consumption of a production line (PL) has to be considered in context with production planning and scheduling operations. In fact, the energy consumption then has to be examined together with all the other production performance indicators, such as through-put time, load factors, utilization etc. Hence, considerations regarding the model design and permissible model simplifications are important to master model complexity. For instance, it is necessary to determine how finely grained approximations for continuous energy consumption processes should be. In [6] a discrete-event approximation of those continuous behaviors is discussed, but depending on the research a more accurate approximation can be required.

In [7] a simulator coupling is proposed to execute manufacturing models with mixed discrete event and continuous process behaviour, what we call hybrid system dynamic. This approach is a customized solution and it shows well-known problems of simulator couplings.

A hybrid modeling approach based on the Discrete Event and Differential Equation System Specification (DEV&DESS) in [8] is discussed in [9]. It uses an in-line integration method that schedules the integration time as discrete events. Thus, continuous processes can be modeled using ordinary differential equations and are solved within a discrete event-oriented simulation environment. Both approaches are limited according to the modularity and clear separation between model specification and simulation execution.

This paper is a refined version of [10] and introduces a multimodeling approach for manufacturing systems to overcome those inadequacies. According to the theories in [11, 12], multimodeling means breaking a system into a network or hierarchy structure of individual models. The models may be specified by different dynamical behavior or are described using different methods [13, 14]. Hence, the overall multimodel is from the dynamical point of view often a hybrid model.

The approach is illustrated by the example of a component based PL with an industrial furnace facility that is refined using multimodeling in different layers. Beside the classical production performance indicators, it predicts the time-dependent energy consumption of its main consumer, the furnace facility. The prototypical example is implemented in the *MATLAB/Simulink* [10] environment using different modelling methods, such as entities, events, statecharts, ODEs and DAEs. Some parts of the implementation, pitfalls and simulation results will be presented to strengthen important parts of the approach.

1 Multimodeling Approach for Manufacturing Systems

In the past, methods of modeling and simulation were mainly used for the planning and optimization of the operation of manufacturing systems to determine production performance indicators, such as through-put time, facility utilizations, etc. The usage of discrete event modeling approaches is typical for those investigations. Figure 1 shows such a model of a simple PL implemented using *SimEvents* within *MATLAB/ Simulink*. The PL is reduced for simplicity to a minimal structure composed of: (i) a source component for generating the parts, called entities; (ii) a queue component with FIFO policy; (iii) a server component named furnace; (iv) a sink component for handled parts.

Statistical ports and signal scopes are omitted in the figure. Such a discrete event-based simulation model allows the prediction of the above mentioned performance indicators.

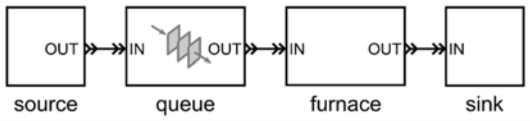

Figure 1: Simple discrete event-based production line model with a furnace component in *SimEvents*.

However, a precise determination of time-dependent energy consumptions of specific components or of an overall system requires a more detailed modeling of relevant components. In the case of the PL, the abstraction of the furnace facility as server in the sense of queuing theory is insufficient. Its abstraction has to be refined. According to [11, 14], states and events at this level of abstraction have to be refined to more accurate events and states at a next lower level. Such refinement leads to a model or network of models at a next lower level, which may be subject to refinement in subsequent steps. The resulting model of such a refined component is called a multimodel, consisting of interacting submodels. The multimodel of a component itself or the overall model often combines several modeling paradigms, and operates with different scales, or is a hybrid system, according to [13], if it includes both continuous-time and discrete-event behavior.

For a refinement of system components in discrete event-based manufacturing models we suggest a layer structure, as illustrated in Figure 2. Each layer represents a specific aspect of the component with well-defined interaction relations between the layers. This approach corresponds to the multilayered architecture, a common design pattern, used in software development [16]. Figure 2 suggests three general layers to refine a manufacturing system component, in which the models of different layers should specify the following characteristics.

- The *material flow* layer describes as highest abstraction the event-based flow of entities (i.e. parts) into and out of the component. It is the basic layer for connecting components to a production line or process chain model, such as illustrated in Figure 1.
  This layer may be refined in further steps using the entity-based modeling method to map internal material flows in more detail or to provide an interface to the other layers.

- The *process control* layer maps the local process control operations of the component. This is especially important for components with several internal manufacturing operations, where the parts are handled in several phases, which may be iterated according to an internal control program or other internal conditions.
- The process *physics* layer implements details of internal process operations that are relevant in the different manufacturing phases, such as energy flows, chemical reactions etc.

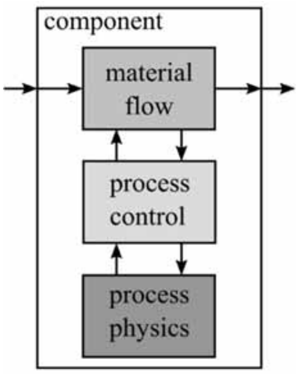

Figure 2: General layer structure to refine a manufacturing system component.

Depending on the specific characteristics of a component, the suggested layers can be arranged hierarchically or as a network of models to form a multimodel. Of course, each layer itself can be refined using models at a next lower level or a layer may be omitted. It is important to adapt the level of abstraction to the questions at hand and only include the processes that are needed to answer them.

Generally, each layer should provide its specific kind of information, which influences the interaction relations between the layers. The material flow layer is mainly concerned with logistic quantities such as waiting times and utilizations; the process control layer gives the order and timing of the different manufacturing phases, which can be useful in the context of other information. The kind of information provided by the physics layer can vary widely depending on the specific component characteristics and implemented details.

The various layers typically demand diverse modeling approaches and, depending on the level of abstraction, their scales are often different. For instance, in the considered example of the furnace component energy flows are accurately modeled based on physical laws, which are described by ODEs or DAEs.

2 Hybrid System Modeling and Simulation

The suggested multimodeling approach for manufacturing system modeling combines several modeling methods to describe different dynamical behaviour, called a hybrid system. Subsequently, we want to highlight some modelling methods and related simulation software.

2.1 Modeling methods

We will consider the modeling methods regarding the suggested layer structure in Figure 2. The material flow layer is often specified using a discrete-event modeling method, which defines abstract entities moving between stationary components and acting on them [8]. The entities are identified in manufacturing systems with workpieces or tools; temporary components move between production facilities.

A convenient method to describe the different manufacturing phases in a production facility, which is the concern of the process control layer, is that of state graphs [17]. The phases directly correspond to the states and the transitions describe the internal process logic. Alternatively, one could again use a process-based approach, wherein the entities denote abstract control tokens.

The actual manufacturing operations, here summarized under the term process physics, are often modeled based on natural or technical laws, e.g. from mechanics, thermodynamics or chemistry. This results in continuous models based on differential equations (ODEs). If the description contains algebraic constraints or the equations are constructed automatically using a physical modeling approach [18], then the mathematical model is enlarged to a system of differential algebraic equations (DAEs).

2.2 Related simulation tools

For the simulation of the logistic and process-oriented aspects of a production system several discrete event-based simulation environments exist and are in wide industrial use, such as *Arena* [19] and *Plant Simulation* [20]. Usually these programs lack algorithms such as ODE or DAE solvers to cope with continuous system specifications. This is why different simulators are coupled to solve such problems, such as in [7]. The introduced multimodel structure supports such simulator couplings, but it cannot rectify its general problems.

Instead, one should use a software environment that is capable of hybrid modeling and simulation. Such an environment, increasingly used for manufacturing system simulation, is *AnyLogic* [21]. It offers system dynamics, discrete event and agent-based methods. However, the mapping of complex ODEs to system dynamics diagrams is quickly confusing and physical modeling techniques, according to [18], are not supported. As a consequence, it may be only a useful choice for multimodeling problems with relatively simple continuous process physics.

Another widely used software supporting multimodeling, although less popular in the manufacturing simulation domain, is the Matlab/Simulink environment. Originally designed for the simulation of continuous systems using the signal flow paradigm, it can be extended using additional toolboxes and blocksets to include discrete, discrete event or physical modeling features: (i) The *SimEvents* blockset enables discrete event modeling based on the entity approach; (ii) *Stateflow* provides state chart modeling techniques; and (iii) *Simscape* expands the continuous tool chest with physical modeling features. This software environment provides the widest range of features for multimodeling today and it is already used and accepted in other engineering domains. Hence, it will be used in the following to illustrate and validate the suggested multimodeling approach by implementing some concrete examples.

