CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2021

2nd Conference on Production Systems and Logistics

Low-Level-Code Based Production Model For Improving Material Requirements Planning In ERP Systems

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Abstract

Single and small-series production companies face specific challenges, such as variable customer order decoupling points (CODP), decreasing quantities and rising cost pressure. This leads to a increasing production complexity and growing requirements on Production Planning and Control (PPC). Digitalization's direct links between objects, people, and machines as well as detailed recording of production progresses opens new solutions for PPC. However, volume of data and the required processing times are increasing. Thus, to achieve near-real-time data processing, a decentralization of decision-making systems can be observed.

The function Material Requirements Planning (MRP) is PPC's original need for Enterprise Resource Planning (ERP) systems. Here, PPC's overall problem (to fulfil primary requirements for products) is divided into subproblems (to fulfil single production orders). Especially companies characterized by an organization in accordance to the workshop principle, high in-house production depth and variable CODP are confronted with high dynamics in their production systems. This ends in significant differences between primary requirements (overall problem) and single production orders (subproblems). Ultimately, these insufficient PPC data result systematically in a non-optimal overall solution despite optimal partial solutions.

This publication combines PPC's fundamentals from existing commonly known models with current implementation concepts of ERP systems. A newly developed Low-Level-Code based Production Model provides explanations for deviations between the overall problem and its subproblems. Furthermore, information flows of PPC can be structured between a periodically actualized vertical and an event driven horizontal information flow. These recognitions lead to an improvement of PPC by ERP systems.

Keywords

PPC; ERP; MRP; Production Regulation

1. Introduction

In recent years production is confronted with increasing market dynamics and demands for individual products. Both result in requests for advanced variability, shorter product life cycles, shorter delivery times and ultimately smaller lot sizes in production [1,2]. In parallel, cost pressure on production is growing because of a worldwide increase in competition [1]. Overall, this results in raising logistics requirements [3] and ask for greater flexibility in production systems [4,5].

PPC's task is optimal positioning of production in conflicting objectives well-known as "dilemma of operations planning". It consists of the opposing objectives of short throughput times, high schedule

DOI: https://doi.org/10.15488/11242

reliability, low capital commitment costs (low work in progress) and low process costs (high utilization). Therefore, PPC is significant for the success of manufacturing companies [6,3,5]. Digitalization of production systems results in improved data timeliness and data completeness. It creates enormous potential to deal with increased dynamics and complexity [7,8]. However, this does not resolve the specific conflict between customer orientation and logistics costs [4]. Moreover, increasing data in different formats from multiple systems lead to a complexity problem in PPC systems. Availability of valid information is therefore crucial for a successful PPC [8].

In the past, demands for a greater flexibility lead to a decentralization of production systems [9]. It began with primarily organizational development of production into autonomous, self-optimizing, decentralized units under the keyword "lean production" [4]. Nowadays, a further step towards decentralization follows with digitalization [10,2]. Direct communication and event-driven data processing enable a decentralization of decision-making systems and automated control in real time [11,12].

Contrary to the trend of decentralization, successful PPC can only be achieved by a coordinated interaction of different production units [4]. In decentralized decision-making systems, however, it is difficult to coordinate decentralized subproblems and the central overall objective [12]. It therefore remains questionable to what extent separately solved subproblems follow the overall goal. It ends up in two questions: How much decentralized decision-making scope should be given? And how can we ensure technically that the subproblems pursue its overall objective? Consequently, the (search for a) optimum PPC system that combines advantages of real-time decentralized data processing and consistent pursuit of the overall goal has not yet been finally completed.

The objective of this publication is to develop a model that links existing findings of actual PPC models with a current implementation concept in ERP systems. This new model is suitable for explaining relationships between theoretical findings and technical implementation as well as for identifying systematic causes for deviations of decentralized subproblems from their central overall problem.

