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Maturity Model for AI in Smart Production Planning and Control System

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Abstract

The utilization of Artificial Intelligence (AI) to improve processes constitutes a main subject for many enterprises. The area of Production Planning and Control (PPC) possesses several functions that could profit from such approaches. However, manufacturing companies find themselves often limited in the application of these approaches. This paper concentrates on three elements to assist enterprises: 1) the clarification of what AI is (in the manufacturing context) and its application to the field of PPC; 2) a review performed together with manufacturing enterprises in Germany and Hungary in order to understand the obstacles for the implementation of AI; and 3) the proposal of a maturity model to help enterprises understand where they are in regards to AI, as a way to help them create a roadmap to achieve their objectives.

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1. Introduction

The world is constantly changing, with enterprises exposed to events that may occur suddenly and unexpectedly. Constantly evolving challenges like the continuing globalization, increasing competition [1], focus towards ecological responsibility and sustainability [2] influence the manufacturers' operations. Additionally, companies have to meet increasing customer needs [3], as they increasingly require more individualized and personalized products [4] at lower prices and with shorter times [5]. As manufacturers have to be able to react to these challenges to stay competitive and have a sustainable business model, there is an emerging need for research activities in this area (such as, for example, ConnectedFactories II [6]).

As a result, the requirements for the area of Production Planning and Control (PPC) are also increasing.

As defined by Wiendahl [7], the term PPC covers the planning and control of orders and resources along the value chain of procurement, production and sales, as shown in Fig.1.

There are already various approaches to handle the arising challenges in these functions. Increasing digitalization, in particular, is changing the availability of data in companies. As a result, one approach that is gaining more and more importance is the use of Artificial Intelligence (AI).

Area	Main Function	Function	
Production Planning	Program Planning	Forecast calculation Rough-cut planning Determination of delivery date	Management of customer order Scheduling of preparation time
	Quantity Planning	Determination of gross requirements Inventory allocation Determination of net requirements	Supplier selection Procurement calculation Stock management
	Scheduling and Capacity Planning	Disposition	
Production Control	Order Initiation	Production order generation	Purchase order generation
	Order Monitoring	Lead time scheduling Capacity requirements planning Capacity synchronization Sequence planning	
		Production order release Receipt creation Production order allocation Work distribution	Purchase order release Purchase order processing Purchase order monitoring
	Production order progress monitoring Quantity and schedule monitoring Quality control	Goods receipt monitoring Quantity and schedule monitoring Quality control	

Figure 1. Functions of PPC.

In the literature, there is no uniform definition of the term AI. Various attempts at definitions are characterized by common characteristics and properties. AI is a subfield of computer science that aims to develop cognitive capabilities in computer systems with the help of algorithms. All attempts to define Artificial Intelligence have in common that AI systems are capable of learning, are trained with data, and perform a described task independently and efficiently without having to reprogram each step. The rules that the AI system follows during processing are not explicitly specified by humans [8,9].

Russel und Norvig [10] divide the cognitive capabilities into eight tasks. Of those, *learning*, *planning*, *problem solving* and *decision making* are relevant to AI in PPC.

Learning refers to the repeated learning of tasks based on training data. *Planning* is the creation of optimal plans, for example, the creation of production plans taking into account personnel, material and machine availability. *Problem solving* means that AI systems find (near) optimal solutions to a problem by searching the possible solution space, e.g. for order sequencing. AI can also be used for *decision making*, e.g. when selecting suppliers. In principle, this last task is relevant for all PPC functions.[10]

This paper proposes a maturity model (MM) to help enterprises understand where they are in regards to AI, as a way to help them create a roadmap to achieve their objectives. This paper is organized as follows. Section 2 provides an overview of the literature on existing AI methods for PPC and existing MMs on this topic. To determine the state of the art in practice, section 3 presents the results of a survey. Section 4 details the approach. Section 5 focuses on a summary, before concluding this paper with an outlook in section 6.

2. AI-supported PPC

2.1. Literature Review

The AI approach is at the heart of many futuristic visions of researchers, politicians and business executives. However, there is no overview of which approaches exist and in which

areas AI is used in PPC. For this reason, a systematic literature review was conducted using three different literature databases: Scopus; Google Scholar; Web of Science. The keywords used for the research included the terms “PPC”, “Order management”, “Order processing”, “Order planning”, “Artificial Intelligence”, “Machine Learning”, “Neuronal Networks”, “Intelligent Systems” and “Self-learning Systems”. The search was conducted looking for papers with titles or abstracts containing the mentioned terms. A further categorization of the papers found was made with regard to the PPC functions described in each one. The terms from Fig.1 were used for this purpose.

In total 66 sources were identified as relevant to the content. Only 35 papers refer to the application of AI methods to individual functions. The following are mentioned: *Program planning*, *material planning*, *scheduling and capacity planning*, *order initiation* and *order processing*.

