Approaching Automation of Production Planning and Control: A Theoretical Framework

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Abstract

The ongoing digitization of production has led to a significant increase in global competition. Manufacturing companies located in high-wage countries such as Germany must find ways to transform their production to economically competitive technologies. Automation is seen as a suitable method for reducing process costs in the manufacturing industry. Especially the automation of production planning and control (PPC) is a major challenge for companies. Since it often is not easy to determine the objectives for automation, identifying automation potentials is a problem. In addition, there are organizational, technical and personnel challenges to automation. While most companies have recognized the potentials of automation they often fail to achieve these in practice. This paper presents a process model that supports companies in systematically automate PPC. The model provides users with guidelines to help to identify automation potentials. It offers the ability to overcome typical barriers to automation through recommendations for appropriate measures and determines the common challenges companies are facing in the field of automation. The process model is divided into two sub-models. In the phase model, the required phases and steps of the model are identified. The task model provides a detailed description of tasks to perform to successfully approach the automation of PPC.

Keywords

Automation; Production Planning and Control; Process Model

1. Introduction

The global race for leadership in digital production has picked up speed considerably in recent years. According to a 2018 study by the management consultancy McKinsey, the digitization of production is the top priority for 69% of German industrial companies when it comes to investment decisions [1]. Consequently, a major structural change has begun in recent years, with more and more production activities being digitized and automated. Automation generally describes *"the replacement of human activity by machine activities"* [2]. While many manual workplaces have already been substituted by automated or autonomous machines or production facilities [3], there still is considerable potential for improvement [1]. This is particularly true, when it comes to organizational tasks in production logistics, especially in production planning and control (PPC) [4]. PPC manages the production-related logistics processes in the company's internal supply chain with a focus on the allocation of orders to resources taking into account overall objectives such as short lead times, high due date reliability and cost minimization [5]. Consequently, the term "automation of the PPC" shall be interpreted as the autonomous fulfilment of the tasks of the PPC, taking into account the strategic objectives. This requires consideration of corporate strategy aspects, technological and process-related constraints, as well as personnel and organizational requirements. Consequently, when automating PPC, companies are facing the problem of having to restructure technical systems, corporate structures as well as

personnel planning and development simultaneously. Automation projects that focus exclusively on one of these aspects (e.g. the technical design) usually fall short of the expected results [6]. Therefore, a systematic approach is required that supports the identification and implementation of "reasonable" automation measures taking into account relevant interdependencies and parameters both within the PPC as well as with adjacent processes, departments and functions. In this context, "reasonable" indicates that for each automation decision, the expected benefit must outweigh the effort required for automation [7]. This paper presents a universal framework to structure this complex task and to systematically support manufacturing companies in establishing "reasonable" automation of PPC. First, an introduction to the theoretical background is given and relevant literature is analyzed (chapter 2). Subsequently, the applied research method is presented in chapter 3. Chapter 4 summarizes the technical, organizational and personnel challenges of restructuring tasks in the context of automation as the first step of the method. On this basis, chapter 4 presents the process model that represents the macro level of the developed framework. It describes phases to follow for automation in a (chrono-)logical order. The task model presented in chapter 5 concretizes these concerning the tasks to be addressed in each phase. Conclusions are given in chapter 6.

2. Theoretical background and literature review

The overall goal of this paper is to provide guidance for approaching automation of PPC structured in a holistic framework. Consequently, the scientific literature must be examined both concerning general approaches and process models for describing and automating the PPC as well as specific solutions that have already been developed for automating the PPC or its subtasks.

