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# Expert systems in special machinery: Increasing the productivity of processes in commissioning

Sebastian Poeschl[a,b]*, Jannik Lieb[b], Frank Wirth[b], Thomas Bauernhansl[c,d]

[a]Graduate School of Excellence advanced Manufacturing Engineering – GSaME, University of Stuttgart, Nobelstr. 12, 70569 Stuttgart, Germany
[b]TRUMPF Lasersystems for Semiconductor Manufacturing GmbH, Johann-Maus-Str. 2, 71254 Ditzingen, Germany
[c]Fraunhofer - Institute of Manufacturing and Automation IPA, Nobelstr. 12, 70569 Stuttgart, Germany
[d]Institute for Industrial Manufacturing and Management IFF, University of Stuttgart, Nobelstr. 12, 70569 Stuttgart, Germany

*Corresponding author. Tel.: + 49 7156 303-32905; fax: +49 (0)7516-303-930560. E-mail address: sebastian.poeschl@gsame.uni-stuttgart.de

**Abstract**

Due to the megatrend globalization, special machinery is gaining significance for the capital goods sector. Characterized by the fulfillment of individual customer requirements, companies in special machinery have to deal with very specific and technologically complex tasks. Hence, managing information and knowledge becomes vital for a company's competitive ability, notably when it comes to expert knowledge. The characteristics of special machines leads to iterative processes for problem solving and thereby, increase lead times significantly. The more technologically complex a machine is, the more scattered the expert knowledge, meaning that many different experts need to be consulted before solving a problem. Up to now, in scientific literature, there has been little discussion about the challenges of special machinery and practical solutions regarding an implementation of technical intelligence in a special machinery environment. Therefore, the goal of this paper is to give an example of how an expert system can be applied to special machinery surroundings and thus, increases productivity. A Bayesian network forms the basis of the system as it allows efficient inference algorithms and reasoning under uncertainty, despite its ability to describe complex dependencies. The expert systems capability has been proven in industrial laser manufacturing.


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*Keywords:* Expert systems, special machinery, knowledge management

## 1. Introduction

Due to the megatrend globalization, special machinery is gaining significance for the capital goods sector [1]. Characterized by the fulfillment of individual customer requirements, companies in special machinery have to deal with very specific and technologically complex tasks [2]. An examination of a special machinery manufacturer displayed how the complexity of special machines leads to iterative processes for diagnosing and problem solving and thereby, increases lead times significantly. Hence, an intelligent management of information and knowledge becomes vital for a company's competitive ability, notably when it comes to expert knowledge.

"Intelligence is the capacity to learn, the capacity to acquire, adapt, modify and extend knowledge in order to solve problems." [3] Thus, when building intelligent entities, problems cannot only be solved by human experts but also by artificial intelligence. One very successful application of artificial intelligence technology are expert systems [4]. According to Maus and Keyes, "expert systems use artificial intelligence concepts to enable computers to function in decision-support roles as advisors, personifying human expert decision-making capabilities." [5] Hence, expert systems cannot replace human specialists, but they can serve as highly efficient support-tools in the decision-making process. In general, expert systems can be used for analyzing, diagnosing, monitoring, forecasting, planning, and designing [6] and have been successfully implemented in various fields; predominantly in medical, manufacturing and business fields


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as shown by Durkin [7]. Nonetheless, there has been little discussion in scientific literature about the challenges of special machinery and practical solutions regarding an implementation of an expert system dealing with uncertainty in a special machinery environment, even though there is a broad consensus on the potential benefits of expert systems [4,5,8,9]

When it comes to the design of knowledge-based methods for reasoning and decision-making, uncertainty plays a significant role [8]. With regard to technical intelligence in manufacturing, Kobbacy and McNaught et al. accentuate that Bayesian Networks are most beneficial when dealing with uncertainty [9].

Therefore, the aim of this paper is to give an example of an interactive probabilistic expert system design using Bayesian Networks and its implementation in a special machinery environment, more precisely in commissioning.

