# Conceptual Prototype of a Planning Software for the CONWIP Production Control System

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***Abstract*—In order to achieve the goals that are defined by the logistical positioning of manufacturing companies, the optimal design of the production planning and control (PPC) is required. Many approaches exist, each showing different properties in different environments. Decisions regarding PPC design can be classified as strategic, while parameterization issues are of tactical nature. The knowledge of different PPC systems and their parameterization is essential for reaching the entrepreneurial objectives. In this paper, an overview of some very common and significant production strategies and systems is presented. The focus here, however, is on systems, which are not requiring extensive computational power solutions, as these systems often just provide the computational result of complex calculations, but retracing of the results is almost impossible for the user. In particular the "constant work-in-process" (CONWIP) system is argued. The paper outlines various aspects of CONWIP as compared to other established production concepts, especially in regard to small and medium-sized manufacturing companies. To give an illustration about the practical suitability, a conceptual prototype of a CONWIP based planning software is presented, which is running test operations in a real production environment.**

***Index Terms*—constant work-in-process, lean management, make-to-order, supply chain management**

## I. Introduction

LOOKING at manufacturing companies of various sizes, globalization brought challenges, risks, and opportunities alike. This continuously evolving economic environment leads to shorter product life cycles, diversified and changing customer demands, higher awareness of quality and rapid advancement of manufacturing technology. In order to deal with these new conditions as well as with increasing global competition pressure, manufacturing companies around the world began to adopt various manufacturing techniques and technologies that would lead to an improvement of flexibility, product quality and production costs. This factual endeavor for improvement and progress has become a continuous and essential process. In particular effective production planning and control systems are required. Effective PPC systems satisfy required customer orders with a minimum of work in process. According to [8], such systems "produce the right parts, at the right time, at a competitive cost". This often requires actions to reduce, among others, inventory, lead time, waste, and machine failures.

Throughout the next chapters, this paper will introduce some popular manufacturing control strategies and systems, particularly discuss the application of CONWIP with regard to small and medium-sized companies and finally describe an early stage conceptual prototype of a CONWIP based planning software, which operates in a real production environment (trial run).

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## II. Production Strategies and Systems

Being an important part of supply chain management, there are generally two kinds of production strategies: "pull" and "push". The use of these terms in conjunction with production control systems is very popular although there are no generally accepted definitions for them [8].

Manufacturing systems that release work orders based on a master production schedule (MPS) are classified as push systems. In this case, production is not based on actual customer demand but on forecasts and/or historical demand instead. Subsequently, schedules are generated, which define the release of new production work. Once a new work order has been released it is being processed at each step of the production line until it is stored at the finished goods inventory. Out of there, those goods are offered to the customer. This means that products are fully produced in advance and sold as products that are not customer-specific, thus anonymous [4].

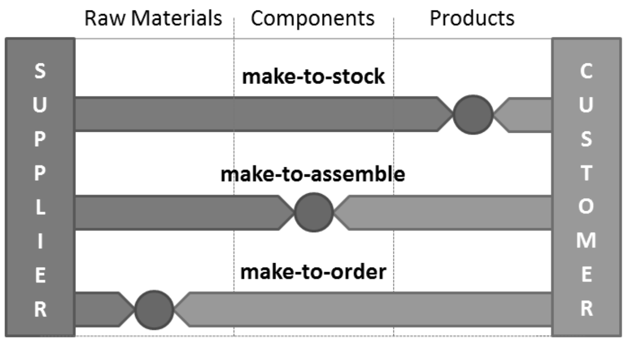


Fig. 1. This is a comparison of three different production approaches. It shows the relative position of the corresponding order penetration points (OPPs). The arrows coming from the left side represent forecast-demand. The arrows coming from the right mark actual customer-demand.