Overall, PPC experienced a rapid evolution from early shop floor control approaches, developed in the early twentieth century, to integrated supply chain planning approaches, managing extensive and complex supply chains or networks [8]. Following the Hanoverian Supply Chain Model (HaSupMo) PPC can be structured into a total of eleven main tasks like inventory management or production planning and puts them in a temporal and logical sequence. [9] For a detailed description of each task, reference is made to [10,5,9]. Within each of the HaSupMo's main tasks, several subtasks are organized – especially dealing with conflicting objectives between the various (sub-) tasks of PPC. [10,11,5] examine the interdependencies and effects of PPC procedures on the logistics performance of production without providing specific guidance to automating the PPC or specific tasks. In contrast, [12] describes a concept for factory digitization. The concept consists of three phases: The Preparation phase, concept phase and implementation phase. In the context of the introduction of the digital factory, economic, technical and organizational aspects of digitization are taken into account. [13] present a concept for the automation of production processes incorporating control loops combining lean methods and capabilities of modern Manufacturing Execution Systems (MES). Besides MES, there is a wide variety of IT systems, such as Enterprise Resource Planning (ERP) systems, available to support or fully perform these tasks [14,8,15,16]. However, because of the conflicting objectives, companies have to face strategic trade-off decisions between the objectives that mostly still require human interaction. While there is lots of work focusing on the selection and implementation of such systems [17,6,18], these often represent isolated solutions that only provide support for specific tasks or have a narrow focus on technical, organizational or personnel aspects. Some examples of this are human-centered support systems [19], also in connection with permanent optimization for scheduling [20], approaches to automating individual PPC tasks using machine learning methods [21,22] or adaptive production control and technical order processing systems based on cybernetic support systems and intelligent sensor technology [23,24]. In practice, however, company-specific adaptations of standard software are widespread. This wide spread IT landscape often results in an uncoordinated, department-specific IT landscape [25], and thus constantly increasing complexity [4]. In addition to the general complexity of PPC, the increasing complexity of IT systems and the qualification and integration of employees represent the major challenges for the automation of PPC [26].To compensate for the increasingly complex processes in indirect areas, which also

include the operation of these systems for performing PPC tasks, Robotic Process Automation (RPA) is becoming more and more popular [27]. RPA is based on the idea of having digital software robots perform simple, repetitive tasks automatically that otherwise would be carried out by humans [28,29]. In particular, the focus is on activities/tasks that do not allow for complete automation or could be implemented profitably because they only occur sporadically. A typical example is the transfer of data from order documents of different formats into ERP systems. While this makes using (even heterogeneous) system architectures less time-consuming and more efficient, RPA does not improve the systems themselves. Also, only those business processes can be automated by RPA that follow clearly defined business rules that can be formulated as if-then-relationships. Decisions such as balancing competing logistics objectives as described by SCHMIDT [5] cannot be made using RPA but still require human judgment and decision-making. [27] Although RPA systems can deal with increasingly complex tasks using machine learning methods, RPA on its own is no suitable tool for automating PPC [27]. Instead, a broader view of PPC and its tasks, including strategic decisions, is needed. Based on this literature review and to the best of the authors' knowledge, a framework that gives systematic guidelines for PPC automation, taking into account not only technical challenges but also those regarding human interaction and integration as well as organizational challenges like production configuration, is not available, yet.

3. Research methodology

The theoretical approach to the research subject as well as the variety of interdependencies and influencing factors to be taken into account do not allow the research question to be answered based on quantitative analyses. However, according to the widely used research approach of applied science (AS) according to ULRICH [30], design principles can be validly derived based on problem-relevant theories of the basic sciences and procedures of the formal sciences. The AS approach is typically motivated by a problem in practice. Specifically, argumentative-deductive reference modeling was used in this work. In reference modeling, simplified and optimized representations (ideals) of systems are usually created inductively (based on observations) or deductively (e.g. from models) to deepen existing knowledge and generate design templates [31]. In addition, WEICK's 'sensemaking' concept [32] was used as a guideline. This emphasizes the relevance of a valid system understanding in the practice of production organization over quantitative research, which always aims to increase accuracy. Following this research methodology, the challenges in automating PPC are structured below and the approach developed is presented on this basis.

