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Hybrid simulation-based optimization of discrete parts manufacturing to increase energy efficiency and productivity

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Abstract

This presented research comprises the development of an optimization module for use in a novel production optimization tool – similar in function but not mode of operation to an Advanced Planning System –, with energy efficiency incorporated into its goal system. The optimization features a hybrid-simulation of production systems as an evaluation function. A hybrid simulation has been developed and presented in preceding publications, in order to enable a sufficient consideration of interactions between material flow and the thermal-physical behavior of the production system. The size of the search space for the complex optimization problem necessitates a customized two-phase-optimization method, which is based on a Genetic Algorithm, with the consideration of linear constraints and extended customizations. The results, obtained in a case study featuring a food production facility, show energy savings of around 20 percent together with significant productivity gains.

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Keywords: sustainable manufacturing; energy efficiency; production planning; optimization; metaheuristics; hybrid simulation; case study

1. Introduction

Human contribution to climate change necessitates urgent action: In the United Nations Framework Convention on Climate Change (UNFCCC) [1] countries worldwide have committed to limiting the manmade temperature rise to 2°C, mainly by reducing energy related CO_2 emissions by 1.9% between 2013 and 2040. The increased awareness and societal pressure for increased sustainability, together with long-term trends of rising energy costs and the fact that the industrial sector is responsible for 31% of the annual energy demand and 36% of the CO_2 emissions globally [2], are turning energy efficiency into a substantial goal for manufacturing enterprises

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[3]. The basic definition of energy efficiency in the context of production is the ratio between the value-added output of a production system and the necessary energy input [4].

In addition to the need to be more energy efficient, there are also chances for companies in the domain of energy efficiency and sustainable manufacturing: The ongoing energy transition towards renewable energy sources leads to a more volatile energy supply. The larger the share of renewable energy in the supply mix, the better the demand has to be aligned with the energy production – bidirectional approaches such as demand response are one way of achieving this [5]. This also means that if companies can predict, plan and control their energy consumption profile according to changing supply situations, they can benefit from very low energy prices on short-term energy markets.

Both goals, increasing energy efficiency and the ability to plan and control the energy consumption profile, necessitate advanced planning tools for companies, especially for manufacturing companies with complex productions systems. Studies show that energy efficiency considerations should be an integral part of Enterprise-Resource-Planning (ERP) and Manufacturing Execution Systems (MES), with simulation based approaches suggested to be the most promising method. However, currently there is a lack of practically applicable planning methods [6].

In order to address this deficiency, this research is meant to develop a novel planning tool that increases both the energy efficiency and general performance of production systems, using a hybrid simulation-based optimization approach. The general planning concept has been published by the research team [7], so has the hybrid simulation concept [8] and the development of the optimization module [9]. The particular paper at hand focuses on the adaption of the planning method to a specific real life industrial application and on evaluating the optimization potential in an industrial use case.

2. Requirements for the Planning Tool and chosen Approach

The **requirements** for a planning tool have been deducted from an analysis of relevant literature, supplemented by expert interviews with managers from application partners within the research project. According to the findings of a large EU research project, based on interviews with 106 international experts, the tools will have to consider both conventional economic planning goals and energy and resource efficiency simultaneously. The planning should be integrated into the existing ICT and the use of detailed simulation models is recommended [10]. Li [11] stresses the necessity for a generalized structure to make the tools available for different application environments. He [3] also emphasizes the need to consider all relevant energy flows and their interdependencies. Concerning the underlying methods, Thiede – among others – declares simulation to be the method best suited to provide the necessary planning support [12]. An automatic decision support function, i.e. in the form of an optimization module, is another major request from prospective industry users. A classic decision support function for production planning and control in company Information and communications technology (ICT) is found in Advanced Planning Systems (APS).

Following a comprehensive evaluation of possible **approaches** for this research, a simulation based optimization emerged as the most suitable option: It enables a planning functionality similar to that of an APS, due to the automatic optimization of production schedules and control of machines in the production process and the periphery. It also enables the simultaneous consideration of the complex system of material flows and the thermal-physical behavior of the production and energy system and its components through a simulation of said production system.

3. Related Work

3.1. Simulation & simulation based Planning approaches

The basic concept of a dynamic simulation is to create a digital model of a real-life system, featuring all relevant characteristics, and to then use that model to conduct experiments in order to gain insights into the system behavior or to optimize and develop plans for the system [13]. Typically, material flows and the processing of orders are simulated utilizing a discrete event simulation (DES), while the thermal-physical behavior of machines and equipment is usually simulated in continuous simulation environments that solve ordinary differential equations (ODEs) or differential-algebraic equations (DAEs). One of the most advanced simulation based concepts for