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During the manufacturing process of push systems, internal states like capacities or work-in-process (WIP) are not considered and do not affect the release of new work orders, so information only flows downstream through the manufacturing chain – from the raw material inventory to the finished goods inventory. Hence, push systems are inherently declared as "make-to-stock" (MTS) (see Fig. 1). Using this build-ahead manufacturing approach, accuracy and reliability of demand forecasts is essential as it will prevent both excessive inventory levels and opportunity loss due to stock-out. Nonetheless, push systems are often considered for high volume products where demand is easily predictable.

Pull systems, on the other hand, are production systems that authorize the release of new production orders based on actual demand. That need for components or products could either be real customer demand or internal demand from succeeding manufacturing stages. Production of goods only starts once a specific order has been received. For example, the use of parts by downstream work centers authorizes the start of the production of more components [8]. Dependence on actual demand inherently categorizes these systems as "make-to-order" (MTO) (see Fig. 1). In case product design and development is also influenced by the customer, such systems are classified as "engineer-to-order" (ETO) instead [4]. Authorization signals and information required in this approach flow upstream only, as each manufacturing step declares demand on certain goods from its precedent manufacturing stage. By producing the exact amounts of a certain product only at the time it is actually needed, inventory and WIP levels are kept low. Therefore, problems of excessive inventory, which is common with the traditional MTS strategy, are relieved so that the amount of products in stock is lower while having more product types available [4]. It is important that the time to produce a single part (lead time) is shorter than the expected delivery time for this production approach to work. If this is not the case, using the MTO approach may create additional waiting time for the consumer to receive the product. In order to avoid such a situation, the manufacturing company must either try to reduce lead time or adopt a different kind of production system (like hybrid production systems, which will be discussed in a later chapter of this paper). Nonetheless, pull systems generally allow for more flexible customization of an order. This type is most appropriate for highly customized or customer-specific products of low volumes.

Pull systems have several important advantages compared to other systems: Unit costs are kept low by high quality standards and maintaining low inventory levels, thus reducing required inventory space. As pull systems only produce parts that are really required, pressure for high internal quality is generated. This may also lead to higher external quality of the final product. Furthermore, the output stream of pull systems is more steady and predictable. By avoiding to release work jobs too early (that is, WIP is kept at about the same low level), production flexibility is improved and floating capacity is encouraged. Pull systems deliberately establish a limit on WIP, while push systems do not limit WIP within the manufacturing system.

Based upon these two principles, various electronic and non-electronic production control system implementations exist. Manufacturing companies should try to adopt the one system that fits their individual situations the most. In the following sections, some fundamental concepts of computer-assisted and manual production control systems are introduced to provide the reader with a general overview. As the focus of this paper is on "constant work-in-process" (CONWIP), said system is discussed in greater detail.

### *A. Material Requirements Planning*

The very popular "material requirements planning" (MRP) system is a production planning and inventory control system, which is basically a push system that could be used for all kinds of production tasks. It plans manufacturing activities, delivering schedules and purchasing activities. Furthermore, MRP ensures that materials are available for production, but also ensures that finished products are available for delivery to customers. Maintaining the lowest possible material and product levels in stock is an important objective of the MRP system. The major problem with MRP, however, is integrity of data: If there are errors in any of the relevant input data, then output generated by MRP will also be incorrect. Another problem is the fact that fixed lead times have to be specified, which will be assumed to be the same for each product, no matter how many items have to be produced or what other concurrent items are being made at that time [8]. This may usually lead to a rather pessimistic specification of lead times, eventually resulting in high WIP and inventory levels. Also, MRP does not take capacity into account, which could lead to implementation problems if there are internal or external capacity constraints. However, this is largely dealt with by another production control system: MRP II.

### *B. Manufacturing Resources Planning*

The successor of MRP is "manufacturing resources planning" (MRP II). It acts as an extension for MRP and largely deals with most of the previously described problems. MRP II is used for effective planning of all resources of a manufacturing company, including human resources. It addresses operational planning in units, financial planning and has a simulation capability to answer "what-if" questions. In contrast to its predecessor, it can use both finite and infinite capacity planning. Even fluctuations in forecast data are taken into account by including simulation of the MPS, thus creating a long-term control. The "enterprise resource planning" (ERP) system could eventually be seen as an evolution of MRP II.