An alternative choice could be to use a *Modelica* based solution [18] with the additional packages described in [22, 23] or *Ptolemy* [24] with the *OpenModelica* extension according to [25]. However, both *Modelica* and *Ptolemy* are even more unknown than *MATLAB/Simulink* in the manufacturing system community.

3 Basic Application to a Manufacturing System Component

To illustrate the introduced approach the furnace component of the PL model in Figure 1 will be analyzed for multimodeling and a set of models with different levels of abstraction will be designed.

3.1 Multimodeling of furnace component

Our objective of multimodeling is the refinement of the furnace component to investigate its time-related energy consumption. Industrial furnaces are widely used in metalworking processes and are one of the most extensive energy consumers in manufacturing systems. In addition, their internal operation is generally rather complex, making this an ideal example for refinement using different modeling approaches. The operation of such a furnace is patterned in the following after the descriptions in [9, 26].

When parts arrive at the furnace, they are collected until a given batch size is reached. A complete batch then enters the furnace, is processed and leaves the furnace. Then, the batch will probably be resolved for processing the parts by other facilities. The refinement of such internal processes of a component is part of the material flow layer, as demonstrated in Figure 2.

Moreover, the heat treatment itself consists of several phases that are implemented by a local control; these are mapped and refined at the process control layer. Figure 3 shows an example of such a control with six operation phases.

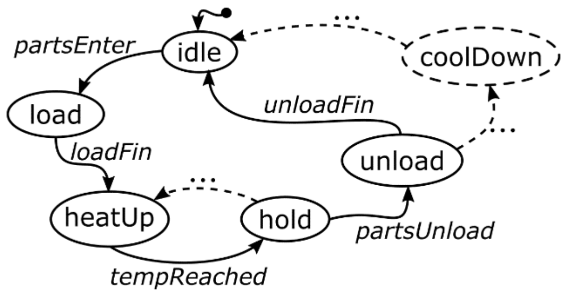

Figure 3: State graph describing a local control of furnace operations.

The idle phase spans the times before parts have entered and after all parts have left the furnace. During the load phase parts enter the furnace. In the heat-up phase the furnace is heated until a given temperature is reached; this is then held constant during the hold phase. According to the requirements, the heat-up and hold phases can be iterated several times with different temperatures. Finally, the parts leave the oven in the unload phase. An additional cool-down phase may be included either to make sure that the parts leave the furnace with a moderate temperature or to describe a shutdown of the furnace.

Since the focus of our example study lies on the energy consumption, the heat flows in the furnace have to be considered in more detail, and must be refined at the process physics layer (Fig. 2). The energy source is the power supply of the actual heater. From here the heat flows mainly through convection and radiation processes to the parts and to the internal structures and the casing of the furnace. During the heat-up and hold phases losses are mainly due to conduction through the casing into the environment, while in the load or unload phases additional losses are caused by the open doors. Because of the complicated geometry, the physical details, especially of the convection processes, are also rather complicated. However, for the estimation of the total heat flows common approximative methods usually give quite accurate results. Concrete mathematical models for specifying the process physics will be considered afterwards in context with their prototypical implementation.

Based on the previous considerations, Figure 4 shows the multimodel structure with defined interfaces for the refinement of our furnace component based on the layers introduced in Figure 2. In this abstraction it consists of three interacting models: (i) MF for the material flow; (ii) PC for the process control; and (iii) PP for the process physics. The labels (B) and (C) are not of interest at this point.

The models have to communicate in several ways:

- MF receives parts from the external input port <1> and sends to the PC the number of parts that have entered the MF.
- When the batch size is reached, the PC starts the PP, which models the different manufacturing phases during the operation of the furnace.
- During the operation of the furnace the PC signals the current manufacturing phase to the PP, which adapts the internal heat flows accordingly. This can mean changing the supplied heat between the heating and holding phases or increasing the losses due to the doors being open while loading or unloading.
- In return the PP sends the current temperature values of the furnace and the parts to the PC, which uses them to determine whether the heat-up phase or the optional final cool-down phase of the furnace is complete (Fig. 3).
- When the manufacturing phase unload (Fig. 3) is finished, the PC sends a *leaving* signal to the MF, which accordingly forwards the processed parts to its external output port <2>.

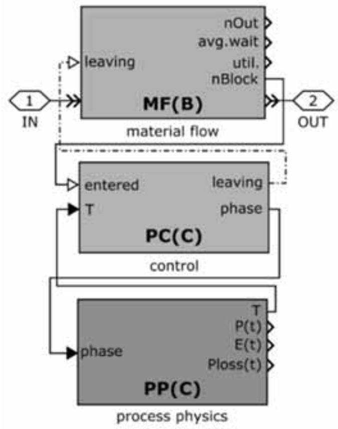

Figure 4: Basic multimodel structure with defined interfaces for the refinement of the furnace component.

Each model has its specific set of parameters and output quantities: The MF defines the batch size and logistic properties such as average waiting time and machine utilization; the PC gets the heating program and outputs the time in the different manufacturing phases. The PP needs a lot of physical parameters for the calculation of the heat flows and provides the power requirements during the process phases as well as the total energy consumption.

3.2 Design of a model library for the furnace component

Based on the basic multimodel structure in Figure 4, a set of models for each layer has been implemented and organized in a library (Fig. 5). The several models use different modeling methods or have varying levels of detail. They are labeled with two letters denoting the layer and a third letter in brackets giving the level of detail in ascending order, with (A) being the simplest model:

- The basic material flow model MF(A) uses only a simple server, while MF(B) explicitly contains an input tray, where the batch is compiled.
- The process control subsystem PC(A) uses a simple entity-based model, implemented in *SimEvents*, to describe one pass through the four basic process phases and ignoring idle and cool-down phases. PC(B) enables a repetition of heat-up and hold phases according to its heat program parameter, implemented as an entity-based model in *SimEvents*. Additionally, PC(C) adds a cool-down phase, but because of the more complex control logic it is implemented using the state machine approach with *Stateflow*.

- The process physics model PP(A) uses only the internal oven temperature and a simple formula for the global losses, while PP(B) adds the temperature of the parts, the heat transfer between oven and parts and additional losses during the load and unload phases. Both use standard *Simulink* blocks to implement the corresponding differential equations. Finally, PP(C) employs physical modeling, which is modeled using *Simscape* for the same physical processes as PP(B). This makes the physical model structure more transparent and easier for engineers to expand.

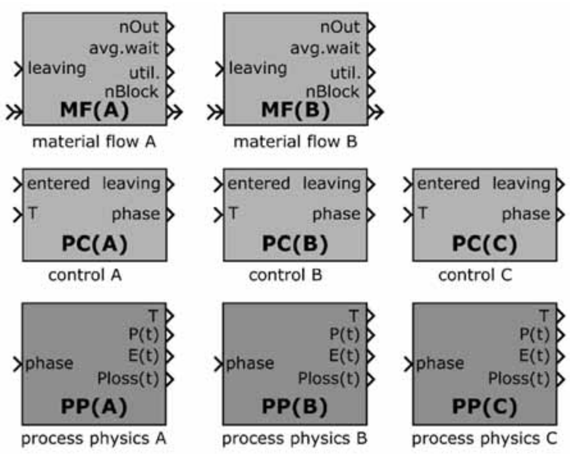

Figure 5: Library with models for composing several multimodels with different levels of detail for the furnace component.

4 Some Modeling & Implementation Details

In the following, three multimodel variants for the furnace will be described in more detail: (i) a very basic multimodel named *ovenBAA* – the capital letters stand for the composition of MF(B), PC(A) and PP(A) models; (ii) a medium complex multimodel *ovenBCA*; and (iii) the most complex multimodel variant *ovenBCC*. While this section is devoted to some implementation details of the single models used in the three multimodels, the next one will discuss some simulation results. The implementation was carried out using the *MATLAB/Simulink* environment and related tools.

4.1 Material flow model

All of the examples considered here use the extended model MF(B) for mapping the internal material flow.

The entity-based model structure of MF(B) (Fig. 6) consists of two simple servers: the first for the *input tray*; and the second (*N-Server*) for the furnace proper. Both hold incoming entities (i.e. parts) up to the given batch size, until their succeeding gates open to transfer the entities to the next stage. The intermediate *Gate* guarantees that a full batch is always delivered to the furnace; the final *Release Gate* is triggered – by the model at the process control layer (Figs. 7, 8) – at the end of the unload phase.