4. Challenges in the automation of PPC

With or through increasing automation, technical as well as organizational and personnel challenges arise [6]. An overview of the different challenges is shown in figure 1. The **personnel challenges** include ensuring the qualification of the employees, the user integration and interaction with the automation solution as well as the employees' overall understanding of the automation concept and the production system. As a result of automation, the employees' work content and structures usually change significantly. Often, fewer but more highly qualified employees are needed in the long term to work with automated systems, so that employees may have to be hired or (re)trained [33,34]. At the same time, it is important to make operating the systems needed for automation as easy as possible. In addition to the basic usability of the systems, the acceptance of the systems and their functionality by the operators is another key success factor for the automation of PPC. If employees do not trust the systems' functionality, efficient automation will not be possible [12,6]. Instead, this tends to foster the establishment of alternative parallel solutions and thus unnecessary interfaces or discontinuities in the information flow. This highlights the importance of creating an understanding of the overall IT and production system, the complex interrelationships within it and those resulting from the automation of PPC tasks, and the benefits of the new solution among the employees [12].

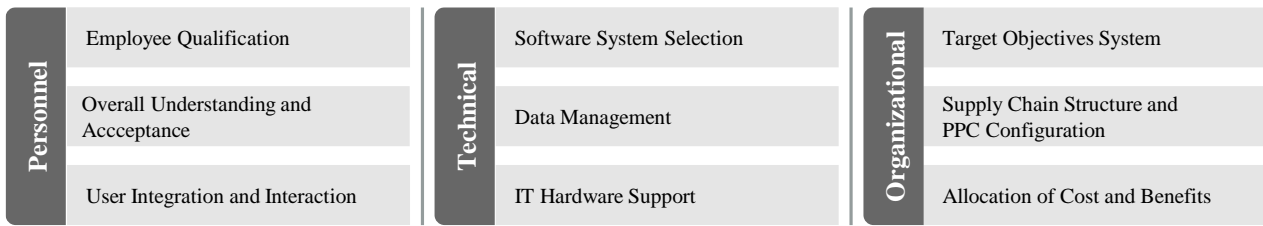| **Personnel**		**Technical**		**Organizational**	
Employee Qualification		Software System Selection		Target Objectives System	
Overall Understanding and Accceptance		Data Management		Supply Chain Structure and PPC Configuration	
User Integration and Interaction		IT Hardware Support		Allocation of Cost and Benefits	

Figure 1: Challenges in the automation of PPC

The **technical challenges** primarily include the selection of suitable software, providing the data required for automated decision-making in suitable quantity and quality, and flexibly adaptable IT hardware and software. The multitude of software systems available on the market today, some of which are highly specialized, as well as the variance of the functions offered in each case, represent major challenges for many companies in identifying the most suitable system for their purposes [6]. The data requirements to be satisfied for the available functionalities must also be taken into account. Although companies often already have large amounts of data, these are often unstructured and of insufficient data quality or granularity [35]. The basis for reliable, automated decision-making is therefore a database that is appropriate for the planned use case and the selected IT systems [12,36,3]. Key to this is, among other things, the linking and provision of data within the company and thus a suitable IT infrastructure. However, the increasing amount of data and the need for worldwide real-time access present challenges to today's IT architectures [37]. The automation of PPC also confronts companies with organizational **challenges originating from the business and process organization**. Today, many manufacturing companies have comprehensive and precisely formulated corporate strategies or visions. However, these often contain contradictory or divergent logistical objectives, which make it difficult or impossible to consistently align the company's processes with them. In particular, the conflicting logistical objectives and mutual dependencies that have to be taken into account represent a major challenge for many companies when defining a transparent target system. They often result is conflicting (divisional) objectives that prevent the achievement of a company-wide overall optimum [36,6,3]. Further efficiency potential remains unrealized if old company processes and structures are not adapted before or when introducing new information systems [12,3]. Especially in the case of automation potentials that are not or only with difficulty monetarily quantifiable - e.g. efficiency gains in indirect activities and areas - the determination of costs and benefits of automation measures represents a further challenge. For example, the costs of employee training measures are often underestimated or the benefits of reducing manual activities are not valued appropriately [3]. In combination, this makes it difficult to prove benefits in the long term. This often leads to limitations in the scope of automation projects or even their cancellation.