### *C. Drum-Buffer-Rope*

"Drum-Buffer-Rope" (DBR) is a manufacturing execution methodology that is derived from the "theory of constraints" (TOC). DBR is classified as pull system and is based on the assumption that there is one or a limited number of scarce resources which control the overall output of the manufacturing plant [5].

Basically, it consists of three key elements: the drum, the buffer, and the rope.

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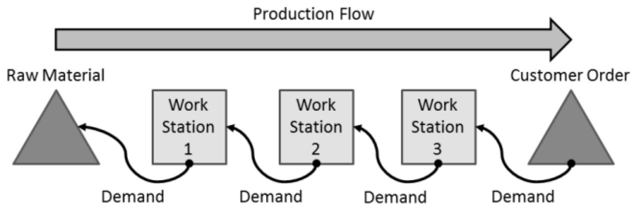


Fig. 2. In Kanban systems, demand is generated only between each workstation of the production line.

The drum is the physical constraint of the factory. It is the element that limits the ability of the entire system to produce more. The rest of the manufacturing plant follows the beat of the drum and makes sure that the drum always has enough work and that anything it has processed does not get wasted.

The buffer protects the drum by ensuring it always has work flowing to it. Buffers in DBR have time as their unit of measure, rather than quantity of material. This makes the priority system operate strictly based on the time an order is expected to be at the drum.

The rope is the work release mechanism for the manufacturing plant. It is dependent on the progress of the drum and releases orders once the drum has finished a certain amount of work.

### D. *Kanban*

The concept of "Kanban" is tightly related to lean manufacturing (LM) and just-in-time (JIT) production. Basically, the focus of LM is on preserving value with less work. The expenditure of resources for any goal other than the creation of value for the end customer is considered to be wasteful, and thus target for elimination. The reduction of lead time is an important part of LM. JIT is an essential pillar of LM and strives to improve the business' ROI by reducing WIP inventory and associated carrying costs (manufacturing only takes place when it is needed).

Generally, Kanban is a manual pull type production control and scheduling system. It utilizes authorization cards (kanbans) that help to create a demand-driven system by signaling depletion of components or products between two workstations of the production chain (see Fig. 2). When this signal is received, a process to replenish the goods at that workstation is triggered. Using a fixed amount of cards, WIP at each manufacturing stage is tightly controlled and limited to the total amount of cards in the card set used between two workstations [6]. Individual card sets are used at different workstations, thus creating individual demand at each precedent workstation.

### E. *Constant Work-In-Process*

The basic notion of "constant work-in-process" (CONWIP) is to ensure a constant level of WIP throughout

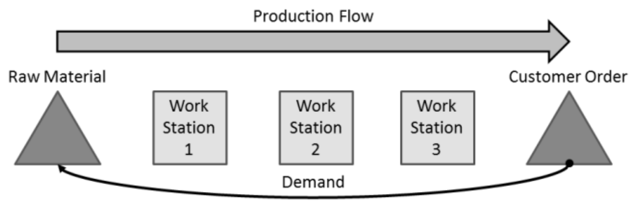


Fig. 3. In CONWIP systems, actual demand from the customer triggers the release of new work items to the production line.