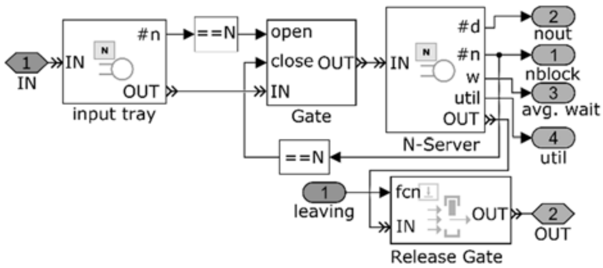

Figure 6: Discrete event-based model of MF(B) using *SimEvents*.

4.2 Process control models

The process control model starts when the number of parts that have entered at the material flow layer is equal to the batch size. In the process control model PC(A) (Fig. 7), implemented using *SimEvents*, this leads to the creation of a control entity that passes through a line of servers denoting the different phases. Except for one, all servers simply have a fixed processing time; only the heat-up phase is different. Here the entity is held in a server until the current oven temperature, which is computed in the model at the physics layer (Figs. 9, 10), has reached the given temperature T_{set}. After the unload phase, the control entity is destroyed and the wake-up signal (*trigger*) is generated, which opens the *Release Gate* in the model at the material flow layer (Fig. 6).

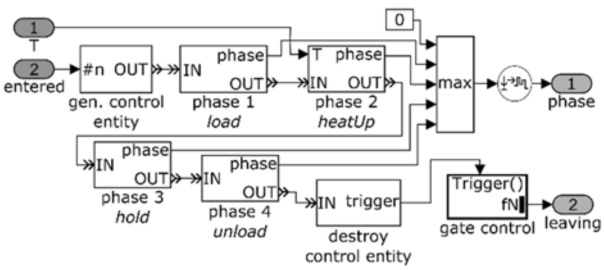

Figure 7: Discrete event-based model of PC(A) using *SimEvents*.

The much more elaborate process control model PC(C) (Fig. 8) incorporates all six phases, pictured in Figure 2, as well as possible repetition of the heat-up and hold phases. According to the theory in [8], it is a hybrid DEV&DESS model. It is modeled based on the state machine approach, but it includes continuous state event handling and has been mainly implemented using *Stateflow*. The two auxiliary subsystems (*schedTEvent, checkTemperature*) create events when the waiting time has changed or the heat-up or cool-down temperature has been reached. The model PC(C) is essentially an adapted version of a model described in [9].

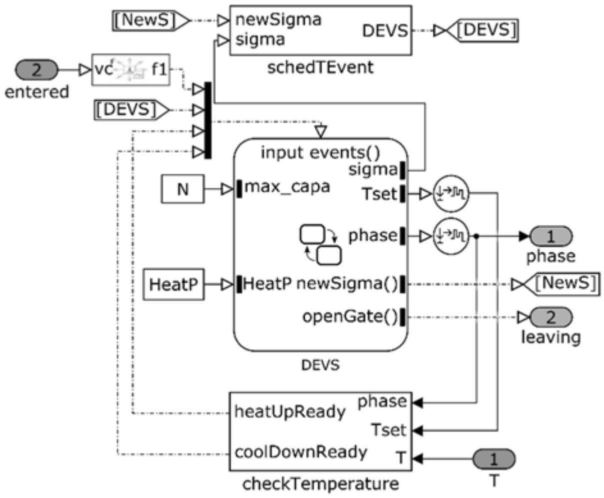

Figure 8: Discrete event-based model with continuous state event handling of PC(C) mainly using *Stateflow*.

4.3 Process physics models

The basic process physics model PP(A) (Fig. 9) uses a simple power balance to compute the change of the oven temperature T_0:

$$C_0 \dot{T}_0 = P_{heat} - P_{loss} \quad (1)$$

where C_0 is the total heat capacity of the oven. The power loss is computed with Newton's simple law of cooling:

$$P_{loss} = k_a (T_0 - T_e) \quad (2)$$

where T_e is the temperature of the surroundings and k_a a constant that subsumes all convective and conductive processes. The heating power is assumed to be constant during the heat-up phase and to match the losses during the hold phase:

$$P_{heat} = \begin{cases} P_H & heat-up \\ k_a (T_0 - T_e) & hold \end{cases} \quad (3)$$

For the computation of the total power demand of the furnace, a constant power P_0 is added, which subsumes all non-heating processes, such as a base load or the power electronics.

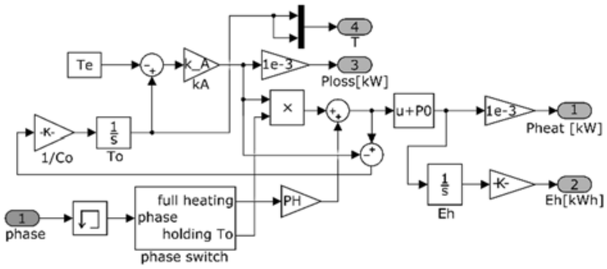

Figure 9: ODE-based model of PP(A) using Simulink.

The model PP(C) (Fig. 10) uses physical modeling based on *Simscape* to incorporate much more physical details, such as convection and radiation from the furnace – during load and unload phases – to the environment. The governing differential algebraic equations are not built up explicitly here; instead, the physical components such as heat capacities and various kinds of heat flow are represented directly, which makes the physical structure of the model much clearer.

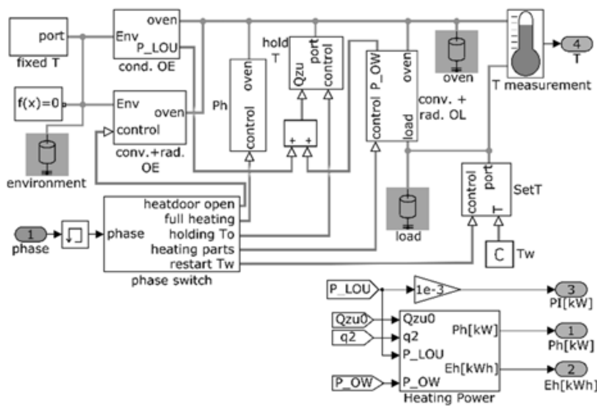

Figure 10: Physical model (DAE) of PP(C) using *Simscape*.

4.4 Implementation pitfalls

The extension of *MATLAB/Simulink* by several packages (blocksets) is necessary to make a multi-paradigm model possible, but it also leads to small inconsistencies, which have to be overcome. A minor nuisance here is the large number of different ways used to express values and signals in the packages used: Simple scalar values can be time-based in *Simulink*, event-based in *SimEvents* or physical-valued in *Simscape*. An event can be defined by a sample time hit, a rapid value change (*edge*), a special trigger signal or a function call.

To clearly define a common interface for the interacting models, their external values are fixed in the following way: The temperature and phase values are time-based; the number of parts is event-based; and the *leaving* signal is a function call. If the internal implementation of a block generates differing types, then one has to use one of the many converter blocks to get the proper kind of signal, e.g. the round *Event to Timed Signal blocks* that can be seen in Figures 7 and 8.

This problem is especially annoying in the physical modeling environment. The large number of necessary converters and reference points clutters the model and destroys the clear physical structure. Hiding them in subsystems is an obvious way to regain an ordered visible representation of the underlying physics model.

5 Exemplary Simulation Results

Using the introduced approach, a large number of simulation studies is possible to calculate multifaceted performance indicators. We will restrict our exemplary consideration to the energy consumption of the furnace that is the main consumer in our simple production line. Moreover, we will investigate the costs of refinement relating to the simulation run time by comparing different multimodels, which use different modeling paradigms or are based on a different level of detail.

5.1 Results relating to the energy aspect

In the exemplary experiment 24 parts were processed using a batch size of six. After the heat-up phase their temperatures were held first to 400 °C for 40 minutes, then to 800 °C for 30 minutes. Figure 11 shows some simulation results related to the energy consumption, calculated using our most complex multimodel variant *ovenBCC*: the temperatures of the furnace and parts, the power consumption of the furnace, the accumulated used energy and the current internal manufacturing phase, each as functions over time.

