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Implementation of a Software Prototype with ConWIP Characteristics for Production Planning and Stock Management

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Abstract

Production planning is an elementary aspect of supply chain management and requires appropriate and effective tools. The purpose of this paper is to present the concept, design, and implementation of a software prototype for production planning that incorporates aspects of the Constant Work-In-Process (ConWIP) manufacturing system. In introductory sections, essential knowledge about fundamental strategies of production planning and the concept of ConWIP are subsumed. After a brief illustration of the manufacturing process in the company for which this work has been conducted, various aspects of the actual software implementation are presented. The paper concludes with a discussion about potentials and limitations of the solution.

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1. Introduction

In order to master an increasingly competitive business environment, the optimization of intra-company logistics and the application of efficient systems for production planning and control (PPC) are nowadays essential for manufacturing enterprises. These enterprises have to analyze the current state of production, examine the prerequisites for improvement, and create resulting concepts to optimize the intra-company logistics and production planning especially in regard to aspects that increase efficiency. Even though many concepts for logistics and

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production planning already exist, the main challenge lies in choosing appropriate processes and procedures, as well as in developing, implementing and optimizing an ideal combination for the respective production environment.

Benefits for business clients are rooted in high quality products combined with competitive prices. But globalization has led to a dramatic intensification of competitiveness in manufacturing industries and only those who react accordingly will be able to retain this combination of quality and price to succeed in the future. The need for adequate concepts for agile and lean logistics and production processes becomes apparent. Thereby, the focus lies on the increase of efficiency, flexibility, quality, and cost effectiveness so that the company remains on par with the global competition and may eventually adapt faster to changing customer demands. Besides, customers have an advantage when their partners are reliable and flexible. A customer-oriented approach of a company is often tantamount to its profitability, so the challenge is to optimize current resource capacities in terms of cost, time, and quality. The ability of companies to remain successful and competitive under current conditions, which are also influenced by the economic crisis, consequently requires simultaneous improvement of three basic factors: increase of flexibility, improvement of quality, and reduction of costs. Optimization of manufacturing processes is currently one of the most common and extensive tasks. Complexity and challenges of the market environment forces companies to pay particular attention to the improvement of operating conditions that also support its competitiveness, implementation of economic objectives, and increase of efficiency.

In this context, the following paper is going to present the concept and implementation of a software application prototype used for production planning and stock management. Development and evaluation of the prototype are done as part of a case-study that aims to modernize and optimize production processes of a medium-sized manufacturing company operating in the sanitary branch of plastics industry. The work of this paper builds upon the scientific findings presented in previous publications, such as Gastermann et al. [2], and Stopper et al. [8].

2. Review of production planning and control systems

In order to discuss production planning software, a basic knowledge of the theoretical background of PPC systems is required. Therefore, this paper will at first provide a short introduction to the most relevant topics required for the understanding of the later sections, though it is not the scope of this paper to discuss them in detail. Various other publications like Gastermann et al. [2], or Stopper et al. [8] already covered these topics to a greater extent, so please refer to one of these papers for a more in-depth view on that matter.

This introductory section will first take a short look at the fundamental strategies of push- and pull-based manufacturing, and describes an enhanced concept that combines both approaches into a single but hybrid system. Additionally, a brief review of the Constant Work-In-Process (ConWIP) production system is provided.

2.1. Basic strategies of production planning and control systems

In respect of their basic modes of operation, two general types of production strategies exist in supply chain management: The first being a push-based approach, and the second being a pull-based approach. Both of these strategies constitute the basis for most of the manufacturing systems like Material Requirements Planning (MRP), Drum-Buffer-Rope (DBR), Kanban, or ConWIP.

Push-based systems are built upon a master production schedule that determines the release of work packages into production. Such schedules are mostly based upon either calculated forecast or empiric historic demand, but are unable to incorporate actual demand. They cause new work packages to be released at a certain rate and pushed through production until work on a package is finished and resulting end products are put on stock. This workflow occurs regardless of actual customer demand of these products, thus its name of a push-based approach.