5. Process model for the automation of PCC

Taking these challenges into account, the following section describes a systematic approach for automating PPC. The model is divided into two sub-models (process model and task model). The process model describes the phases to be passed to automate PPC. The phases describe individual sections of the developed process. They are aligned sequentially and delimited at the end of each phase by gates that check the transition to the next phase based on different criteria. Each phase consists of several steps that address different issues in PPC automation (see figure 2). The definition of the various phases is based on the approach for factory digitization by BRACHT et al. [12]. They propose a step-by-step procedure that, due to its systematic and holistic approach, forms a suitable basis for developing a procedure for automation in production logistics. Their approach was adapted to the requirements of production logistics, while the separation into different phases was adopted to structure the developed model. However, the grouping of several steps into phases can also be found in work by numerous other authors (e.g. [23,6]). The sequence of the steps was determined based on relevant literature in context of PPC automation, in particular [12,38].

Phase 1 Logistics configuration			Phase 2 Automation concept				Phase 3 Implementation
Automation environment	Logistics objectives system	PPC procedures	Organization	Software, hardware and data requirements	Employees	Cost and benefit	Implementation
Definition of the basic environment conditions for automation	Development of a consistent objective system at corporate and divisional level	Selection of suitable PPC procedures to achieve target objectives	Planning of necessary adjustments to company processes and structures	Assessment of the required software and hardware support as well as data including their quality and quantity	Planning of the necessary modifications in the number and qualification of employees	Estimation of the costs and benefits of PPC automation	Implementation of the concept for PPC automation
Project management							

Iteration for different PPC tasks and evaluation points in time
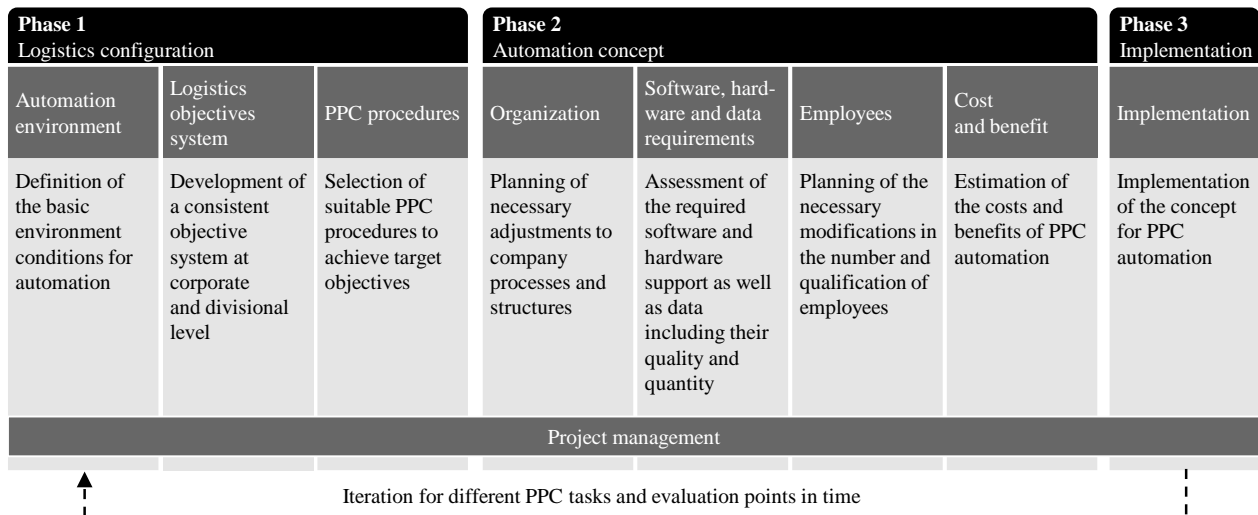
Figure 2: Process model for PPC automation