The results are similar to those presented in [9], but *ovenBCC* incorporates more details, especially of the physical model layer. The other two example models *ovenBAA* and *ovenBCA* basically reproduce the results from [9], since they are based on the same physical model assumptions. For comparison, Table 1 shows the total energy use E_1 at the exit of the last part and E_2 at the end of the simulation; Figure 12 displays the power consumption for the three models.

Model	E_1 [kWh]	E_2 [kWh]
ovenBAA	71.3	108.8
ovenBCA	69.0	106.6
ovenBCC	82.6	117.6

Table 1: Comparison of the total energy consumption.

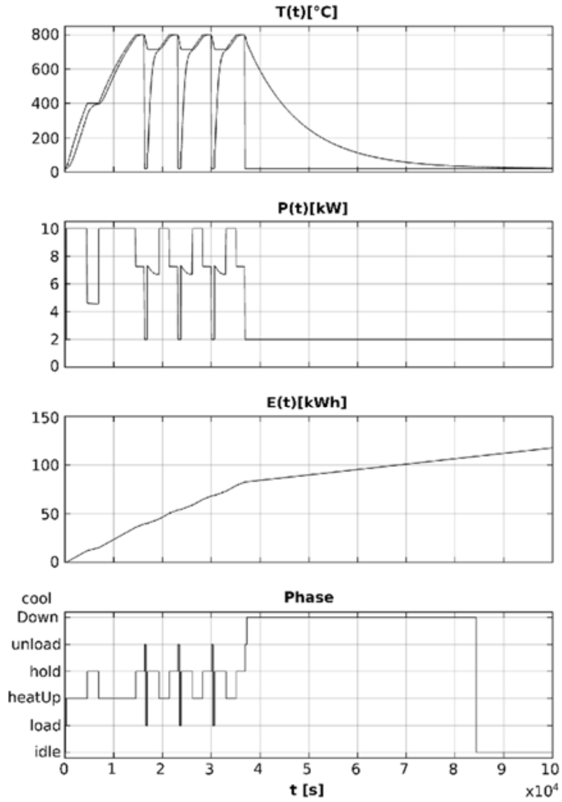

Figure 11: Simulation results of model variant ovenBCC.

The higher energy needs in variant *ovenBCC* are due to the heating of the parts, which enter the oven with the low temperature of the environment – an effect that has not been taken into account in the other models. The small difference between the two simpler multimodel variants results from the different timing of the phases, as can be seen from Figure 12.

It is interesting to note that the total energy results only differ by 10 % - 15 %. If this level of accuracy is sufficient for the question at hand, e.g. for a global assessment of a complex production line, then one can use one of the simple physics models. However, Figure 12 shows that for a detailed examination of the power needs during the individual phases one has to stick to the complexities of multimodel variant *ovenBCC*.

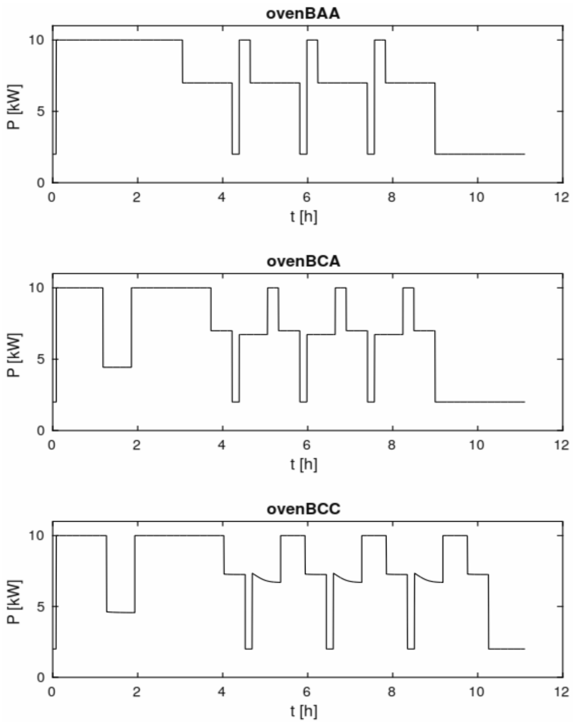

Figure 12: Comparison of the power results.

5.2 Comparison of run times

How much do we pay for the additional level of detail in the complex multimodel? For a comparison of run times, the number of parts was raised to 600 and three runs were performed for each multimodel. To get rid of loading and compile times, the means of only the last two results were taken, leading to the values in Table 2.

Model	Run Time [s]
ovenBAA	25.1
ovenBBA	27.7
ovenBCA	20.7
ovenBCB	39.3
ovenBCC	49.8

Table 2: Comparison of run times.

The results show that the complex physical model using *Simscape* in multimodel *ovenBCC* (line 5) costs a factor of two in execution time, which can be reduced in this case to a factor of 1.6 by replacing DAE-based physical modeling with standard ODE methods using Simulink (*ovenBCB,* line 4). However, we see essential differences in execution time for multimodels with the same simple process physics model PP(A) (line 1-3), which are surprising.

The multimodels *ovenBBA* (line 2) and *ovenBCA* (line 3) use process control models of nearly the same complexity, but in *ovenBBA* implemented with *SimEvents* and in *ovenBCA* with *Stateflow*. Moreover, the multimodel *ovenBCA* (line 3) uses the more complex process control model PC(C), than *ovenBAA* (line 1) with the PC(A) model that was implemented with *SimEvents*. Apparently, the implementation of *SimEvents* has some potential for optimization.

6 Conclusion

The introduced multimodel approach supports the component-oriented refinement of manufacturing system models, using various modeling methods and models with different levels of abstraction. Generally, it suggests a refinement of components based on the three logical layers material flow, process control and process physics.

The first layer maps the internal material flow. It delivers an external input and output interface for connecting with other components in a manufacturing system model and an internal interface for communication with the second layer. The dynamic behavior at this layer is generally discrete event-based. In the second layer local process control operations are modeled. This layer provides event-based control inputs for the other two layers, but it could be necessary to handle state events of continuous values as well. In the third layer specific process operations should be mapped. The dynamic behavior at this layer can vary significantly and particularly depends on the level of abstraction. Of course, depending on the characteristics of a system component and the intended level of abstraction, layers may themselves be omitted or refined using several interacting models.

The paper illustrated the approach using the example of a production line with an industrial furnace as the main component. According to the layers, models with different levels of abstraction have been implemented for the furnace, which could be aggregated to a multimodel. Then, the energy consumption of the furnace was investigated with three different multimodels and the simulation run times were measured. Hence, accuracy effects and computing costs could be compared.

The approach opens many new ways for investigating manufacturing systems, but the complexity is increasing. Hence, in the next step it should be combined with metamodeling techniques such as those considered in [27].

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EUROSIM 2019

10th EUROSIM Congress on Modelling and Simulation

La Rioja, Logroño, Spain, July 2019

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snorek@fel.cvut.cz

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a.w.heemink@its.tudelft.nl

DBSS / A. W. Heemink
Delft University of Technology, ITS - twi,
Mekelweg 4, 2628 CD Delft, The Netherlands

DBSS Officers	
President	A. Heemink, *a.w.heemink@its.tudelft.nl*
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djouani@u-pec.fr

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Last data update March 2008

ISCS – Italian Society for Computer Simulation

The Italian Society for Computer Simulation (ISCS) is a scientific non-profit association of members from industry, university, education and several public and research institutions with common interest in all fields of computer simulation.

→ *www.eurosim.info*
Mario.savastano@uniina.it
ISCS / Mario Savastano,
c/o CNR - IRSIP,
Via Claudio 21, 80125 Napoli, Italy

ISCS Officers	
President	M. Savastano, *mario.savastano@unina.it*
Vice president	F. Maceri, *Franco.Maceri@uniroma2.it*
Repr. EUROSIM	F. Maceri, *Franco.Maceri@uniroma2.it*
Secretary	Paola Provenzano, *paola.provenzano@uniroma2.it*
Edit. Board SNE	M. Savastano, *mario.savastano@unina.it*

Last data update December2010

LIOPHANT Simulation

Liophant Simulation is a non-profit association born in order to be a trait-d'union among simulation developers and users; Liophant is devoted to promote and diffuse the simulation techniques and methodologies; the Association promotes exchange of students, sabbatical years, organization of International Conferences, courses and internships focused on M&S applications.