On the contrary, pull-based manufacturing systems depend on real demand in order to release work packages to production. In this case, the source of demand is irrelevant, so it could either be an actual customer order or internal demand generated by subsequent manufacturing steps. In other words, as soon as any kind of demand is present and the current system state allows it, the release of new work packages to the previous stage of the production chain is authorized or triggered in order to satisfy these requirements. When looking at the whole production chain, this process appears as if demand were pulling new work packages along the production line from start to finish up to the point where the demand is met by the work packages' output.

Apart from the distinction between push and pull, production systems could also be classified as “make-to-stock” (MTS) or “make-to-order” (MTO), with the first often being a synonymous description for push-based systems that produce just for stock, and the latter often referring to pull-based production that targets specific orders.

While both of these approaches are general concepts, there are situations in which none would be sufficient on its own. The concepts of push and pull are not mutually exclusive [7], so it is possible to combine both of them into a hybrid manufacturing system. Such a system is often referred to as “make-to-assemble” (MTA). The name derives from subdividing the system into a first stage incorporating MTS and a second stage consisting of MTO production. The two stages are separated by a component inventory, which also represents a point that is called the Order Penetration Point (OOP) [6] or Customer Order Decoupling Point (CODP) [3]. The first MTS manufacturing stage is responsible for the production of basic components from raw materials, which are then stocked in the component inventory. This happens regardless of demand or customer orders. The MTO production stage, however, reacts to external needs and triggers the production of the final products from the previously stocked components based on incoming demand or customer orders. The advantages of this approach are increased responsiveness and improved flexibility due to the construction of end products (or variants) at the latest point, thereby reducing lead time.

As already mentioned before, various manufacturing systems exist that are built upon these basic principles. Each of them incorporates different properties and targets varying areas or purposes. For the context of this paper, however, only two such systems are relevant: Re-Order Point Planning (ROP) and ConWIP. Both of them are used in the manufacturing process presented later in section 3 of this paper, although the focus of this work remains on ConWIP. Following a short introduction to ROP, the ConWIP system is discussed in the next section.

ROP is an inventory control method that aims to minimize total inventory holding costs and ordering costs. It is also often used for inventory automation. The re-order point itself is defined by a certain inventory threshold that, when reached, triggers the replenishment of inventory from internal or external sources. It is the challenge of this method to set this point to an appropriate level so that both brimming and empty stocks are avoided.

2.2. Constant Work-In-Process (ConWIP)

Spearman et al. [7] presented Constant Work-In-Process (ConWIP) first in 1990 as an enhanced and generalized form of Kanban. The intention of ConWIP is to ensure a constant level of work-in-process for the whole manufacturing system. In spite of its similarities to Kanban, ConWIP is not a pure pull-based system but incorporates aspects of both push and pull approaches [3]. It extends the advantages of Kanban in regard to demand-driven production with the push-based approach of MRP. While Kanban uses individual card sets for each manufacturing workstation pair, ConWIP only employs a single global card set that is used for the whole production process. This approach results in an almost constant level of work-in-process that has the advantage of easily predictable flow times [7] and improved delivery reliability [1]. Furthermore, ConWIP production systems are generally easier to manage due to the fact that only a single set of cards has to be adjusted for the whole manufacturing process.

In its most basic form, ConWIP corresponds to a pull-based system in which demand at the end of the production chain triggers the release of new work at the beginning. Each work package that is released is required to have approximately the same size (in terms of time or work required to process a package). As soon as a work package enters production, it is assigned an authorization card from the global card set. Card and work package remain associated until the manufacturing process is completed, at which point the card is released and put back into the card stack. All released work packages that entered production are pushed through the manufacturing chain until they are fully processed and their outcome leaves production. In case all available cards are assigned, no additional work is allowed to enter production. This mechanism ensures a constant level of work-in-process not only for a single production step but for the whole production chain because the amount of available cards is typically limited. In case of a bottleneck, ConWIP allows to reduce the total number of cards. On the other hand, it is also possible to raise the level of work-in-process and ensure higher throughput by increasing the number of cards.

