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Simulation of production processes involving cyber-physical systems

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Abstract

It has become common practice to apply simulation during product development and production planning. The increasing demand for individualized goods requires the ability to produce in small lot sizes and therefore more flexible resources, which leads to the use of cyber-physical systems (CPS) in manufacturing. This papers aims to look at the changing requirements, pitfalls and possible solutions when applying simulation to CPS. The research is based on a case study of a large car manufacturing company that has already implemented CPS in one production line. The paper will also provide an overview of simulation types and discuss their fitness.

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1. Introduction

One of the main challenges within the industrial sector is to produce with high resource efficiency. [1] In order to operate at full capacity, and thereby minimizing buffer stock as well as defective parts, it has become common practice to apply simulation methods and models during process planning.[2]

At the same time, industrial companies face the challenge that their customers demand more and more individualized products.[1] In addition, the market changes rapidly and existing parts and products have to be adapted often. To cope with these two conflicting issues, flexible and adaptable concepts are necessary within the field of production. Such concepts are based on decentralization and include e.g. lean management, modularization, or the fractal factory.[3, 4] Companies increase their degree of decentralization as this allows for faster decision-making since there are fewer organizational units involved in a decision.[5] Currently, cyber-physical systems (CPS) and the so-called smart factory are under development as the latest addition to the field. As "self-conscious" resources they are part of a decentralized production environment and able to make independent decisions.

The impact of CPS on production processes and simulation thereof within production planning will be outlined in the following paper, which is structured as follow: First, the research question and the derived methodology are introduced; in the next step, the state of the art in simulation is described. The concept of CPS and the smart factory are defined in the following chapter. The paper closes with the requirements and recommendations with regards to simulation.

2. Research Question and Methodology

This paper aims to answer the following research question: Which impact do CPS have on production processes as well as production planning and how do simulation models and tools have to be adapted to cope with the necessary changes?

The paper follows the research process of design-oriented information systems research, with is in line with the design science approach.[6, 7] The process consists of Analysis, Design, Evaluation and Diffusion (cf. Figure 1).

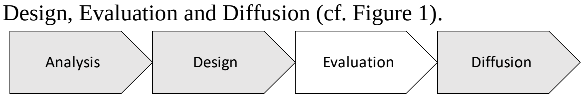

Fig. 1. Research Process

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During the analysis phase, the state of the art within simulation as well as cyber-physical systems is depicted. This is based on a literature review on the two topics. In addition to the literature review, a case study [8] of a pilot manufacturing line of internal combustion engines that uses CPS as well as an interview with an expert who produces CPS were conducted.

The case study consists of multiple interviews with the people responsible for the production line (two from production management, one person from IT) and a visit of the factory. The interviews had a duration of at least one hour and took place at two different points of time: the first ones in 2012, the last one in 2015. During the interviews, notes were taken and the visit was documented afterwards

The guided interview with the manufacturer of CPS took place in 2016 and has a duration of two hours and was recorded and transcribed. The interviewee has a background in computer science and has worked at the company for about three years.

During the design phase, first requirements were derived from literature, the case study and the interview. As a second and last step, recommendations on how to adapt simulation tools are given. Evaluation of the results is pending. This paper is part of the diffusion of the results.

3. Simulation

Simulation always deals with complex problems that cannot be solved using simple (mathematical) models because the problems are dynamic and there are elements of uncertainty.

There are different types of simulation. They can be divided by the kind of problem that is supposed to be supported by the usage of simulation. There are managerial, most often strategic problems, with can be assisted with management-oriented simulation methods like Monte-Carlo-simulation or scenario analysis.[9] These methods can be enhanced by visualization or incorporation of historical data.[10] An example might be supply chain planning [11], including warehouse positioning or selection of suppliers.

The other kind of problem is technical, most often operational problems. These problems arise from engineering and the decisions in this area can be backed by technical simulation. As such, they are part of the digital factory.[12] This paper distinguishes between two types of technical simulation: the simulation of complete production processes [2, 13] and the machine-oriented simulation, which focuses on individual manufacturing cells.[14]

The first type of technical simulation has the goal to support the planning of a specific production process or the improvement of an existing process with regards to its key performance indicators, such as cycle times or OEE. (cf. Fig. 2)

In the past, these used to be single, linear processes, which could be optimized by production planning to reduce waste within this process. As we will describe later on, this will change with the introduction of CPS.

This kind of process simulation can be useful during planning of new production lines, new facilities, their initial implementation and adjustment during operations.[2, 15]

The second type deals with individual production resources, in this case, a machine or a manufacturing cell. The purpose is to explore and define the limits of the machine (e.g. constructed space) and to ensure a stable process quality.[14] The machine-oriented simulation can also be applied during development, implementation and operations, only the scope is different.

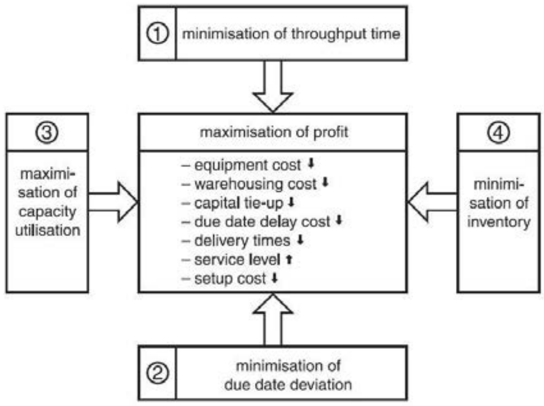

Fig. 2. Goals of process simulation [2]

Considering robots as resources, the focus is on collision detection, especially when interacting with a human.[16, 17] This kind of simulation relies on kinematics and graphics. It is applied during ramp up, but also during product development and operation (e.g. NC simulation).[14]

Another criterion to distinguish different kinds of simulation is the determinism. Simulation like the last-named collision detection or the simulation of individual machines work on the basis of the finite element method and will produce the same result within each simulation run. [18] Non-deterministic simulation however, will lead to divergent results on multiple simulation runs. This will be the case when CPS are introduced to the production environment as the production process will no longer be completely predictable.

4. Cyber-physical Systems

4.1. Definition

CPS are „integrations of computation with physical processes“ [19]. This means that computing gets information on the physical world around it and can react to it. The information is collected using sensors, then processed internally by the CPS and leads to actions that are realized by actors and correspond to the current state of the environment.

CPS can be applied in different fields, in this case the paper focuses on manufacturing. Since CPS have to work in real world and the real world is complex and not predictable, robustness is a basic property of CPS that they are able to react to unforeseen challenges. However, this robustness is hard to achieve.[20]

CPS are based on the internet of things, which means that a CPS has a virtual identity and can be addressed within a network. This enables communication and coordination between the distributed CPS.[21]