the whole production. In [8], Spearman, Woodruff and Hopp presented CONWIP, which is still quite unknown in Europe, as an enhanced and generalized form of Kanban. Compared to Kanban, however, it is not a pure pull system, but incorporates aspects of both push and pull [4]. It extends the advantages of Kanban's demand-driven production with the push approach of MRP. While Kanban uses individual card sets between each pair of workstations, only a single global set of cards is used for the whole production process in CONWIP (see Fig. 3) [5]. CONWIP generally is a list-based pull system where demand triggers the release of new work orders. Each of these orders is then assigned a global authorization card that remains associated to this specific work order until production is complete. Once released, the work item is pushed through the manufacturing system until the final product leaves production. At that point, the card associated with this work item is released, which allows a new one to enter the production system. Using this approach, WIP is not only controlled for each production step but for the whole production system. WIP remains constant (thus the name of CONWIP) as the total amount of cards within the manufacturing system is also maintained. If a bottleneck occurs, CONWIP allows for reduction of the total number of cards. On the contrary, it also allows increasing the number of cards in order to raise WIP and to ensure a higher throughput [6].

The implementation of CONWIP in production systems brings several advantages, which may be especially important for small- and medium-sized businesses: Flow times of CONWIP systems are easily predictable due to constant WIP levels [8]. Hence, the delivery reliability is also increased [1]. CONWIP allows MTO production even when many variants and materials are used. Furthermore, it also supports prioritization. Especially for smaller companies it could sometimes be required to use priorities for work orders based on customer importance, for example. When compared to Kanban, CONWIP production systems are easier to manage because there is only one set of cards that has to be adjusted [6].

According to [2], however, it is hard to compare the actual performance of CONWIP with that of other systems like Kanban or MRP. It was found that different studies came to varying conclusions in regard to performance of these systems, as seen in [1], [2], [3], and [5]. Therefore, it is not feasible to provide a general recommendation on which manufacturing system to use. An individual evaluation based on the operational area should be done instead.

## III. Hybrid Production Strategies

For many manufacturing companies it is not appropriate to adopt either the MTS or the MTO production approach. But push and pull systems are not mutually exclusive [8], so it is possible to combine both systems into a hybrid production line. Such hybrid systems are often also referred to as "make-to-assemble" (MTA) (see figure 1) and/or "assemble-to-order" (ATO). MTA/ATO is a manufacturing strategy where basic components of a product are produced and stocked based on forecast demand.

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Up to this point, all parts are produced anonymously, that is, without a specific customer order [4]. However, as soon as a customer order is placed, these stocked components are then used to assemble the final product. When looking at this process, the inventory of components clearly marks the point that splits the manufacturing chain into MTS and MTO production. This point of transition from MTS to MTO is called the "order penetration point" (OPP) [7] or "customer order decoupling point" (CODP) [4]. The position of this spot varies between manufacturing companies, dependent on the kind of approach they have decided to adopt. It is important to wisely choose its location in order to gain benefits from both push and pull strategy. Moving the OPP closer to the customer, for example, improves responsiveness, while moving it farther away from the customer improves flexibility. Having the right balance, a hybrid approach allows for higher order customization and flexibility as well as smaller lead times when compared to traditional MTS or MTO production [7].

## IV. Implementation of CONWIP: A Case Study

Now that different production systems and their individual characteristics have been discussed, this section is about to present a case study, in which CONWIP has been implemented for evaluation in a separated area of a company's manufacturing plant. The case study has been conducted in a medium-sized manufacturing company operating in the sanitary branch of plastics industry. The motivation to implement CONWIP is derived from the fact that said company did not incorporate an efficient production planning and control system. Up to that point, manufacturing planning had been done solely by manual methods. This approach may work under certain circumstances, but in order to keep up with competition and increasing demand it becomes necessary to incorporate an approved and effective production planning and control system. At first, the requirements for such a system had to be specified. The target was to apply a production system that is transparent, easy to manage, and highly efficient for the type of production performed at that company. Classical ERP solutions, for example, provide an extensive range of functionality, but are therefore also mostly afflicted with high complexity. However, high complexity for production planning was definitely not a desirable objective, so other production strategies have been assessed as well. In the end, the decision to implement a hybrid production strategy has been made because of the inherent advantages of such a manufacturing system.