2. Terms and Definitions

The Hanoverian Supply Chain Model (HaSupMo) [13] is based on the Aachen PPC Model [14] and Lödding's Manufacturing Control Model [4]. It combines the organizational processes of company's supply chain with logistics objectives of PPC. Furthermore, the Two-Stage Control Loop Model [15] illustrates the relation between primary requirements (overall problem) and single production orders (subproblems). Therefore, we combine the Two-stage Control Loop Model with the named and in German-speaking areas commonly known PPC models in section 2.1. PPC's core function of ERP systems is Material Requirements Planning (MRP) according to the MRPII concept [16]. A program-technical method for this is called low-level-code (LLC) procedure [2], which we want to detail in section 2.2.

2.1 Fundamentals of PPC

HaSupMo [13] distinguishes primary requirements initiation into sales order-neutral (production program planning) and sales order-specific (order management). Derived from them, gross and net dependent requirements are determined cyclically by MRP. Net requirements trigger external and internal planned replenishment elements which lead to dependent requirements based on their Bill of Material (BoM) explosion. In accordance with Aachen PPC Model, a distinction is made between external and in-house PPC [14]. Following Lödding's Manufacturing Control Model in task order generation, planned orders are transformed into final production orders. Here, procurement type, lot size and scheduling are finally determined. Further PPC tasks like order release, capacity control and sequencing as well as production itself depend on these production orders [4]. Moreover, in HaSupMo, the task availability check for verification if required resources of a production order are available, is explicitly listed [8].

The Two-Stage Control Loop Model illustrates main information flows of PPC, which are based on variables of a control loop (see Figure 1). Visualized information flows are:

- **Reference variable w_1:** production program planning as well as order management define primary requirements. These are processed in MRP (outer controller) to determine net requirements as well as to generate planned replenishment elements (e.g. planned orders). W_1 operationalizes company's central logistics objectives into the specific fulfilment of demands for products (overall problem).
- **Reference variable w_2:** after order generation final production orders are created. Their planning data (e.g. procurement type, lot size, scheduling) form the production plan, which is input for the inner controller. Hence, production orders of production planning (outer controller) contain reference information for the subproblems.
- **Actuating variable y:** production control specifies *actual input* (availability check, order release) and *actual sequence* (sequencing) of production orders (subproblem) in production (controlled system). Furthermore, production control influences *actual output* of production by capacity control.
- **Control variable x:** With actual data from confirmations of production, Lödding defines control variables *backlog* and *sequence deviation* as difference between planning data of production orders (subproblems) and actual data of production. Moreover, he specifies control variable *work in progress* as difference of actuating variables actual input and actual output [4,1,15,13].

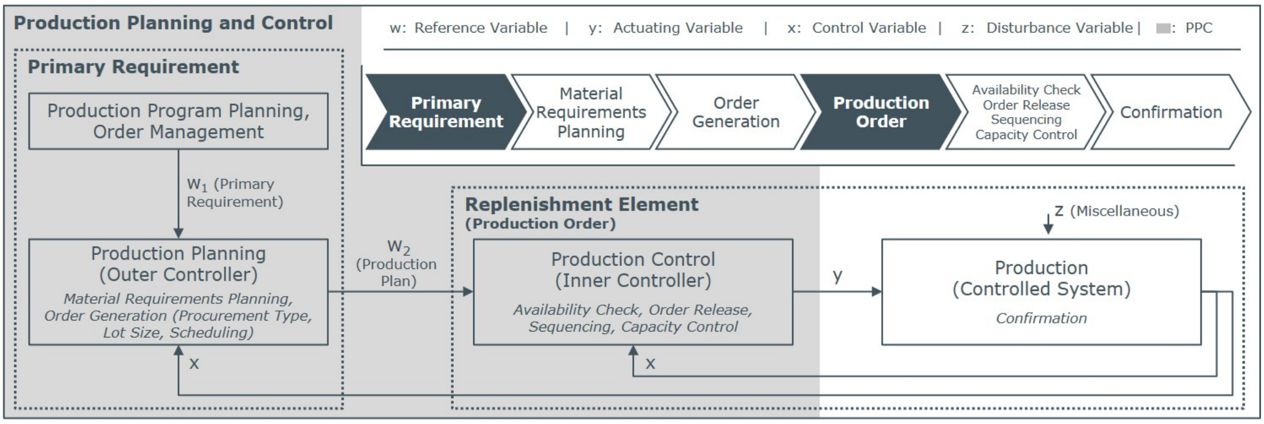

Figure 1: Two-Stage Control Loop Model [1,15]