→ *www.liophant.org*
info@liophant.org
LIOPHANT Simulation, c/o Agostino G. Bruzzone,
DIME, University of Genoa, Savona Campus
via Molinero 1, 17100 Savona (SV), Italy

LIOPHANT Officers	
President	A.G. Bruzzone, *agostino@itim.unige.it*
Director	E. Bocca, *enrico.bocca@liophant.org*
Secretary	A. Devoti, *devoti.a@iveco.com*
Treasurer	Marina Masseimassei@itim.unige.it
Repr. EUROSIM	A.G. Bruzzone, *agostino@itim.unige.it*
Deputy	F. Longo, *f.longo@unical.it*
Edit. Board SNE	F. Longo, *f.longo@unical.it*
Web EUROSIM	F. Longo, *f.longo@unical.it*

Last data update June 2016

LSS – Latvian Simulation Society

The Latvian Simulation Society (LSS) has been founded in 1990 as the first professional simulation organisation in the field of Modelling and simulation in the post-Soviet area. Its members represent the main simulation centres in Latvia, including both academic and industrial sectors.

→ *briedis.itl.rtu.lv/imb/*
merkur@itl.rtu.lv
LSS / Yuri Merkuryev, Dept. of Modelling and Simulation Riga Technical University
Kalku street 1, Riga, LV-1658, LATVIA

LSS Officers	
President	Yuri Merkuryev, *merkur@itl.rtu.lv*
Secretary	Artis Teilans, *Artis.Teilans@exigenservices.com*
Repr. EUROSIM	Yuri Merkuryev, *merkur@itl.rtu.lv*
Deputy	Artis Teilans, *Artis.Teilans@exigenservices.com*
Edit. Board SNE	Yuri Merkuryev, *merkur@itl.rtu.lv*
Web EUROSIM	Vitaly Bolshakov, *vitalijs.bolsakovs@rtu.lv*

Last data update June 2016

KA-SIM Kosovo Simulation Society

Kosova Association for Modeling and Simulation (KA – SIM, founded in 2009), is part of Kosova Association of Control, Automation and Systems Engineering (KA – CASE). KA–CASE was registered in 2006 as non Profit Organization and since 2009 is National Member of IFAC – International Federation of Automatic Control. KA-SIM joined EUROSIM as Observer Member in 2011. In 2016, KA-SIM became full member.
KA-SIM has about 50 members, and is organizing the international conference series International Conference in Business, Technology and Innovation, in November, in Durrhes, Albania, and IFAC Simulation Workshops in Pristina.

→ *www.ubt-uni.net/ka-case*
✉ *ehajrizi@ubt-uni.net*
⌧ MOD&SIM KA-CASE; Att. Dr. Edmond Hajrizi
Univ. for Business and Technology (UBT)
Lagjja Kalabria p.n., 10000 Prishtina, Kosovo

KA-SIM Officers	
President	Edmond Hajrizi, *ehajrizi@ubt-uni.net*
Vice president	Muzafer Shala, *info@ka-sim.com*
Secretary	Lulzim Beqiri, *info@ka-sim.com*
Treasurer	Selman Berisha, *info@ka-sim.com*
Repr. EUROSIM	Edmond Hajrizi, *ehajrizi@ubt-uni.net*
Deputy	Muzafer Shala, *info@ka-sim.com*
Edit. Board SNE	Edmond Hajrizi, *ehajrizi@ubt-uni.net*
Web EUROSIM	Betim Gashi, *info@ka-sim.com*

Last data update December 2016

PSCS – Polish Society for Computer Simulation

PSCS was founded in 1993 in Warsaw. PSCS is a scientific, non-profit association of members from universities, research institutes and industry in Poland with common interests in variety of methods of computer simulations and its applications. At present PSCS counts 257 members.

→ *www.eurosim.info* (*www.ptsk.man.bialystok.pl)*
✉ *leon@ibib.waw.pl*
⌧ PSCS / Leon Bobrowski, c/o IBIB PAN,
ul. Trojdena 4 (p.416), 02-109 Warszawa, Poland

PSCS Officers	
President	Leon Bobrowski, *leon@ibib.waw.pl*
Vice president	Tadeusz Nowicki, *Tadeusz.Nowicki@wat.edu.pl*
Treasurer	Z. Sosnowski, *zenon@ii.pb.bialystok.pl*
Secretary	Zdzislaw Galkowski, *Zdzislaw.Galkowski@simr.pw.edu.pl*
Repr. EUROSIM	Leon Bobrowski, *leon@ibib.waw.pl*
Deputy	Tadeusz Nowicki, *tadeusz.nowicki@wat.edu.pl*
Edit. Board SNE	Zenon Sosnowski, z.sosnowski@pb.ed.pl
Web EUROSIM	Magdalena Topczewska *m.topczewska@pb.edu.pl*

Last data update December2013

SIMS – Scandinavian Simulation Society

SIMS is the *Scandinavian Simulation Society* with members from the four Nordic countries Denmark, Finland, Norway and Sweden. The SIMS history goes back to 1959. SIMS practical matters are taken care of by the SIMS board consisting of two representatives from each Nordic country (Iceland one board member).

SIMS Structure. SIMS is organised as federation of regional societies. There are FinSim (Finnish Simulation Forum), DKSIM (Dansk Simuleringsforening) and NFA (Norsk Forening for Automatisering).

→ *www.scansims.org*
✉ *esko.juuso@oulu.fi*
⌧ SIMS / Erik Dahlquist, School of Business, Society and Engineering, Department of Energy, Building and Environment, Mälardalen University, P.O.Box 883, 72123 Västerås, Sweden

SIMS Officers	
President	Erik Dahlquist, *erik.dahlquist@mdh.se*
Vice president	Bernd Lie, *lie@hit.noe*
Treasurer	Vadim Engelson, *vadim.engelson@mathcore.com*
Repr. EUROSIM	Erik Dahlquist, *erik.dahlquist@mdh.se*
Edit. Board SNE	Esko Juuso, *esko.juuso@oulu.fi*
Web EUROSIM	Vadim Engelson, *vadim.engelson@mathcore.com*

Last data update June 2016

SLOSIM – Slovenian Society for Simulation and Modelling

SLOSIM - Slovenian Society for Simulation and Modelling was established in 1994 and became the full member of **EUROSIM** in 1996. Currently it has 90 members from both Slovenian universities, institutes, and industry. It promotes modelling and simulation approaches to problem solving in industrial as well as in academic environments by establishing communication and cooperation among corresponding teams.

→ www.slosim.si

slosim@fe.uni-lj.si

SLOSIM / Vito Logar, Faculty of Electrical Engineering, University of Ljubljana, Tržaška 25, 1000 Ljubljana, Slovenia

SLOSIM Officers	
President	Vito Logar, *vito.logar@fe.uni-lj.si*
Vice president	Božidar Šarler, *bozidar.sarler@ung.si*
Secretary	Aleš Belič, *ales.belic@sandoz.com*
Treasurer	Milan Simčič, *milan.simcic@fe.uni-lj.si*
Repr. EUROSIM	B. Zupančič, *borut.zupancic@fe.uni-lj.si*
Deputy	Vito Logar, *vito.logar@fe.uni-lj.si*
Edit. Board SNE	B. Zupančič, *borut.zupancic@fe.uni-lj.si* Vito Logar, *vito.logar@fe.uni-lj.si* Blaž Rodič, *blaz.rodic@fis.unm.si*
Web EUROSIM	Vito Logar, *vito.logar@fe.uni-lj.si*

Last data update December 2016

UKSIM - United Kingdom Simulation Society

The UK Simulation Society is very active in organizing conferences, meetings and workshops. UKSim holds its annual conference in the March-April period. In recent years the conference has always been held at Emmanuel College, Cambridge. The Asia Modelling and Simulation Section (AMSS) of UKSim holds 4-5 conferences per year including the EMS (European Modelling Symposium), an event mainly aimed at young researchers, organized each year by UKSim in different European cities.

Membership of the UK Simulation Society is free to participants of any of our conferences and their co-authors.