Based on the sources, three drivers for AI use in PPC can be identified. One of them is the *limitations of traditional methods* [11–13]. One of the works mentioning this issue (Schneckenreither et al.) also describes a method for dynamically considering lead times, showing that traditional methods assume static lead times and thus cannot react to new challenges and changing production requirements [13]. According to the authors, the *human factor* represents another limit [14–16]. In their work, Meier and Zoller describe a solution for knowledge sharing in PPC based on KNN algorithms, describing the issue that people decide which data is relevant in a subjective manner. [16] Additionally, various authors also mention the *systems themselves* as a limitation. [17,18] Ronald et al., for example, criticize that MRP systems provide incomplete information. They describe an approach to the economic batch scheduling problem as a solution. [17]

The authors specify four goals that the AI approach in PPC can achieve: *short lead times*, *low inventories*, *high capacity utilization* and *high on-time delivery* [14,19–24].

2.2 Maturity Models

A MM comprises a sequence of maturity levels for a class of objects. It thereby describes the anticipated, desired or typical development path of these objects in successive discrete ranks. [25]

MMs are used to determine the current status, identify potentials for improvement and derive fields of action. [26]

The MM presented in this work was developed on the basis of the process model presented by Knackstedt et al. Their model describes eight steps: (1) Problem definition; (2) Comparison of existing MM; (3) Determination of the development strategy; (4) Interactive MM development; (5) Conception of transfer and evaluation; (6) Implementation of the transfer means; (7) Implementation of the evaluation; (8) Rejection of the MM. [25] The current work addresses the first four of these steps.

Before a MM can be developed, a comparison of existing MMs must be carried out to avoid overlaps (second step). Based on this, the development strategy can then be determined. This includes the new or further development of a model, the combination of several models into a new model or

the transfer of contents and structures to a model of a new application area. [25] For this, a systematic literature review was conducted. The keywords used for the research included the terms “Maturity Model”, “Artificial Intelligence” and “Production”. The specification was made by the term PPC.

The research identified 8 approaches related to the above-mentioned terms (except PPC). The evaluation resulted in 21 dimensions that were considered for the MM development. These are shown in Table 1.

Table 1. Overall comparison of AI dimensions.

		Author								
		[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	
Dimension	Data									
	Data acquisition			x						
	Data connection			x						
	Historical data acquisition					x				
Dimension	Organisation									
	Strategie & Vision		x	x	x	x			x	
	Financing and investment			x		x				
	Innovation management			x						
	Use Cases						x			
	Affected business units									
	Lifecycle integration, environment, network		x	x						
Dimension	Human									
	User acceptance								x	
	Management acceptance			x						
	Employee competence		x	x		x	x	x		
Dimension	Technology									
	Systemintegration			x						
	Realtime data analysis; Data use			x						
	Compatibility			x					x	
	IT Systems	x	x	x	x				x	x
	Big data analysis			x						
	Data-driven services			x						
	Digital production			x						
	Analytical skills									
Dimension	Dynamic capabilities									
	Coordination; Perception; Learning							x		

Only one additional approach could be identified in relation to the term PPC: the model presented in Busch et al. [35]. This focuses on four maturity levels: (1) Analog planning; (2;3) Digital Planning; (4) Digital and intelligent planning. It therefore does not consider the control functionalities in PPC.

3. Survey

3.1. Survey structure

This expert survey was based on the procedures of Diekmann [36] and Reinecke [37].

The questionnaire for the survey was developed based on extensive research and analysis on the topic of AI in PPC, as well as experiences of the authors from previous industrial and research projects. The aim of this questionnaire was to investigate how companies evaluate the use of AI to handle challenges in PPC. The research question of this survey can hence be formulated as follows: *To what extent are Artificial Intelligence methods suitable for improving production planning and control?* Accordingly, hypotheses were formulated addressing important topics that should be considered when using AI in PPC:

H1: Companies do not see the benefits of an AI implementation in their operations

To analyze this hypothesis, questions were formulated relating to the topic of AI in the company. For example, the participants were asked how they assess the benefits of AI for their enterprise and whether the introduction of AI has already been planned.

H2: PPC faces new challenges and requires new tools like AI in order to overcome them

The questions posed to analyze this hypothesis focused on the challenges in the area of PPC. Participants were asked, for example, how they rated the influence of various factors known to increase the complexity faced by PPC. These factors were based on the turbulences described by Wiendahl [38].

H3: The benefit of AI methods in PPC is difficult to assess for companies

To analyze this hypothesis, questions similar to those used for H1 were asked. However, the focus of the questions was specifically on the area of PPC.

H4: Basic data requirements for the use of AI methods in PPC are not fulfilled

Eight questions were defined to find out whether the basic data requirements had already been fulfilled by the companies. The questions focused primarily on data capture, the degree of digitalization and data quality.