A classification of different controller types is given by Niehues [1]. Furthermore, HaSupMo and Lödding's Manufacturing Control Model show a direct influence of these control variables on logistics objectives as throughput time, schedule reliability, work in progress and utilization. Due to opposing nature of these objectives, two aspects can be observed: temporal instability and different focuses between functional areas (e.g. purchasing, distribution, production). Hence, an improvement in direction of a company's optimum is difficult [5]. Besides, logistics objectives depend on CODP and are thus subject to market-driven dynamics. For example, in anonymous make-to-stock production, there is a stronger focus on logistics costs (work in progress, utilization). Contrary, in customized make-to-order production, logistics performance (throughput time, schedule reliability) are dominant [5]. However, the transition between make-to-stock and make-to-order production is often dynamic and overlapping. Thus, in production, the conflict occurs not only among different shop floor areas but also between different production orders in one shop floor area [3,5]. Overall, in recent years, there has been a growing focus on logistics performance [2].

2.2 Material Requirements Planning based on LLC Procedure

The Two-Stage Control Loop Model shows transformation of primary requirements for final products into individual replenishment elements (e.g. production orders). It illustrates importance of MRP for PPC (see Figure 1). Central task fulfilling primary requirements of a company [5] are thus divided into subtasks.

Within PPC, ERP systems often serve as a basis. Additionally, they integrate other functions such as accounting, sales and purchasing, and thus form a common data basis. Thanks to central data management, this data can always be retrieved despite different use cases, and redundant data storage is avoidable [17,2]. As in ERP systems many materials are to be processed, MRP takes place successively and hierarchically in stages. A program-technical method for this is called low-level-code (LLC) procedure. Here, materials are grouped according to their lowest BoM explosion level (low-level-code) and processed together according to their ascending LLC (see Figure 2) [18,2]. As a result, all dependent requirements of a material are known at the time it is processed. Thus, it only must be processed once. The required LLC is part of master data of all materials and is usually determined automatically [16]. Figure 2 visualizes the following relations:

- **BoM and LLC (right site, Figure 2):** material's LLC is its lowest BoM explosion level. Purchased part P2 is a component of materials F1 (LLC (1)) and U1 (LLC (2)). Hence, it is on LLC (3).
- **Primary and dependent requirements (left site, Figure 2):** LLC (1) contains only primary requirements, as there are no requirements from above (see LLC (1), Figure 2). On subsequent LLC levels primary and dependent requirements are totaled per material (see LLC (2) and (3), Figure 2).
- **Requirements and replenishment elements (left site, Figure 2):** MRP compares quantities of requirements (negative) and replenishment elements (positive) over time to calculate net requirements. Besides this, both are completely decoupled (see LLC (2), Figure 2).
- **Replenishment element and its dependent requirements (left site, Figure 2):** components of planned orders are determined from material's BoM as well as requirements dates from its routing [18].