However, the concept of ConWIP rarely made it beyond its theoretical approach. PPC systems that actually implement ConWIP are scarce, which is the reason why it still remains relatively unknown around the world but especially within Europe, despite having shown improvements to inventory levels, lead times, and output rates in

various studies, such as [1], [5], and [4]. Nonetheless, a final conclusion about the actual performance of ConWIP in comparison to other manufacturing systems remains the subject of ongoing research.

3. Manufacturing layout and process description

This section provides a basic overview of the production and outlines material flows within the production facility of the company for which this work has been conducted. This needs to be considered in order to understand the entry points for the suggested software solution and their procedures. Figure 1 illustrates the layout of the production and highlights relevant material flows:

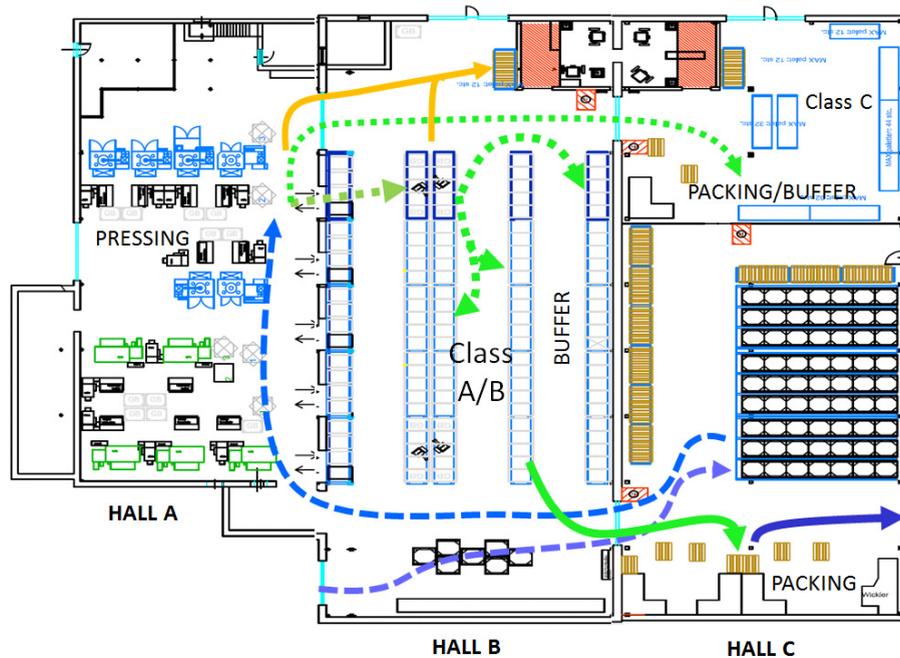


Fig. 1. Overview of the company's production layout with regard to the flow of material.

The production process comprises two stages: the pressing stage and the assembling stage. The pressing stage produces numerous semi-finished products (components), depending on the different colors of the duroplast raw material and the type of pressing tool. These components may also include customer-specific logos. In the second production stage, the components are packed into a box together with hinges and other parts, according to customer requirements. Figure 1 illustrates plastic molding presses in hall A and assembling/packing stations in hall C.

The material flow in the manufacturing process starts with the supply of raw material. Following the dotted purple line at the bottom of the figure above, raw material enters the production in so-called octabins in hall B and is then stored in hall C. Each octabin is then marked with an identification code and subsequently scanned by a portable device connecting each octabin to the respective purchase order for traceability reasons. Additionally, a code indicating its position within the storage is also recorded. The release of raw material to production is triggered by a production order causing a single octabin to be transported to the respective plastic molding press. Produced components are put into lattice box pallets and then placed on interim storage racks on the left side wall of hall B. The next step in the manufacturing process is the grinding station. Grinding still belongs to the production stage and is essential to product quality. Both pressing and grinding can result in fully or partially defective components. In case the defects can be repaired at the grinding station, these parts are brought to the polishing station along the orange line, according to figure 1. Otherwise, they are directly moved to trash.

