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Process planning in special machinery: Increasing reliability in volatile surroundings

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Abstract

In Germany the growing demand for customized systems and integrated solutions in machinery enhance the importance of special machinery. Within this industry, the commissioning process represents a significant part in the product engineering process and forms the base for reliability and performance during future operation. However, there is little research focusing on this process for special machinery. In particular, there has been little discussion on methods to evaluate alternative test processes or arranging test processes along the commissioning process. Therefore, this paper develops an application-oriented simulation tool that allows an evaluation of test alternatives and an arrangement of test processes during the commissioning process in special machinery. The authors decided to use Bayesian Networks to model the commissioning process as they enable the connectivity of multiple modules and integrate the stochastic dependencies along the processes. In addition the paper reveals two concepts to deal with unknown processes and the lack of data. Applying the simulation tool in a laser system manufacturer reveals that the simulation tool allows an evaluation as well as the identification of risks and need for countermeasures.

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1. Introduction

Cooperate studies from VDMA and McKinsey reveal that the German machinery industry identified an increasing demand for customized and integrated solutions [1]. This trend drives machinery manufacturers to offer specific engineer-to-order solutions with low quantities which characterizes them as a special machinery constructor [2]. Within special machinery the commissioning process is an important process as it accounts for 15% to 25% of the overall lead time [3]. This phase encounters increasing complexity [4] while having decreasing time available for completion [5]. Therefore, a high importance lies in speeding up the commissioning process. According to Buchholz [6] long lead times, adherence to delivery dates and complexity of interfaces are the main challenges for special machinery constructors. These imply problems for speeding up the commissioning process as they lead to difficulties when evaluating different or changed processes and methods in order to reduce the lead time. While prototypes and pilot series enable testing and thereby establish an evaluation basis [7] as well as learning in a serial production [8], they are far more cost and time-consuming in special machinery. Therefore, this paper presents a methodology for special machinery to allow an evaluation of processes during the commissioning process based on simulation. The simulation uses Bayesian networks to model the commissioning process as they can handle uncertainties well [9]. This simulation

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enables easy usage for production planning, when process changes are to be assessed. These changes include replacing existing commissioning processes by alternatives or reordering the process sequence.

2. Characteristics in special machinery

Special machinery solutions gain more importance for German machinery constructors as they pair innovations with customized solutions and thereby establish themselves as stand-alone suppliers in a certain area [10]. Special machinery is characterized by engineer-to-order solutions that often include an individually aligned production process [2]. These customized solutions require a high engineering effort [11,12] but are associated with small quantities and a large share of manual work. Manual processing time and lack of data respective the small amount of available data, make data acquisition for simulation input difficult [13]. In this case expert knowledge can help collecting relevant data. Even though acquiring technical knowledge is not a strength of expert interviews, there are little alternatives when the relevant data is not available [14]. Furthermore, experts often use vague expressions in interviews. Therefore, Section 2.3 gives a brief introduction in dealing vague knowledge by using fuzzy sets.

2.1. Commissioning process within special machinery

The main task in the commissioning process is "to establish the functionality and the functional interaction of previously assembled components as well as their testing" [15]. The commissioning process is challenged by complexity, time pressure and concurrency of errors [5]. With the first alignment of different components the technical problems usually increase [16]. These problems are cost-intensive and time-consuming and can cause delays. Furthermore, the commissioning process accounts for capital commitment costs as well as a shortage of available space on the shop floor [17]. Paired with the long lead times, high capital costs and the complexity in special machinery, the commissioning process represents a high saving potential for special machinery manufacturers. While a large amount of studies focused on the commissioning process along the ramp-up of serial production, very little research is conducted on this process in small-scale production environments such as in special machinery.

2.2. Bayesian Networks

Bayesian Networks also known as belief networks are directed, acyclic graphs (DAG). The nodes represent random variables which are connected by directed edges modeling the cause-effect relation [18]. The strength of these dependencies is based on the conditional probability and can be calculated using Bayes' theorem [9]. They have the advantage of being able to model uncertainty and combining data from diverse origin [19,20]. Furthermore, they proved to handle complexity by decomposability [9,20]. Moreover, Bayesian Networks are easy to update and, therefore, suited in a dynamic environment [21]. Thus, they are often used for decision, failure and risk analysis [19,22–26].

2.3. Data acquisition

In special machinery there is only a small amount of available data. Therefore, expert knowledge plays an important role in the data acquisition process before starting a simulation. Expert knowledge is vague and subjective [20,2]. Fuzzy sets are an opportunity to deal with vague knowledge [27]. They include a membership function that makes a statement on the degree of membership of an element to a specific set [9]. This "provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership" [27]. Therefore, various authors use fuzzy sets for safety and reliability analysis to deal with human influences such as expert knowledge [28–32]. As research has shown, fuzzy sets are a proven concept to deal with vague knowledge and can help to acquire data in a special machinery environment. However, simulation results largely depend on the quality of input data [13]. Therefore, additional concepts to secure high input quality of expert interviews are presented in this paper.

2.4. Simulation for an evaluation of process sequences and alternatives

A simulation models a system under dynamic influences and enables the transfer of findings to a real system [33]. In order to run simulations a precise simulation model is needed. This model is build by reducing and abstracting the real system. Afterwards, the model can be used for experiments. As soon as the results of the conducted experiments are available, they can be analyzed and interpreted to gain a conclusion. Based on the conclusion changes for the real system are initiated. This simulation process is usually understood as a repetitive loop [13]. The following Fig. 1 illustrates this loop.

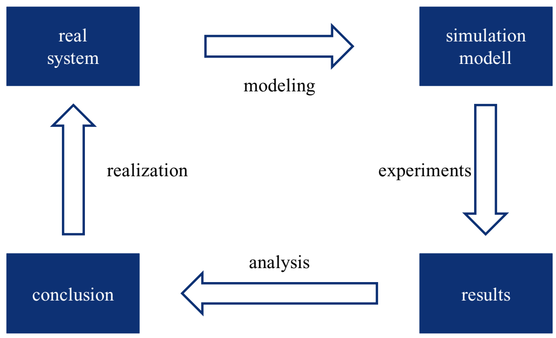

Fig. 1: Simulation process as a loop according to [13]

In the last years, the usage of simulation in production planning environment has increased. Multiple software companies offer simulation solutions for e.g. factory planning, logistics systems, robots or ergonomics and allow an optimization of specific production planning tasks [34–38]. These simulations focus on the exact function and interaction of the modeled system and its components. Therefore, they need deep knowledge of the system and its individual components. However, for a process evaluation, as discussed in this paper, it is sufficient to model the cause-effect relation

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