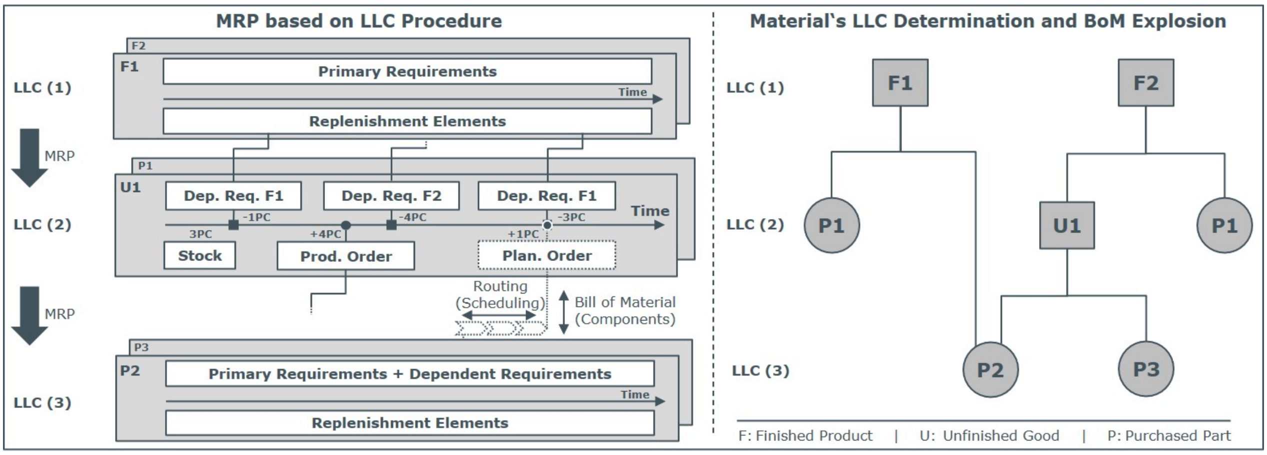

Figure 2: Material Requirements Planning based on LLC Procedure [18]

3. Decision Problem

Every day, production control faces decision problems of which resources are to be used for which production orders. These decisions refer to the production orders (subproblem) and are thus decoupled from their overall problem. In practical use of MRP in several companies with operation type variant manufacturer according to Schuh [14] we determined systematic deviations between planning data of subproblems (w_2) and overall problem (w_1). We observed that especially the following characteristics of companies are critical:

- **Variable CODP:** primary requirements of production program planning are subject to a certain degree of uncertainty due to a lack of a specific order reference. Therefore, primary requirements are not stable. It results in a dynamic in reference variable w_1 and thus significant differences between reference variable w_1 and production orders (w_2).
- **Decentralized workshop production:** undirected material flow of workshop production leads to a further increase of dynamics in production systems and at the same time to a tendency towards high

lead times. Moreover, decentralized organization (responsibility per workshop) favors a pursuit of decentralized goals and focusses even more on reference variable w_2.

- **Complex product structure and high in-house production depth:** a complex product structure coupled with a high in-house production depth leads to complex interrelationships in manufacturing. Therefore, differences between w_1 and w_2 are even more difficult to identify.

PPC's deviations between w_1 and w_2 means that decisions of the inner controller are based on incorrect information. For example, in practical application we observed that in the analyzed use cases on average every production order deviates in scheduling from its requirements at least once. Consequently, this leads to a suboptimal overall result despite optimal solutions of subproblems. Therefore, the question for information technology arises how we can more efficiently support PPC regarding overall logistics objectives. In view of this superior question, the goal of this publication is to develop a model that provides the following answers:

- Explanation for systematic causes of deviations between overall problem and its subproblems.
- Representation of basic information flows from PPC's decisions.

These answers are intended to provide approaches for improvements in practice. They also help us to explain why especially described characteristics of operation type are critical in this context (see section 5). With objective of reducing complexity, we focus on ERP systems with following assumptions:

- Dependent requirements are determined mainly deterministically by MRP in LLC procedure,
- Production planning is organized centrally, while production control is decentralized according to its work center,
- Component availability check is taken as decisive criterion for PPC's task order release.

We justify these as plausible by an operation type (variant manufacturer) and our choice of an established ERP system (SAP ERP).

4. Low-Level-Code based Control Loop Model

We showed that the Two-Stage Control Loop Model (see Figure 1) reflects basic elements of established PPC models. In view of requirements set here, however, it shows considerable uncertainties. On the one hand, it is not obvious what the deviations between w_1 and w_2 are due to. On the other hand, it neither considers details of availability check in production control nor its information flows and technical interrelationships in ERP systems. Hence, we use the Two-Stage Control Loop Model, which is basically suitable for explaining PPC's fundamentals, as a starting point to develop a new model oriented to the questions of this publication.

Challenging in representing relationships between production planning and production control in a common model are their different reference objects. While production planning is based on requirements and replenishment elements (MRP elements), production control as well as production are decentralized, and work center related. We start derivation of a new model with production planning (section 4.1). Afterwards we continue with production control and production (section 4.2).