Fig. 4 illustrates the schematic composition of the new production process. As depicted, the process is a typical MTA approach that is divided into two manufacturing areas:

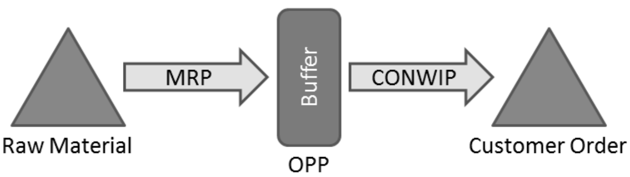


Fig. 4. This shows the current schematic composition of the production flow within the company in which the case study has been performed.

The first manufacturing stage acts as a classical MTS production that is handled by MRP, while the second step is a MTO system, which uses CONWIP for production planning and control. Within the first step, raw material is being processed by plastic molding presses, which produce generalized components based on forecast-demand. These components are then stocked on a buffer – an intermediate component storage that also acts as the system's OPP. From this point onwards, CONWIP is used for production planning. During the second manufacturing stage, components from the buffer are then used to assemble the final and ordered products. Unlike in the first phase, the further workflow is triggered by actual demand and customer orders. Additionally, finished products are also packed for delivery during this last manufacturing phase.

However, problems arise from the fact that – especially in Europe – CONWIP is quite unknown and unusual to work with. In addition, many ERP systems are still not capable of executing CONWIP production method. The ERP system that is required and has been agreed upon for customer order management is capable of handling MRP production, so the first manufacturing step is covered. Unfortunately, it lacks management functionality for CONWIP production method. Therefore and due to the fact that there is no accepted and easy to use CONWIP production planning tool, it became necessary to develop a customized solution.

## V. Conceptual Prototype of a Planning Software

In general, CONWIP is suitable for a wide variety of production environments but it has many advantages that could be particularly important for small and medium-sized companies. Such firms usually have limited manufacturing capacities and capabilities. Therefore, implementation of sophisticated production planning systems is not always appropriate. Sometimes a company lacks the required resources to implement, handle or maintain such complex systems. In the previously introduced case study it was the intention to use a production system that is simple, without much overhead and easy to work with even for unskilled staff. In this respect, CONWIP is such a simple approach as it could be implemented effortless as a basic list of production orders. The following chapter discusses the characteristics and implementation of the conceptual prototype of a planning tool for CONWIP. Generally, it does not matter how such a list is realized. For example, it could either be done by standard (spreadsheet) software or by a custom software tool. In the context of this paper, however, implementation is done in the form of the latter.

### A. *Production Planning based on a List*

Basically, the simplest way to perform production planning in CONWIP systems is by means of a production order list [1]. Using such a list it is possible to plan and trigger the release of work items to the production line. The list is filled with production orders by a MPS system that works independently from the production control system. Work items in this list are then sequentially processed by the manufacturing system. The arrangement and the release of

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| Index | Amount | Status | Target Date | Priority | Order Details |
|---|---|---|---|---|---|
| 1 | 2070 | completed | 11.10.2011 | | ... |
| 2 | 940 | completed | 13.10.2011 | | ... |
| 3 | 5400 | in production | 15.10.2011 | | ... |
| 4 | 1750 | in production | 16.10.2011 | | ... |
| 5 | 3200 | in production | 17.10.2011 | | ... |
| 6 | 7000 | in production | 20.10.2011 | | ... |
| 7 | 2550 | in production | 22.10.2011 | | ... |
| 8 | 4750 | scheduled | 23.10.2011 | | ... |
| 9 | 6500 | scheduled | 25.10.2011 | | ... |
| 10 | 1500 | scheduled | 30.10.2011 | | ... |
| 11 | 8775 | scheduled | 02.11.2011 | | ... |
| 12 | 3550 | scheduled | 03.11.2011 | | ... |
| 13 | 6400 | scheduled | 04.11.2011 | | ... |
| 14 | 2100 | scheduled | 06.11.2011 | | ... |
| 15 | 4120 | pending | 07.11.2011 | | ... |
| 16 | 9300 | pending | 09.11.2011 | | ... |
| 17 | 3600 | pending | 10.11.2011 | | ... |