The process starts with the identification of company-specific and context-specific conditions or constraints that need to be taken into account during PPC automation. In particular, these include the business model, the supply chain structure and the order processing strategies pursued. They can differ considerably between individual companies and. Based on these parameters, an objective system needs to be defined at the company and divisional level. Based on this, the economic and logistical objectives of the company must be defined as a guideline for all subsequent phases. [39] Before developing specific measures for automation, a suitable configuration of PPC must be defined. This includes the selection and parameterization of PPC processes to ensure that they are consistent with the company's objectives. The first phase of the model, the logistics configuration phase, represents the basis for subsequent automation. Since there are numerous potential logistic objective systems and a high number of configuration options (e.g. measures to manage order release or sequencing) to be aligned with these objectives, it can be found that the logistics configuration is the most complex phase of the model, requiring the highest effort for users of the model. Since the adaptation of the organizational structures forms the basis for the selection and adaptation of the technical systems, first the organization and afterward the software, hardware and data requirements for the automation of the PPC have to be adapted [6]. During this process, the possibility of automating individual PPC tasks is examined from various perspectives. These ensure a systematic consideration of the challenges presented in chapter 3. The automation concept phase focuses on verifying the organizational, technical and personnel feasibility of automation measures. Once the organizational and technical basis has been defined, the integration of personnel and their interaction with the technical systems must be defined [38]. If the feasibility of the automation is verified, an evaluation of the costs and benefits of the measures is required to prove the profitability of the automation projects. Since profitability mostly represents the overall goal of every automation measure, only those measures that pass this assessment can be transferred to the final implementation phase. To support the automation projects, an ongoing project management is necessary throughout the entire duration of respective projects. While the phase-based structure describes a purely sequential process, these are usually repeated iteratively to advance the automation step by step. Normally, there should be at least one iteration per each PPC main task. In addition, more iterations can be used to check the usefulness of automation at different points in time.

6. Task model for the automation of PPC

As described earlier, there are numerous steps in chronological and logical order within each of the phases. All of these steps each have defined inputs and outputs and are logically linked to each other. Due to the size of the model (figure 3), it is not possible to describe each of the tasks incorporated in this article. However,
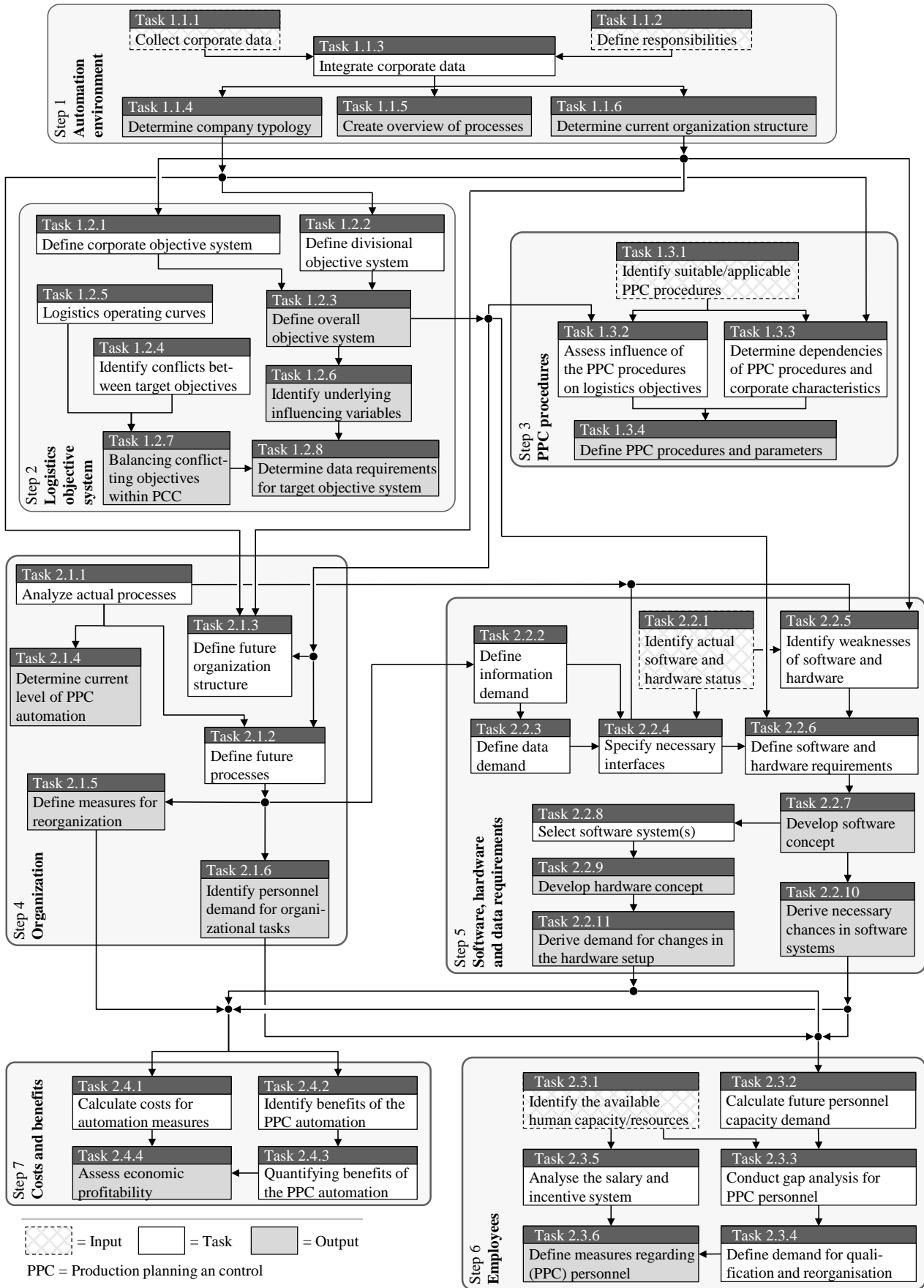
Step 1 Automation environment