→ *www.uksim.org.uk*

david.al-dabass@ntu.ac.uk

UKSIM / Prof. David Al-Dabass
Computing & Informatics,
Nottingham Trent University
Clifton lane, Nottingham, NG11 8NS
United Kingdom

UKSIM Officers	
President	David Al-Dabass, *david.al-dabass@ntu.ac.uk*
Secretary	A. Orsoni, *A.Orsoni@kingston.ac.uk*
Treasurer	A. Orsoni, *A.Orsoni@kingston.ac.uk*
Membership chair	G. Jenkins, *glenn.l.jenkins@smu.ac.uk*
Local/Venue chair	Richard Cant, *richard.cant@ntu.ac.uk*
Repr. EUROSIM	A. Orsoni, *A.Orsoni@kingston.ac.uk*
Deputy	G. Jenkins, *glenn.l.jenkins@smu.ac.uk*
Edit. Board SNE	A. Orsoni, *A.Orsoni@kingston.ac.uk*

Last data update March 2016

RNSS – Russian Simulation Society

NSS - The Russian National Simulation Society (Национальное Общество Имитационного Моделирования – НОИМ) was officially registered in Russian Federation on February 11, 2011. In February 2012 NSS has been accepted as an observer member of **EUROSIM**, and in 2015 RNSS has become full member.

→ *www.simulation.su*

yusupov@iias.spb.su

RNSS / R. M. Yusupov,
St. Petersburg Institute of Informatics and Automation RAS, 199178, St. Petersburg, 14th lin. V.O, 39

RNSS Officers	
President	R. M. Yusupov, *yusupov@iias.spb.su*
Chair Man. Board	A. Plotnikov, *plotnikov@sstc.spb.ru*
Secretary	M. Dolmatov, *dolmatov@simulation.su*
Repr. EUROSIM	R.M. Yusupov, *yusupov@iias.spb.su* Y. Senichenkov, *senyb@dcn.icc.spbstu.ru*
Deputy	B. Sokolov, *sokol@iias.spb.su*
Edit. Board SNE	Y. Senichenkov, *senyb@dcn.icc.spbstu.ru*

Last data update June 2016

EUROSIM OBSERVER MEMBERS

ROMSIM – Romanian Modelling and Simulation Society

ROMSIM has been founded in 1990 as a non-profit society, devoted to theoretical and applied aspects of modelling and simulation of systems. ROMSIM currently has about 100 members from Romania and Moldavia.

→ *www.eurosim.info* (*www.ici.ro/romsim*)
sflorin@ici.ro
ROMSIM / Florin Hartescu,
National Institute for Research in Informatics, Averescu Av. 8 – 10, 71316 Bucharest, Romania

ROMSIM Officers	
President	
Vice president	Florin Hartescu, *flory@ici.ro* Marius Radulescu, *mradulescu.csmro@yahoo.com*
Repr. EUROSIM	Marius Radulescu, *mradulescu.csmro@yahoo.com*
Deputy	Florin Hartescu, *flory@ici.ro*
Edit. Board SNE	Constanta Zoe Radulescu, *zoe@ici.ro*
Web EUROSIM	Florin Hartescu, *flory@ici.ro*

Last data update partly June 2017

MIMOS – Italian Modelling and Simulation Association

MIMOS (Movimento Italiano Modellazione e Simulazione – Italian Modelling and Simulation Association) is the Italian association grouping companies, professionals, universities, and research institutions working in the field of modelling, simulation, virtual reality and 3D, with the aim of enhancing the culture of 'virtuality' in Italy, in every application area.

MIMOS became **EUROSIM** Observer Member in 2016 and is preparing application for full membership.

→ *www.mimos.it*
roma@mimos.it – info@mimos.it
MIMOS – Movimento Italiano Modellazione e Simulazione; via Ugo Foscolo 4, 10126 Torino – via Laurentina 760, 00143 Roma

MIMOS Officers	
President	Paolo Proietti, *roma@mimos.it*
Secretary	Davide Borra, *segreteria@mimos.it*
Treasurer	Davide Borra, *segreteria@mimos.it*
Repr. EUROSIM	Paolo Proietti, *roma@mimos.it*
Deputy	Agostino Bruzzone, *agostino@itim.unige.it*
Edit. Board SNE	Paolo Proietti, *roma@mimos.it*

Last data update December 2016

CANDIDATES

Albanian Simulation Society

At the Department of Statistics and Applied Informatics, Faculty of Economy, University of Tirana, Prof. Dr. Kozeta Sevrani at present is setting up an Albanian Simulation Society. Kozeta Sevrani, professor of Computer Science and Management Information Systems, and head of the Department of Mathematics, Statistics and Applied Informatic, has attended a EUROSIM board meeting in Vienna and has presented simulation activities in Albania and the new simulation society.

The society – constitution and bylaws are being worked out - will be involved in different international and local simulation projects, and will be engaged in the organisation of the conference series ISTI – Information Systems and Technology. The society intends to become a EUROSIM Observer Member.

kozeta.sevrani@unitir.edu.al
Albanian Simulation Goup, attn. Kozeta Sevrani
University of Tirana, Faculty of Economy
rr. Elbasanit, Tirana 355 Albania

Albanian Simulation Society- Officers (Planned)	
President	Kozeta Sevrani, *kozeta.sevrani@unitir.edu.al*
Secretary	
Treasurer	
Repr. EUROSIM	Kozeta Sevrani, *kozeta.sevrani@unitir.edu.al*
Edit. Board SNE	Albana Gorishti, *albana.gorishti@unitir.edu.al* Majlinda Godolja, *majlinda.godolja@fshn.edu.al*

Last data update December 2016

EUROSIM Federation of European Simulation Societies

General Information. **EUROSIM**, the Federation of European Simulation Societies, was set up in 1989. The purpose of **EUROSIM** is to provide a European forum for simulation societies and groups to promote advancement of modelling and simulation in industry, research, and development.

Member Societies. **EUROSIM** members may be national simulation societies and regional or international societies and groups dealing with modelling and simulation. At present **EUROSIM** has sixteen *Full Members* and two *Observer Members*, and one member candidate.

→ *www.eurosim.info*

Snapshot New EUROSIM Website, Societies' Page

EUROSIM Events

EUROSIM is supporting, organising and co-sponsoring the following event types:

- **EUROSIM Congress** - triennial, organized by a EUROSIM member society
- **EUROSIM Conference** - international conference by a EUROSIM member society with EUROSIM advertising support
- **EUROSIM Event** - international conference or workshop organized by EUROSIM member society
- **EUROSIM Co-Sponsorship** – int. conferences of other organisations with mutual benefit contract

The **EUROSIM Congress** can be seen as constant within these developments – each three years simulationists from all over the world gather in one European country to exchange information on development in modelling and simulation.

The 10th EUROSIM congress will take place in July 2019 in La Rioja, Logroño, Spain.

EUROSIM 2019

10th EUROSIM Congress on Modelling and Simulation

July 2019, La Rioja, Logroño, Spain

www.eurosim.info/events/eurosim-congress/

EUROSIM Conference

EUROSIM member societies are entitled to organise a **EUROSIM Conference** - an international conference on any subject on modelling and simulation. An international conference organised under the trademark **EUROSIM Conference** is advertised via EUROSIM's mailing data base, and by publication space in **SNE** - Simulation Notes Europe.

Reduced fees are offered to all members of the EUROSIM member societies. EUROSIM expects a small percentage of the income.

At present the following conferences are organised under the trademark EUROSIM Conference:

- **MATHMOD Conference Series**, Vienna, Austria (organised by **ASIM**, the German simulation society), see *www.mathmod.org*
- **ICBTI - UBT Conference Series**, Durres, Albania (organized by KA-SIM, the simulation Society of Kosovo), see *conferences.ubt-uni.net*

MATHMOD 2018

9th Vienna Int. Conference on Mathematical Modelling

February 21 - 23, 2018, TU Wien, Vienna, Austria

www.mathmod.at

The **MATHMOD 2018** continues the conference series *MATHMOD Vienna* in February 2018. It provides a forum for professionals, researchers, and experts in the field of theoretic and applied aspects of mathematical modelling for systems of dynamic nature.

The scope of **MATHMOD 2018** conference covers theoretic and applied aspects of the various types of mathematical modelling (equations of various types, automata, Petri nets, bond graphs, qualitative and fuzzy models, etc.) for systems of dynamic nature (deterministic, stochastic, continuous, discrete or hybrid with respect to time, etc.). The topics to be discussed include e.g.