H5: Consultants / researchers rate the potential of AI in PPC higher than employees in manufacturing companies.

To assess this hypothesis, participants were asked general questions about their personal backgrounds. These included, for example, questions about the hierarchical level and area in which the respondents worked, the size of the company and the industrial sector.

3.2 Results

18 companies from Germany and Hungary participated in the survey. 63% of the participants stated that they work as scientists or consultants. Based on the survey results, hypothesis H5 can be refuted. The participants from manufacturing companies rate the potential of AI in PPC higher than scientists or consultants. The result also shows that the participants’ assessment of the benefit of AI for each company differs from that for PPC specifically, with the participants rating the benefit for PPC higher. However, it can be seen that, in general, the estimated benefit is not very high. Although benefits are not seen across the board, participants see challenges in PPC and the need to use tools such as AI. From a digitalization view, however, companies still lack the prerequisites for using AI.

4. Maturity Model

4.1. Problem definition

The aim of the MM presented in this paper originates in shortages identified in the performed survey and literature review of existing MMs, namely the missing focus on AI in relation to PPC. Companies are hence missing a guiding element to help them implement AI in PPC. As a result, they have no way to locate themselves in relation to their objective of utilizing AI in PPC and no means to know in which direction they should move regarding necessary data, areas to prioritize, etc.

The MM presented in this paper attempts to address these knowledge gaps by identifying influencing factors, associated minimal requirements, and organizing them into dimensions.

4.2. Dimensions

The dimensions for the presented MM were determined based on the requirements of AI, the analysis of the existing MMs and considering the functions of PPC. In order for PPC to be supported by AI, 18 dimensions need to be considered, divided into the five categories as shown in Fig.2.

Minimum requirements are defined for the individual dimensions, which must be fulfilled in order to be able to implement AI in the area of PPC.

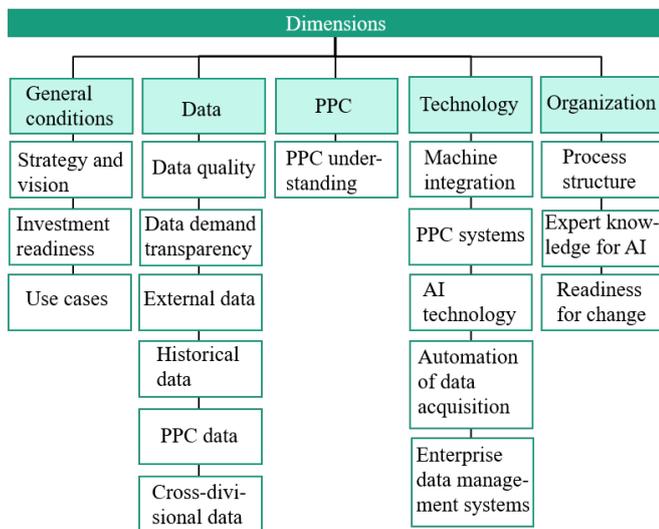


Figure 2. Dimensions and categories.

The Framework **conditions** category includes dimensions that must be used as a basis for each dimension:

- *Strategy and Vision*
Successful implementation of AI depends to a large extent on whether the company is pursuing a digitalization strategy. The strategy and vision must be defined and known to the employees involved.
- *Investment readiness*
The implementation of AI requires the consideration of investments. These are required, for example, for new

hardware and software, but also for the training of the concerned employees.

- *Use Cases*
Properly defined use cases are required for a successful implementation and analysis of the requirements.

The category **data** contains, as its name indicates, all dimensions to provide the AI with the necessary data:

- *Data quality*
The dimension of data quality is essential for the results that can be achieved with AI. The basis for this are the five data quality dimensions [39]. Poor data quality leads to incorrect statements by the AI.
- *Data demand transparency*
In order to implement AI, the data requirements must be known. This must be analyzed individually according to the use case for each function. It is necessary to identify each data requirement and to have an overview of whether the corresponding data is available.
- *Historical, PPC and cross-divisional data*
These dimensions comprise individual data groups on which data needs are based. Which data must be available in each individual case must be analyzed separately for each use case.

The **PPC** category includes the dimension PPC understanding. The minimum requirements are characterized by the existing understanding of PPC. It is necessary to know the functions and the associated tasks. This is the basic prerequisite for being able to assess the benefits and use of AI to improve the goals of PPC. There is also a correlation between this dimension and the transparency dimension of data needs.