Task 1.1.1 Collect corporate data

Task 1.1.2 Define responsibilities

Task 1.1.3 Integrate corporate data

Task 1.1.4 Determine company typology

Task 1.1.5 Create overview of processes

Task 1.1.6 Determine current organization structure

Step 2 Logistics objective system

Task 1.2.1 Define corporate objective system

Task 1.2.2 Define divisional objective system

Task 1.2.5 Logistics operating curves

Task 1.2.4 Identify conflicts between target objectives

Task 1.2.3 Define overall objective system

Task 1.2.6 Identify underlying influencing variables

Task 1.2.7 Balancing conflicting objectives within PCC

Task 1.2.8 Determine data requirements for target objective system

Step 3 PPC procedures

Task 1.3.1 Identify suitable/applicable PPC procedures

Task 1.3.2 Assess influence of the PPC procedures on logistics objectives

Task 1.3.3 Determine dependencies of PPC procedures and corporate characteristics

Task 1.3.4 Define PPC procedures and parameters

Step 4 Organization

Task 2.1.1 Analyze actual processes

Task 2.1.3 Define future organization structure

Task 2.1.4 Determine current level of PPC automation

Task 2.1.2 Define future processes

Task 2.1.5 Define measures for reorganization

Task 2.1.6 Identify personnel demand for organizational tasks

Step 5 Software, hardware and data requirements

Task 2.2.2 Define information demand

Task 2.2.1 Identify actual software and hardware status

Task 2.2.5 Identify weaknesses of software and hardware

Task 2.2.3 Define data demand

Task 2.2.4 Specify necessary interfaces

Task 2.2.6 Define software and hardware requirements

Task 2.2.8 Select software system(s)

Task 2.2.7 Develop software concept

Task 2.2.9 Develop hardware concept

Task 2.2.10 Derive necessary chances in software systems

Task 2.2.11 Derive demand for changes in the hardware setup

Step 7 Costs and benefits

Task 2.4.1 Calculate costs for automation measures

Task 2.4.2 Identify benefits of the PPC automation

Task 2.4.4 Assess economic profitability

Task 2.4.3 Quantifying benefits of the PPC automation

Step 6 Employees

Task 2.3.1 Identify the available human capacity/resources

Task 2.3.2 Calculate future personnel capacity demand

Task 2.3.5 Analyse the salary and incentive system

Task 2.3.3 Conduct gap analysis for PPC personnel

Task 2.3.6 Define measures regarding (PPC) personnel

Task 2.3.4 Define demand for qualification and reorganisation

= Input = Task = Output

PPC = Production planning an control

Figure 3: Task model for the automation of production planning and control

6

the structure and application are demonstrated below using two steps as examples (section 5.1 and 5.2). As mentioned earlier, from a production logistic perspective, these represent the core of PPC design and thus are shown as examples in the context of this paper.