- modelling theory; first-principles, identification, optimization, order reduction and validation
- automation of modelling and software tools
- computer modelling, modelling for/by simulation, co-simulation, modelling standards
- qualitative, modular, interdisciplinary modelling
- comparison of methods for modelling, alternative modelling methods (CAS, fuzzy, NN, QSS, etc.)
- model analysis and calibration, effects of modelling errors on overall performance of an engineering system
- applications in the field of engineering systems and in natural sciences
- applications in environmental systems, biotechnology, etc.
- applications in operation research, logistics and planning
- applications in medicine, physiology, health care and health technology assessment
- education in/for/with modelling
- modelling aspects in scientific computing
- modelling for control and real-time applications

MATHMOD 2018 Important Dates

- End September, 2017:
  Full Contribution Submission Deadline
- Midst November, 2017: Discussion and Student Contribution Submission Deadline
- Begin January, 2018: Notification to authors

ICBTI 2017

6th International Conference on Business, Technology and Innovation

October 27 – 29, 2017, Durres, Albania

conferences.ubt-uni.net/2017/

KA-SIM, the Kosovo Simulation Society, invites to the **UBT** *6th Annual International Conference* , the **ICBTI** – *International Conference on Business, Technology and Innovation*, which will be in Durres, Albania, on 27-29 October. The conference is organized by UBT, the University for Business and Technology, Pristina, Kosovo.

The aim of the conference is to facilitate the exchange of knowledge between innovative academics, post-graduate students, doctoral candidates, young researchers, researchers and industrial experts and to share views and experiences in the field of science, technology, business and innovation and other related areas.

Scope and Topics are general, in each area sessions will deal with modelling and simulation.

- Computer Science and Communication Engineering
- Management, Business and Economics
- Mechatronics, System Engineering and Robotics
- Energy Efficiency Engineering
- Information Systems and Security
- Architecture - Spatial Planning and Civil Engineering
- Civil Engineering, Infrastructure and Environment
- Journalism, Media and Communication
- Food Science and Technology
- Medical, Chemical and Pharmaceutical Sciences
- Education and Development

ICBTI - UBT 2017 Important Dates

- Midst September, 2017: Abstract Submission
- End September, 2017: Notification to authors
- Midst October 2017: Full Paper Submission

New EUROSIM Website

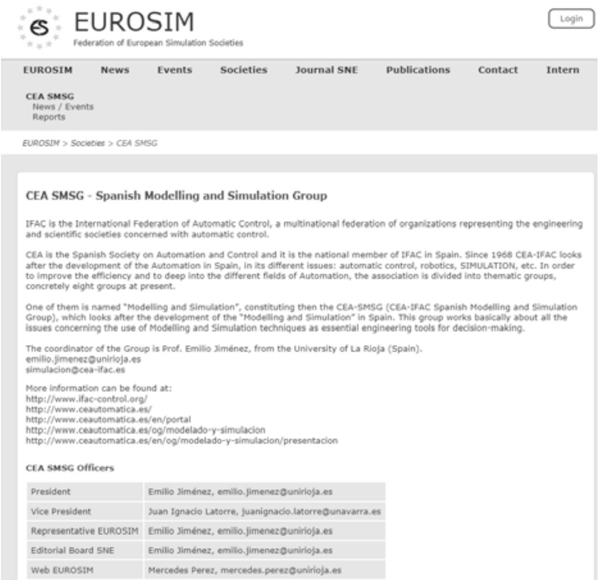
The EUROSIM website *www.eurosim.info* has been completely redesigned and installed on state-of-the-art technology. Responsive design adapts the layout to a variety of devices. Most essential and recent content has been transferred to the new site. We apologize for the problems with the previous website in begin of 2017, caused by severe hacking attacks.

Snapshot of new EUROSIM Website, Home Page

A short guide through the sections should explain the website's features (snapshot of homepage see before).

The *News* section and the *Events* section are maintained by the EUROSIM webmaster(s) compiling classical news lists and events lists. Please send an e-mail to *webmaster@eurosim.info* if you have an announcement to be posted (general news, general news about a society, conference announcements).

The *Societies* section – see snapshot of societies' webpage before - provides information on all EUROSIM societies – the content is managed by the societies themselves, usually structured with first page, and with sections on news, events, reports, and publications. The first webpage of each society gives a summary on the society, and lists officers of the society. We ask all societies to update this list regularly, with actual president and other administrative officers and with officers responsible for society representation in EUROSIM, for SNE news editorial board, and for the society's content maintenance at EUROSIM website –snapshot below.



Snapshot of New EUROSIM Website,
Individual Society – First Page

The *Journal SNE* section shortly introduces **SNE – Simulation Notes Europe** as official membership journal of EUROSIM and links to the **SNE** website. With **Online SNE** (Online ISSN 2306-0271) the publisher **ARGESIM** follows the Open Access strategy, allowing download of published contributions for free.

Access for members of EUROSIM Societies. High-resolution **Online SNE**, full SNE Archive, and sources of benchmarks or other additional documents are available for members of EUROSIM societies. Login data are distributed by the EUROSIM societies to their members directly, with yearly change of password:

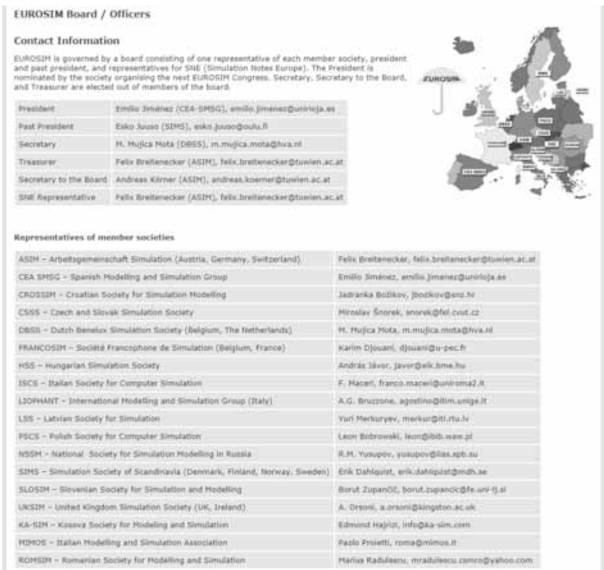
- (Sample) Login: `asim-member`
- Password: `xxxxxx`

This login works as well at the SNE website (for **SNE** download; snapshots next pages), as well as at the EUROSIM website (for publication download, see below) – please use *Login button*, or enter *Login section* resp.

There is also available a print version of **SNE**. The publisher **ARGESIM** itself produces sample copies for promotional purposes (samples for authors and societies, copies for conferences, etc.). And generally, **TU-Verlag** (TU Wien Publisher - **www.tuverlag.at**) provides *Print-on-Demand* service for SNE issues, whereby each **Print SNE** issue is identified by an individual ISBN number from TU Verlag – starting with SNE Volume 27. Printed copies can simply be ordered in the webstore at *www.tuverlag.at*.

The *Publications* section is intended to provide Proceedings from EUROSIM congresses and from EUROSIM conferences (e.g. MATHMOD, ICBTI). Members of EUROSIM societies can download full documents using the Login described before – starting in October 2017.

And last but not least the *Contact* section provides main contact emails for EUROSIM and for all member societies – sample see below (update taken from the individual society pages).



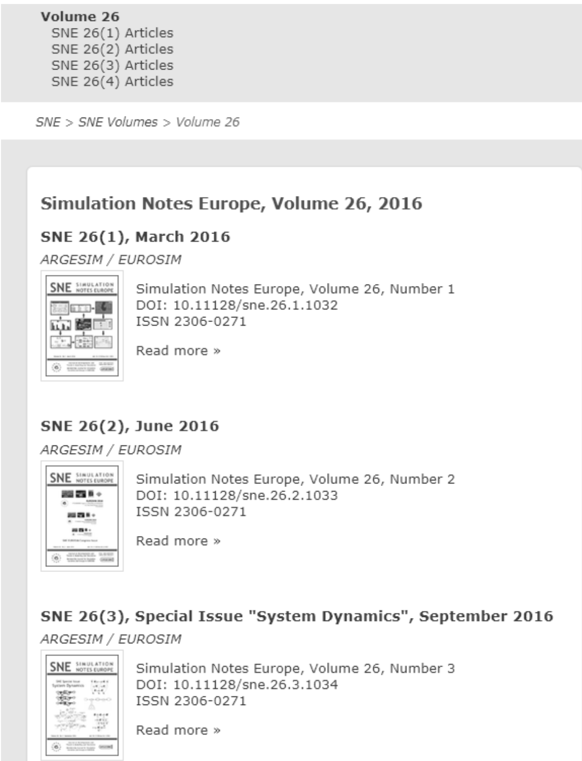
Snapshot of New EUROSIM Website, Contact Info Page

New SNE Website

Also a relaunch of the website for the journal **SNE Simulation Notes Europe** is in progress, where members of EUROSIM societies can download high-resolution SNE issues and SNE single contributions, and further publications. Login data are distributed by the EUROSIM societies to their members directly, with yearly change of password:

- (Sample) Login: `asim-member`
- Password: xxxxxx

New SNE Website, Homepage



New SNE Website, SNE Volumes Page

The entry page of SNE's new website (snapshot left, above) offers a direct quick access to the newest issue, and the menu with sections first provides information on aims and scope, and on the editorial board.