Based on a preceding ABC analysis, component variants are grouped into three categories. Category A is used to classify highly important variants of high volume. Additionally, these variants do not require a change of the pressing tool and can therefore be produced continuously without any interruption. This category represents approximately 20% of the total production volume whereas category B represents about 60% of the total volume. Category C combines all other variants of low volume and minor importance. Typically, category C comprises more than 50 different variants whereas category A and B only have 18 different component variants altogether. After the grinding station the material flow is divided into two different lines. Only flawless parts of categories A and B are put into the buffer storage for semi-finished products at hall B. Following the light green dotted line in figure 1, all other components are moved to the category C storage. Each of these two material flows leads towards separate stations where end products are assembled from semi-finished products, packaged, stocked, and eventually delivered to their respective customers.

Generally, customers demand delivery times far shorter than the production lead time. The company is neither able to fulfill customer orders directly from the pressing stage, nor is it able to stock all kinds of finished products. Customers, however, accept longer lead times for products of category C, so that variants of this group are directly associated with customer orders. The MRP approach, which is available within the company's Enterprise Resource Planning (ERP) system, represents the appropriate scheduling method for these orders.

Provided that the right variants are available in the buffer storage, the company is able to assemble end products from category A or B components within the desired customer delivery time. Within this hybrid production situation, the buffer storage represents the CODP because variants are associated with specific customer orders from this point onwards. For the first manufacturing stage upstream of the CODP, the ROP planning method enables the management of production orders for the molding presses. However, in order to ensure on-time delivery of customer orders, assembly/packaging stations downstream of the CODP need to be fast and flexible. The ConWIP planning method supports this customer-oriented pull-based approach for packaging orders. As this approach had not been part of the company's ERP system, the software solution described in the next section of this paper was developed.

4. Prototyping a software solution

Previously, this paper dealt with the more theoretic background of PPC systems and outlined the company's manufacturing process. Based upon this introduction, the following section is going to focus on technical aspects as it describes the design and actual implementation of the manufacturing planning software prototype.

The reason for the development of a proprietary software solution for production planning was the need for a highly efficient, yet transparent and easy to manage system. Due to its promising performance and other inherent advantages like its stability, the decision to use ConWIP for the last stage of the company's hybrid production approach was made. A classical ERP system by Infor had already been adopted, but it neither satisfied the company's ambitious goals for the planning of packaging orders out of the box nor did it incorporate any ConWIP mechanics. As a result, a custom and proprietary solution for this production stage had to be found.

The primary requirements for such a tool were integration into the existing Infor ERP system, ease of use, and most importantly effective planning capabilities. In order to achieve these goals, initial work centered on a ConWIP planning concept first introduced by Altendorfer and Jodlbauer [1], which is going to be summarized shortly in the next section of this paper for the sake of a better understanding. Of course, the ability to plan is but one fragment of the solution. Staff must be able to quickly evaluate the current production situation and act accordingly. Thus, it is necessary to provide trend data about each stage of the manufacturing system: production of components, inventory levels, and packaging of products. To meet these requirements, full integration with the data pool of the central ERP system is required. But full integration was impeded by the absence and the high acquisition costs of a public interface to the system. Therefore, it was decided that a partial integration with the system would be enough for a first prototype. Necessary data is therefore directly pulled from the ERP system's underlying Microsoft SQL Server database in a one-way or rather read-only manner. This approach is limited, however, as all actions and changes conducted in the course of production planning have to be repeated manually at the ERP system's user interface. Automating this step, unfortunately, is not feasible without an accessible Application Programming Interface (API) or precise knowledge about the system's internals. Refer to section 4.2.3 for more details on this process.