All dimensions that influence the AI implementation in the PPC from a technological point of view are summarized under the category **technology**:

- *Machine integration*
Machine integration is required to meet the demand for feedback data from the shop floor. Machines must be able to collect and report real-time data.
- *PPC systems*
The use of PPC systems (software) is required to collect PPC data. As a minimum requirement, PPC systems must be used to execute the PPC functions.
- *AI technology*
In order to implement AI, appropriate AI technologies must be in place.
- *Enterprise data management systems*
Depending on the function to be supported by the AI in PPC, interfaces to other company areas and to external actors such as customers and suppliers may be required. The minimum requirement for the AI implementation is central data management systems, which enable both data capture and data exchange.
- *Automation of data acquisition*
As a minimum requirement, at least some of the data must be exchanged digitally. However, it must be taken into account that manual data entries are prone to errors,

making a high proportion of digitally entered data desirable.

All dimensions that relate to the organization and people are grouped under the category of **organization**:

- *Process structure*
It is important to consider the process structure dimension given the requirement for data from different areas. Processes must be defined for the implementation of AI.
- *Expert knowledge of AI*
Expert knowledge plays an outstanding role in AI implementation. Only if this is available can the implementation succeed and the potentials be exploited. Measures to meet the minimum requirements include, for example, hiring new employees, bringing in external consultants, or training employees.
- *Readiness for change*
Willingness to change is important because the success of AI also depends on the people involved. There is therefore a special correlation with the dimension of data quality. For example, the lack of readiness for change can lead to incomplete data collection by not meeting basic requirements from the responsible parties. Thus, for AI implementation, the change must already have been initiated.

4.2 Maturity Model Levels

In the presented model, five maturity levels are considered, as shown in Fig.3.

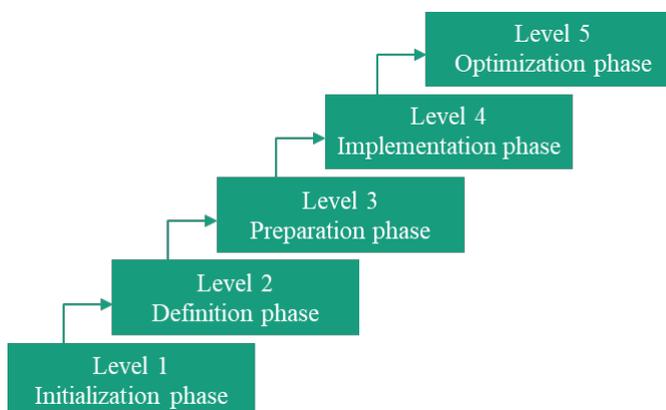


Figure 3. Maturity levels.

The presented approach includes two levels of intelligence: the conditionally and the fully intelligent PPC. The PPC is conditionally intelligent if all dimensions meet the minimum requirements. This corresponds to maturity level 4. The PPC is then fully intelligent, reaching maturity level 5, when all functions can be supported by AI and all requirements are met without restrictions.

The content of **Level 1** refers to the fact that the companies should start the process by planning the basis and conditions for implementing AI in PPC. In order to climb to **Level 2**, it is necessary to obtain expertise for the AI implementation, set a strategy and define use cases. Based on this, the data requirements are to be derived. To reach **Level 3**, companies

must make the strategy known to all employees. Measures must also be taken to capture and process the data digitally and to create interfaces within the company. **Level 4** involves individual functions being supported by AI, with humans and AI working together in the decision-making process. To achieve **Level 5**, external interfaces must be created in addition to the internal interfaces. Level 5 means that AI is used in an aim-oriented manner and that humans are no longer involved in the decision-making process.

5. Summary

Due to arising challenges for companies, the requirements in PPC are also increasing. This paper proposed the use of AI as a possible approach to handle this situation.

In order to support companies in evaluating the current situation regarding AI in PPC, and subsequently deriving potentials and fields of action, this paper proposes a maturity model.

The maturity model for AI in PPC is based on the requirements of AI for handling the challenges in PPC, with reference to the basic ideas of other maturity models. 18 dimensions were identified as requirements, which were then divided into five categories. In contrast to other MMs, a focus was made on helping companies looking to implement AI in PPC, defining dimensions and minimum requirements to be met. The advantage over other MMs is that even companies without expertise in AI in PPC can use this model as a guideline.

The presented maturity model for AI in PPC comprises a total of five maturity levels: *initialization phase*, *definition phase*, *preparation phase*, *implementation phase* and *optimization phase*. With maturity level four, a conditionally intelligent PPC can be achieved. For a fully intelligent state of PPC, maturity level five must be fulfilled.

A comparison based on the survey conducted shows that more than 50% of the examined enterprises failed to fulfil the derived minimum maturity levels. This proves the necessity of a MM as the one presented to help companies organize their activities and efforts.

6. Outlook

In the next steps, the proposed model will be tested in order to examine its suitability to be applied in practice. To achieve this, cooperation with a manufacturing company is suggested, as well as specifying the model for the individual functions of PPC. This would also imply a further analysis of the data requirements.

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