WIP cap; capacity trigger; anticipation horizon; processing rule; dispatching rule

Fig. 5. This is a basic example of a conceptual CONWIP production planning list. Each row represents a different work item. The vertical bars mark the scope of relevant list parameters.

production orders (in the form of work items) to the production line are influenced by various parameters [1]: work-in-process (WIP) cap, anticipation horizon, dispatching and processing rule, and capacity trigger. In the following section, each of these parameters is described in further detail:

*Anticipation Horizon*

The anticipation horizon is the timeframe in which work items are scheduled and released for production (see Fig. 5, indices 2 to 14). This only occurs if their target dates lie within the timeframe of the anticipation horizon. The purpose of this is to avoid that too much work is released for production in low-selling periods. Thus, the system is allowed to automatically reduce WIP and output quantity to the level of actual demand. It is not unusual to move known production orders forward or to switch over to anonymous (that is, MTS) production in order to bridge the time of a low-selling period. However, this is not a desirable behavior in CONWIP as it is always possible that customers request to change or even cancel certain orders at short notice.

When adjusted, the effect of automatic WIP reduction could decrease if the anticipation horizon is set too high. In contrast, it could result in poor delivery reliability if its value is set too low. The scheduling date of each work item is calculated by the term: “target date” minus “anticipation horizon”. Items that have reached this date of scheduling are usually expected to have all necessary raw materials in store. This is not required for items that are not yet scheduled, though.

*Capacity Trigger*

The capacity trigger describes the maximum amount of work the production line can handle within a certain timeframe without the allocation of additional working resources (for example: overtime or extra shifts). Consequently, this parameter helps to detect capacity bottlenecks early. If such a bottleneck occurs, it is required to provide supplementary production capacities in order to maintain high delivery reliability. The capacity trigger supervises the whole amount of pending work within the anticipation horizon, that is, a combination of the current WIP level and the amount of scheduled work (see Fig. 5, indices 3 to 14). An incorrect setting of this parameter might either cause premature allocation of resources if it is set too low, or a delayed reaction, if any, to bottleneck situations if set too high. The capacity trigger is not only capable of detecting over-utilization but is also capable of recognizing under-utilization if the sum of work lies far below its value. According to [1], an approximate calculation of the capacity trigger could be performed by the following term: “average throughput” multiplied by “anticipation horizon”.

*Dispatching and Processing Rule*

The dispatching rule determines the sequential arrangement in which scheduled work items are released for production (see Fig. 5, indices 8 to 14). By default, the rule is based on the date of delivery [8]. In this case, the scheduled work item having the earliest delivery date would be released next. In Fig. 5, for example, this would be the item at index 8. However, depending on the type of manufacturing system it may be appropriate to use a different dispatching rule.

On the other hand, the processing rule determines the order in which a certain manufacturing step processes work items that have already been released and are therefore currently in production (see Fig. 5, indices 3 to 7). Usually, this is the item, which already spent most of the time in production. Similarly to the dispatching rule, the processing rule may also require adaption on a per-system basis.

Although these rules determine the arrangement of work items within the list, it is always possible to overrule the suggested order and individually prioritize certain work items – even if this would mean that items with later target dates would be completed earlier than others. This could become necessary if some customers are more important than others. Certainly, doing so might influence other work items. The impact on other production orders, though, depends on the actual workload and the target date of the prioritized work item.

*Work-In-Process Cap*

The work-in-process (WIP) cap describes the maximum amount of work that the production system is allowed to concurrently work on (see Fig. 5, indices 3 to 7). In this context it does not matter in which unit the actual work is measured – it could be described either in hours or in pieces, for example, depending on which unit of measurement is more appropriate of the respective production type. The WIP cap limits the release of new work items for production. New items are only allowed to be released if they do not exceed the currently set WIP cap.