The sections *SNE Volumes* allows selection and display of the issues of the specific volume, see snapshot left, below. There, the *Read more* link in the issue display opens information and download possibilities for the specific issue,

Alternatively, the *SNE nn(n) Articles* link at top of the volumes page switches to the page with list of articles in this issue – snapshot below.

New SNE Website, Articles List Page

And there finally, the *Read more* link in the articles list page provides bibliographical information, abstract, and download possibilities for the specific article – see next snapshot.

Here, at bottom, download files for the article are offered. The pdf-files with ending OA are open access, download of files with ending RA (restricted access) requires Login with the society's member login. In case of benchmark articles here also files with sources are offered for download with restricted access, or other specific documents related with the article


Volume 26
SNE 26(1) Articles
SNE 26(2) Articles
SNE 26(3) Articles
SNE 26(4) Articles

SNE > SNE Volumes > Volume 26 > SNE 26(1) Articles

Simulation Notes Europe, Volume 26(1), March 2016

Modeling Garage Parking

Oliver Ullrich | Charaf Azzouzi | Benjamin Brandt | Daniel Lückerath | Naphtali Rishe

Simulation Notes Europe SNE 26(1), 2016, 1-8
DOI: 10.11128/sne.26.tn.10321

Abstract

Described is a simulation model of cruising for garage parking, intended both for the calibration and evaluation of real-time parking recommendation methods, and as a base for predictive guidance to available parking. The model combines the event-based and agent-based simulation approaches to represent the parking garage and the driver behavior. It is validated by simulating a real-world parking garage and comparing the model's output with observations. The validation results show the model's capability to predict a garage's state over the course of an operational day, even though specific results are not yet precise enough for the intended use.

After an introduction to scope and aims, the paper shares some background on garage parking and related work, followed by a description of the simulation model, and its validation based on a representation of a realworld parking garage.

Related Files

- sne.26.1.10321.tn.OA.pdf | 205 KB
- sne.26.1.10321.tn.RA.pdf | 5 MB

New SNE Webpage, SNE Article Page

The sections *Contribute / Contact* are still under work. Information for authors are given there, and submission templates in doc format and tex format can be downloaded, as well as information on the reviewing process.

Since 2012, **Online SNE Issues** and **Online SNE Articles** are identified by a DOI (Digital Object Identifier) and registered at Crossref immediately after publication. DOI prefix is 10.11128, followed by issue or article identification (this issue DOI 101128/sne.27.2.1037).

Relaunch of the SNE webserver requires modification of DOI registration at Crossref, so that DOI search will work again in October 2017.

If you have any questions or comments please send an e-mail to *webmaster@eurosim.info*
or to *webmaster@sne-journal.info*

ASIM
German Simulation Society
Arbeitsgemeinschaft Simulation

ASIM (Arbeitsgemeinschaft Simulation) is the association for simulation in the German speaking area, servicing mainly Germany, Switzerland and Austria. **ASIM** was founded in 1981 and has now about 600 individual members, and 90 institutional or industrial members.

→ *www.asim-gi.org* with members' area
info@asim-gi.org, admin@asim-gi.org
ASIM – Inst. f. Analysis and Scientific Computing
TU Wien – Technical Univ. Vienna
Wiedner Hauptstrasse 8-10, 1040 Vienna, Austria

ASIM is organising / co-organising the following international conferences:

- ASIM Int. Conference 'Simulation in Production and Logistics' – bi-annual – **ASIM SPL** Conference
- ASIM 'Symposium Simulation Technique' – bi-annual – **ASIM SST** Conference
- **MATHMOD** Int. Vienna Conference on Mathematical Modelling – tri-annual

Furthermore, ASIM is co-sponsor of WSC – Winter Simulation Conference

ASIM is structured in *ASIM Sections*, dealing with various methods and applications. Within the sections or across sections, working groups discuss and document new developments

ASIM Sections	
GMMS	Methods in Modelling and Simulation Th. Pawletta, *pawel@mb.hs-wismar.de*
SUG	Simulation in Environmental Systems J.Wittmann, *wittmann@informatik.uni-hamburg.de*
STS	Simulation of Technical Systems Walter Comerell, *Commerell@hs-ulm.de*
SPL	Simulation in Production and Logistics Sigrid Wenzel, *s.wenzel@uni-kassel.de*
EDU	Simulation in Education/Education in Simulation A. Körner, *andreas.koerner@tuwien.ac.at*

Coming Events

Every two years the ASIM Dedicated Conference organized by the ASIM Section *Simulation in Production and Logistics* presents recent developments and interesting applications of simulation.

ASIM SPL 2017
SIMULATION IN PRODUCTION AND LOGISTICS
September 20 – 22, 2017, Univ. Kassel, Germany
www.asim-fachtagung-spl.de

Aims and Scope. This largest European simulation conference for production and logistics is well balanced between research, development and industrial use. New scientific papers are discussed as well as successful applications of simulation in companies.

Hereby representatives of companies, which have not been using simulation before, can get first impressions in possible applications of simulation and are able to estimate the benefits of simulation for their own business.

Exhibition. Simulation users can share experiences, evaluate new offers and participate in professional discourses. Workshops intensify the discussion on specific latest topics. The connected exhibition with renowned companies in the simulation industry creates opportunities to review recent developments and service offerings.

ASIM Master Theses Award. On occasions of this conference, ASIM awards for the first time two outstanding master theses in the field of discrete-event simulation. The authors of the awarded theses win a price of 1000 €, are invited to the conference, and get free ASIM membership for three years. The award is intended to be conferred at the future biannual conferences.

SNE Promotion with Printed Special Issue. ASIM SPL 2017 conference promotes SNE by providing for each participant a print copy of SNE 27(2), a SNE special issue on *Simulation in Production and Logistics - Impact of Energetic Factors*.

MATHMOD 2018
9th Vienna Int. Conference on Mathematical Modelling
February 21 - 23, 2018, TU Wien, Vienna, Austria
www.mathmod.at

MATHMOD 2018 provides a forum for professionals, researchers, and experts in the field of theoretic and applied aspects of mathematical modelling for systems of dynamic nature. **ASIM** is the main co-organiser of the MATHMOD conference series (**EUROSIM Conference**; see also news page N9 or *www.mathmod.at*.

News from ASIM Sections and Working Groups

The working group *Consideration of Energetic Factors in Simulation in Production and Logistics* within the ASIM Section *Simulation in Production and Logistics* has compiled a SNE Special Issue

Simulation in Production and Logistics
- Impact of Energetic Factors.

The guest editorial board consisted of S. Wenzel (Univ. Kassel), H. Pitsch (INCONTROL Simulation Solutions, Wiesbaden), C. Pöge (Volkswagen AG, Wolfsburg), M. Selmair (BMW AG, München), J. Stoldt (Fraunhofer-Institut IWU, Chemnitz), and T. Uhlig (Univ. der Bundeswehr, München). A print copy of this special issue SNE 27(2) will be distributed to all participants of **ASIM SPL 2017** conference.

New ASIM Website

The ASIM website *www.asim-gi.org* has been completely redesigned and installed on state-of-the-art technology (snapshot of homepage see below). Responsive design adapts the layout to a variety of devices.

The webpage offers open access for basic versions of publications (proceedings, reports). ASIM members can download high-resolution publication, and proceedings, books, and reports with restricted access using the general *ASIM Member Login* (sent to members in July 2017; this login works also for SNE download at the SNE website). The individual members' login – for changing personal data, etc – will be available again end of September 2017.

ASIM, A. Körner, andreas.koerner@tuwien.ac.at

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