4.1 Production Planning (MRP element)

LLC procedure processes materials successively according to their LLC. Hence, we conclude that we can better identify weaknesses in a model based on LLC. For this reason, we first detail existing model from Figure 1 in outer control loop according to LLC. Figure 3 visualizes this by separating production planning in vertical dimension. While inner controller, controlled system as well as variables y, x and z remain unchanged compared to Figure 1, reference variable w_1 and w_2 are detailed. We differentiate LLC as follows:

- **LLC (1):** like Figure 2, requirements of materials on LLC (1) include primary requirements only (see input to production planning, Figure 3). Planned and final replenishment elements from in-house production trigger dependent requirements, which are further processed on subsequent LLC. Moreover, production orders form reference variable w_2 for production control (see output from production planning, Figure 3).
- **LLC (n):** here, input to the outer controller consists of the sum of primary and dependent requirements from previous LLC (see input to production planning, Figure 3). As it is the last LLC, no dependent requirements are triggered here (see output from production planning, Figure 3). Usually, only purchased parts are processed on LLC (n).

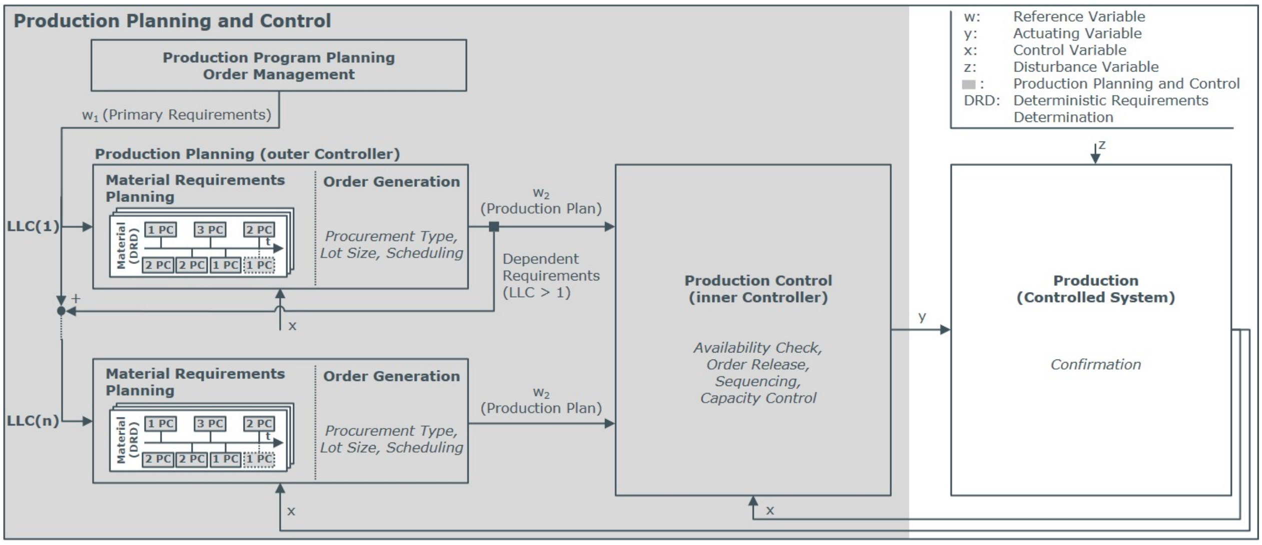

Figure 3 Production Planning in LLC based Control Loop Model

Furthermore, we can derive that a LLC (i) follows the systematic of LLC (1) on its output and LLC (n) on its input side. Finally, Figure 3 visualizes following details:

- Requirements and replenishment elements are decoupled after their processing in MRP. Thus, there is no link between these MRP elements. Hence, production orders are independent from its requirements in production control and production.
- Primary and dependent requirements are summed up per material and processed together on its LLC. Therefore, MRP does not differentiate primary from dependent requirements.

4.2 Production Control (operation of production order)

In this section, we use Figure 3 as a starting point to detail information flows between inner controller and controlled system. As we described previously, the work center related part of a production order is the reference object for this section. In ERP systems, this are production order's operations. They contains all planning data including necessary resources (especially components) for this processing step.