The value for this parameter is usually determined by the bottleneck of the production line. It should be set to a value that ensures that the bottleneck never runs out of material – even in disadvantageous and unexpected situations. A reduction of the WIP cap would consequently also reduce both WIP and lead time of production. If set too low, this could cause negative effect on output quantity and delivery reliability.

Reference [1] suggests that values for the WIP cap as well as the anticipation horizon should be set carefully in newly deployed CONWIP production systems. During that phase both parameters are recommended to be deliberately adapted in line with general manufacturing improvements. Due to the fact that CONWIP reorganizes many parts of the production process, it is furthermore not advised to rely on historical data from previous WIP recordings.

*List Layout and Item States*

Fig. 5 depicts a simplified CONWIP production control list and all its parameters, which have previously been discussed. Each production order that is added to this list is required to contain information about the amount of work it takes to complete as well as a target date. Based upon these two values the CONWIP list can be generated. The list is divided into four sections, each containing production orders of a different status.

The topmost section (see indices 1 and 2 in Fig. 5) contains production orders whose status is “completed”. This means that each of these work items has already successfully run through production and the finished products are now available on stock in the specified quantity. These completed work items are no longer considered for production planning.

The second section (see indices 3 to 7 in Fig. 5) contains work items that are currently being processed in the production line, thus having the status “in production”. The total amount of work within this section (that is, work-in-process) must not exceed the specified WIP cap. As already mentioned, the order in which these work items are processed is determined by the processing rule.

All other work items within the anticipation horizon, which would be ready for production but cannot be started yet because of the WIP cap, are placed in the third section of the list (see indices 8 to 14 in Fig. 5). Their status is marked as “scheduled” because work items are allowed to enter production as soon as a currently processed item is finished and the difference between actual WIP and WIP cap is enough for the work item to fit in. The arrangement of production orders in this section is determined by the dispatching rule. Production orders that are not yet captured by the anticipation horizon are marked with the status “pending” as they are still waiting for the date of scheduling. Pending work items form the last section (see indices 15 to 17 in Fig. 5) of the CONWIP production planning list.

### *B. Functional Range and User Interaction*

The previous section discussed the fundamental operating mode of the CONWIP production planning list, which remains the same no matter which kind of implementation is chosen. For example, a CONWIP production planning list could be implemented either using standard software, such as Microsoft Excel, or using any other custom software development framework. Based on the work in this paper, it is assumed that the tool will be a Windows Presentation Foundation (WPF) application developed using Microsoft .NET Framework. Then, this custom application would have to be deployed to computers where staff is able to manage and organize production.

At first, the list must be filled with production orders. This is automatically being accomplished by synchronization of the company’s ERP system with the application’s database. As soon as a customer places an order, it is recorded and saved by the ERP system. At the same time, an equivalent entry, which represents the customer’s order in the ERP, must be written to the application’s central database. In turn, updates performed by the CONWIP planning tool on any of the entry’s properties (for example: status or target date) must also be sent back to the ERP system via a callback channel. This way, the production planning list is filled and synchronized with the ERP system. If required, the user now has the option to individually adjust each previously discussed list parameter value and define dispatching and processing rules. During production, staff must always have the possibility to overrule the arrangement of work items determined by the applied rules. To do so, the user could either drag an item at the desired position or manually enter a priority value and let the application recalculate new item arrangements. However, as soon as a rule is assigned again, the manual priority changes would be lost.

## VI. CONCLUSION

The task of production planning and control (PPC) can be managed by different logistic planning methods depending on manufacturing environment and manufacturing structure. This paper evaluated different PPC systems with the focus on CONWIP, which shows very good delivery reliability at low work in process. Additionally the practical suitability of CONWIP was outlined in form of a conceptual prototype of a CONWIP based planning software, which is running test operations in a real production environment.

Further research should be conducted in improving the CONWIP software prototype regarding parameter control, use case robustness and dynamic environment adaption.

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