6.1 Definition of the objective system (Example 1)

The definition of a consistent logistics objective system at the corporate and division level (Task 1.2.1 and 1.2.2) represents the second step of the logistics configuration phase. This serves the consideration and transparent structuring of different, partly contrary logistic objectives. For this purpose, all corporate objectives and their mutual cause-effect relationships are identified. Defining the objective system also requires the corporate typology and organizational structure, which are the outputs of the previous model phase (Analyzing the automation environment). Based on this an objective system is defined on the corporate level and adapted to individual corporate or supply chain segments (Task 1.2.3). There are different, in some cases contrary, relationships between objectives. To overcome the resulting objective conflicts, objectives must be weighted (Task 1.2.4). Logistics operating curves are a suitable instrument for weighting target variables, as they represent the relationship between different target variables [40]. The positioning between conflicting logistic objectives is done by defining operating points on the logistics operating curves (Task 1.2.5 and 1.2.7). The objectives mutually influence each other but are also influenced by other influencing parameters. These parameters are also of significant relevance for automation. For example, the objective "lead time" is influenced by the parameter "sequence of production orders", which is defined in the step "Configuration of PPC" and PPC task "sequencing". Therefore, it is necessary for all objectives in the PPC-relevant business units, to determine the influencing parameters that have a significant impact on the achievement of the objectives (Task 1.2.6). An approach for the systematic analysis of the effect of different PPC methods on the logistic objectives can be found in MÜTZE et al. [10]. To automate PPC, data requirements for collecting the KPIs and defining objectives must be determined (Task 1.2.8). The output of the second phase is the overall objective system and its influencing parameters, the target weighting and the data requirements for calculating the KPIs within the objective system (see figure 3). These outputs serve as required inputs for the subsequent steps of the model.

6.2 Configuration of PPC procedures (Example 2)

The configuration of PPC is required before the tasks of PPC can be automated. This includes the selection of suitable procedures as well as their parameterization [39]. For this purpose, the definition of the from the previous step is used as an input to limit the selection of procedures (e.g., to date-oriented sequencing procedures) and which is also used as an input for the parameterization (Task 1.3.1). Further restrictions for the selection of procedures can be made based on the corporate typology, an output which was analyzed in step 1. The potentially suitable PPC procedures are used to determine which of the procedures supports the previously defined objectives (Task 1.3.2). Also, a continuous review of the compatibility of PPC procedures and the typological characteristics of the applying corporation is required (Task 1.3.3). The corporate typology, the output of step 1, is again used for this purpose. When selecting PPC procedures, corporations can refer to numerous publications on this subject (e.g. [41,42]), which is why the selection process is not described in further detail in this paper. The output of step 3 is a list of selected PPC procedures and their parameterization for each PPC task (Task 1.3.4). The preparation phase is completed with the selection of PPC procedures, which serve as an input for the subsequent steps of the model.

7. Conclusion

The automation of production planning and control is an important instrument for increasing efficiency in the manufacturing industry. Nevertheless, only little of this potential has been utilized so far - in particular,

due to various, often complex challenges. The approach presented in this paper structures the necessary steps for meaningful automation of PPC within a phase model as well as a task model, which arranges the decisions and tasks to be performed in the respective phases into a chronological and logical sequence. Previously, the focus was primarily on in-house production planning and control as a task without comprehensive, direct influence from customers or suppliers. Although the process model is not limited to any specific main PPC task, it still requires verification of its applicability to other main PPC tasks with greater customer or supplier involvement. In this context, it is necessary to examine how decision-making processes can be integrated into an automated PPC environment and which tasks can be automated through this and to what extent. An example is to link tasks from production planning and control via production program planning directly to information from suppliers, thus eliminating the need for coordination across a large number of task and activity areas.

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