## 2. Commissioning in special machinery

Special machinery can be described as a function of mechanical engineering with the purpose of producing specialized machines according to customer specifications [10]. The main criteria for a differentiation between mechanical engineering and special machinery is the degree of individuality and the batch sizes of the products [2,11]. A typical batch size of one machine and the high degree of individuality in special machinery leads to an Engineer-to-Order manufacturing concept and mostly to a manual and individually modified production process [2,10]. Special machines are designed to fulfill very specific and technologically challenging tasks. Hence, manufacturers in special machinery need to act globally in order to be able to generate sufficient demand to be profitable. But by virtue of a global presence, these companies also face great challenges due to a higher cost pressure. Therefore, international companies need to generate competitive advantages through short time-to-market cycles. [2] In this respect, a high potential for rationalization can be exploited in the commissioning phase, since problems that have not been detected in earlier production stages concur during commissioning [12]. According to Weber, commissioning describes the transfer of a machine from idle state to a continuous operating state. Ideally, commissioning in special machinery results in a fast transfer into a stable continuous operating state, as special machines are usually linked to high investment costs [13]. Therefore, problems need to be detected and eliminated quickly [12]. Systematic knowledge acquisition and management in commissioning can increase efficiency and, thus, the competitiveness of future projects significantly [13,14]. In the form of so-called expert systems, knowledge management provides a powerful tool for diagnosing and decision making and, thus, can shorten commissioning and time-to-market cycles substantially.

## 3. Expert systems

### *3.1 Characteristics*

Puppe separates the architecture of expert systems (XPS) into two main modules: the knowledge base and the control system. The knowledge base consists of domain-specific, case-specific knowledge and (intermediate and final) results, whereas, the control system, also known as shell, contains an inference component that provides problem solving strategies as well as the user interface. [15] The main purpose of the user interface is to gather factual data. It can either interact with the user in a dialogue and, thereby, acquire knowledge or read in measured data. In addition the user interface should provide an explanation component since a transparent presentation of results and the underlying reasoning correlates strongly with the acceptance of an expert system [16]. A key factor for the effectiveness of an expert system is the quality of the knowledge base [17]. Expert systems can provide fast and reliable answers and based on the studies of Tversky, Kjræulff and Madsen conclude that the quality of decisions improves when human decisions are being supported by recommendations from an expert system [19,20,18].

### *3.2 Knowledge acquisition as bottleneck*

The acquisition of knowledge is often the bottleneck in the construction of expert systems [17,21–23]. The reasons for this are diverse but one of the main difficulties is to make the knowledge of a human expert explicit. For one, human experts use tacit or implicit knowledge and common sense as well as everyday knowledge to solve problems. Furthermore, expert knowledge is characterized by complex and large amounts of information and human experts occasionally give inaccurate or incomplete descriptions of problems and solutions. [8,17,24]

### *3.3 Uncertainty in knowledge*

Decision environments and data sources are often afflicted with uncertainty and, therefore, most cause effects are uncertain [18,26,25]. Consequently the management of uncertainty is central for decision support systems. While rule-based systems have serious limitations when it comes to reasoning under uncertainty, inference nets and namely Bayesian networks “(…) enable to perform probabilistic calculus and statistical analyses in an efficient manner [18,27].“

## 4. Bayesian networks for diagnosis

A Bayesian network (BN) is a directed acyclic graph (DAG) in which nodes represent events and directed links causal dependencies. When observing new evidences, the updated probability distribution can be calculated for the remaining variables. [28] Moreover, it is possible to combine hard statistical data with softer expert knowledge as well as handling incomplete data sets and, thus, provide a powerful tool for diagnostic expert systems [29,31,30].

## 5. Literature review on BN and expert system applications in manufacturing

An extensive literature review on Bayesian networks and expert systems that have been applied in manufacturing from 2000 to 2016 has been conducted. Therefore, categories have been defined according to Stefik and Mertens characterization of expert tasks [32,6].