In Figure 3 the vertical dimension is already occupied for differentiation according to LLC. Therefore, Figure 4 divides information flows of production control and production in horizontal dimension according to work centers. Here we retain the original structure of the inner control loop (cf. Figure 1). When taking a more differentiated look at work center B, the following information flows are shown in Figure 4:

- **w_2:** planning data from production planning stored in operations of production orders specify the production plan of individual work centers.
- **Components availability:** corresponding to LLC's definition all components of a production order are on subsequent levels. Thus, to check components availability of a production order requires information from lower LLC.

– **x (1) and y:** according to description of inner control loop in section 2.1.
– **x (2):** a progress confirmation (following open operations) affects production control of next work center, as the production order is ready to be processed there.
– **x (3):** final confirmations (no following open operations) of a production order leads to a change in material stock and thus affects component availability at superior LLC.

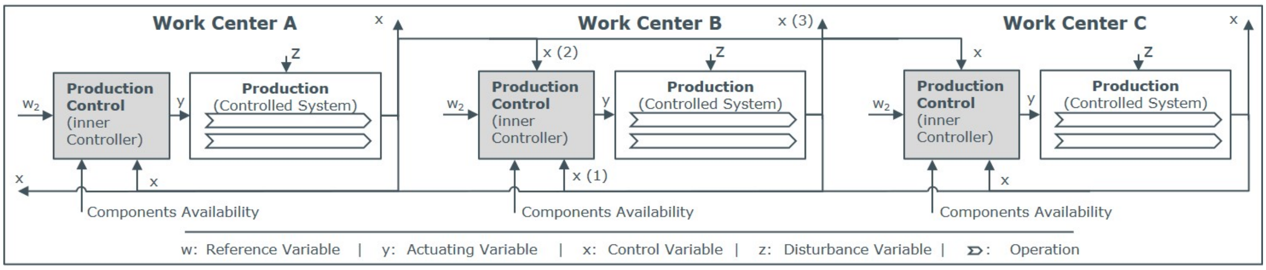

Figure 4: Information flows of inner control loop

Linking these information flows with the model extended in section 4.1, leads to a jointed model shown in Figure 5. There, we took production planning (left side) unchanged from Figure 3, while we derived production control and production (right side) from Figure 4. It requires following further explanations:

– To keep established structure of Figure 1, we had to separate production control in his role as inner controller from its work centers (controlled system). Irrespective of this, the organization of production control remains work center related and thus decentralized.
– LLC structure leads to a differentiation in inner controller and controlled system according to LLC levels. Furthermore, it should be noted that neither production control nor production operates on LLC levels. Dashed lines in Figure 5 indicate that respective worklists are the total across all LLC. Finally, in Figure 6 this becomes completely clear.

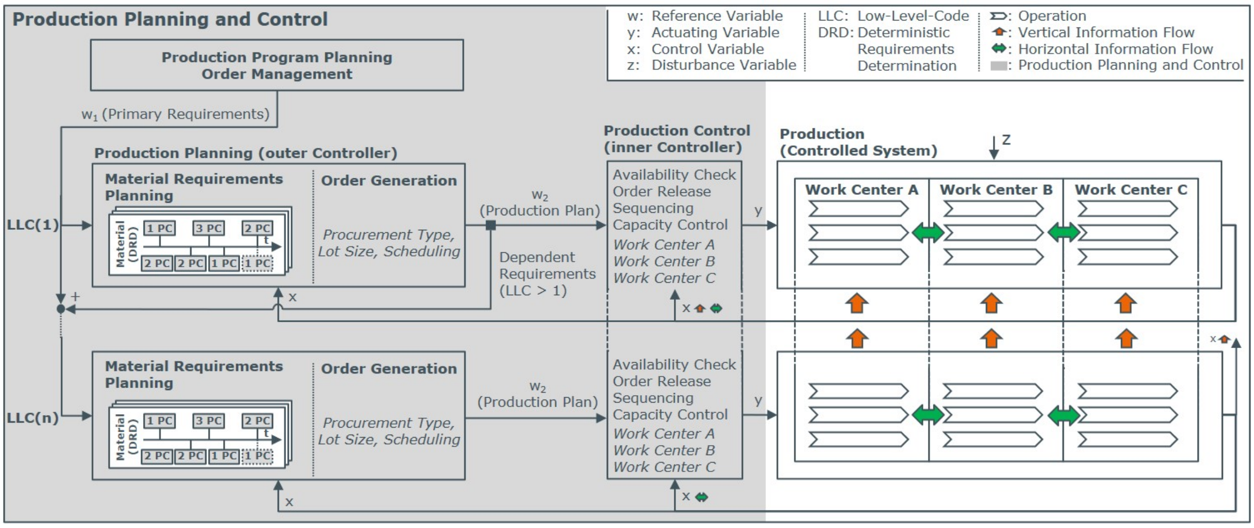

Figure 5: Production Control in LLC based Control Loop Model

Figure 5 shows compared to Figure 3 mainly the same information flows and control variables meanings. Thanks to the differentiation by LLC we can distinguish control variable x of inner control loop by following information flows:

– **Horizontal information flow (horizontal green arrows):** progress confirmations affect production control of next work center (see Figure 5; x (2), Figure 4).
– **Vertical information flow (vertical orange arrows):** final confirmations on low LLC (here LLC (n)) influence PPC's task availability check on higher LLC (here LLC (1)) (see Figure 5; x (3), Figure 4).

In summary, we structured Two-Stage Control Loop Model according to LLC in production planning. It enables us to describe MRP in greater details. Moreover, a closer look on inner control loop makes us to distinguish between a vertical and horizontal information flow. In extension to existing models the new model considers theoretical findings of PPC combined with technical implementation in ERP systems.

5. Application of model

With our new model we can concretely name existing weaknesses in current ERP systems implementation concepts that result in the deviations described in section 3. In Figure 6 we illustrate, in a visualization reduced to one generic LLC (i), weaknesses (1 to 3), which base on the following three findings:

- In MRP constant links between MRP elements are missing. Due to this decoupling, primary requirements are totaled with dependent requirements of higher LLC regardless of their reference to primary requirements. However, with high dynamics in PPC system (variable CODP), planning data of production orders deviate from their primary requirements in terms of quantity as well as scheduling very quickly. Moreover, longer throughput times of workshop production raises duration of decoupling and thus increase these deviations. Hence, these weaknesses in MRP systematically leads on subsequent LLC to growing differences between w_1 and w_2. Furthermore, MRP's single level perspective makes it within high in-house production depth difficult/impossible to identify if there is a deviation in the path above. Once again, this underlines independence of production orders from its primary requirements. Finally, it ends up in the observed deviations between overall problem (w_1) and its subproblems (w_2) as well as faulty information for PPC's decision problem (see 1, Figure 6).
- PPC's vertical information flow is significant for availability check in production control. Due to missing link between requirements and replenishment elements, an availability check is complex. Thus, for decisions which resources are to be used for which orders, both a central-optimal assignment of MRP elements as well as an event-driven data processing for decentralized-flexible decisions are desirable (see 2, Figure 6).
- In addition, information about progress of preceding operations are necessary for optimal production control. This information should be updated event-driven as well (see 3, Figure 6).

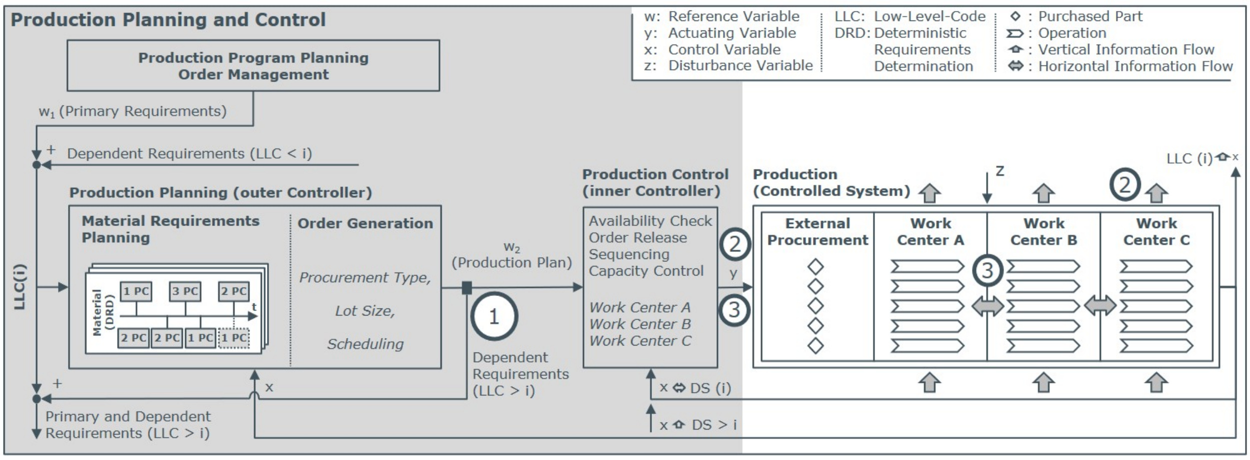

Figure 6: Low-Level-Code based Production Model

In practical application (see section 3), following measures were taken in accordance to named weak points:

- We aligned entire production system with its primary requirements. For this purpose, we adjusted scheduling of replenishment elements to their requirements in MRP. In addition, we saved links of MRP elements temporarily between two MRP calculations. Thus, we could use that information during availability check in production control. It provides a quantity-based allocation of replenishment elements to requirements. Furthermore, we transferred only dependent requirements with reference to primary requirements to subsequent LLC and production control. These measures reduced the deviations between w_1 and w_2 through all levels (see 1, Figure 6).

- In accordance with these changes, only production orders with reference to primary requirements are now available in production control. To maintain decentralized flexibility, we implemented PPC's vertical information flow by a fully integrated warehouse management system. In addition to the quantity-based availability, which is only actualized after a complete MRP calculation, this complemented information for production control by a location-based availability. Moreover, it enabled an event-driven update of location-based availability check. To ensure decentralized flexibility, we used this location-based availability as leading criterion for controlling worklists in production control (see 2, Figure 6).
- At last, we realized PPC's horizontal information flow by integrating confirmation capability of operations (event-driven) as a criterion for its appearance in the worklists (see 3, Figure 6).

In conjunction with these implementations we achieved significant improvements in logistics objectives work in progress and utilization with constant throughput time and schedule reliability. Thus, we reached an improved operating point and research goal of this publication.

6. Summary

In this publication we developed a new LLC based Production Model, which links theoretical findings of PPC with their technical implementation in ERP systems. With this model we can explain root causes of the deviations between the overall problem and its subproblems in MRP. Moreover, it differentiates between a horizontal and vertical information flow.

To resolve the conflict between centralized optimization (overall problem) and decentralized flexibility (subproblems), we propose to correct multilevel scheduling of production orders according to their primary requirement and to assume reference to a primary requirement as a prerequisite for processing production orders in production control. This supports centralized optimization (overall problem). To keep and improve decentralized flexibility (subproblem) we suggest assisting production control in its decisions by an event-driven horizontal and vertical information flow. Furthermore, we recommend this decentralized information flow as leading criteria for the composition of the worklists. For technical implementation we propose to enhance MRP as well as to use a fully in ERP system integrated warehouse management system and confirmation capability of operations. Through these improvements in PPC software, we were able to better synchronize worklists in practical application and better achieve logistics objectives.

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Biography

Felix Wimmert (*1992) attended a cooperative mechanical engineering education program at University Niederrhein, Krefeld, Germany. After he finished his Master of Science, he started to work for an international company in the ETO to ATO sector as SAP project manager. Nowadays he is responsible for SAP Manufacturing and Logistics at multiple production plants and researching on PPC in context of his PhD studies at University Duisburg-Essen.

Jan Hicking (*1991) studied mechanical engineering and business administration at RWTH Aachen University. After a stint as an energy consultant, he started to work as a digitalization project manager at the FIR at RWTH Aachen University and earned a doctorate in mechanical engineering. Nowadays he is the head of the information management department at FIR. His field of research is the digital transformation in the manufacturing industry.