Transparency and usability are important aspects of the software solution that have to be taken into consideration during the whole application design process. The primary user target group for this software are employees responsible for production and, consequently, production planning. For instance, the production manager requires a quick and focused overview of all the production stages. He must be able to comprehend involved processes and interdependencies. Production is first and foremost based upon his evaluation of the current situation, which is why transparency of the background software processes and ease of use are especially important. Besides, sales staff could represent an additional target group. Being in charge of taking orders from customers, sales personnel are also responsible to negotiate delivery dates and communicate possible deviations. Due to the fact that customer orders and packaging orders are tightly coupled, they could use this software to check the automatic creation of packaging orders from new customer orders (see section 4.2.1) and validate changes of delivery dates.

4.1. Concept of ConWIP-based production planning

Before it was possible to deal with the actual implementation of a prototype, an initial and appropriate concept had to be found. This section provides an overview of the general concept that formed the basis of the implemented prototype. However, Altendorfer and Jodlbauer [1], or Gastermann et al. [2] already provided a comprehensive view on that concept, so please refer to one of them for more details as it would exceed the scope of this paper.

Considering the operating mode of ConWIP, this is a rather simple approach without much overhead and easy enough to work with even for unskilled staff. The simplest way to perform ConWIP-based production planning is by means of a production order list. As depicted in figure 2, such a list consists of various work orders and is used to plan and trigger the sequential release of these orders to the production line. Based on their status and other characteristics, listed orders are grouped into four areas. List properties like the sequence of work orders are controlled by various parameters. The scope of each parameter is highlighted in figure 2 by vertical bars.

Index	Quantity	Status	Target Date	Other Data
1	1470	completed	30.08.2013	...
2	4657	in production	02.09.2013	...
3	2719	in production	04.09.2013	...
4	0921	in production	04.09.2013	...
5	3575	scheduled	12.09.2013	...
6	1772	scheduled	17.09.2013	...
7	2530	pending	03.10.2013	...

Fig. 2. Schematic illustration of a ConWIP-based production order list including scopes of relevant parameters.

The timeframe in which work orders are scheduled and released to production is defined by the work-ahead-window (WAW) (see vertical bar #3 in figure 2), which avoids that too much work is released during low-selling periods. After all, it is not desired that later orders are processed earlier just to bridge such a period. The capacity trigger (see bar #2) determines the maximum amount of work the production line can handle within a certain timeframe without the allocation of additional working resources. The dispatching rule (#5) describes the sequential arrangement of scheduled work orders and the sequence in which they are released. This is typically determined by the finishing or delivery date, although other methods are also possible. Similarly, the processing rule (#4) determines the order in which released orders are processed within the production line. Finally, there is also a work-in-process cap (#1) that defines the maximum amount of work the system is allowed to work on simultaneously.

The core functionality of the implemented prototype was built upon this production planning concept. Refer to section 4.2.3 later in this paper for a discussion about a practical application and implementation of this concept.

4.2. Actual prototype implementation

Considering the underlying technological aspects, the production planning software prototype was developed using the Microsoft .NET Framework because of previous experience of the company with this specific software development kit. The software was implemented as a Windows Presentation Foundation application for the Windows desktop. For better maintainability, the Click-Once mechanism was selected as the preferred way of deployment as it features automatic installation of dependent frameworks and libraries, and offers automatic and consistent application update routines.

Connectivity with the ERP system was achieved by plain SQL query commands. With each manually or periodically triggered update, queries are sent from the application directly to the Microsoft SQL Server database that backs the ERP system. Incoming results are then merged and transformed into proper data types for further processing. Eventually, everything is cached in a private local Microsoft SQL Server Compact Edition database solely used by this application. Caching is an important step as staff must be able to continue working for at least a short period even if the local network is unreachable or the ERP system is offline. In this case, data may not be up-to-date, but production planning would still be possible to a certain extent.

The final design of the software prototype consists of three main views, which will be explained in the following sections. Apart from switching between these three screens, the user always has the possibility to manually trigger an update of all displayed data, and open a configuration dialog that offers settings for various parameters.

4.2.1. Customer and packaging order correlation view

The first of the three main screens displays the correlation view for customer orders and packaging orders. Though being of minor relevance for actual production planning, it is still very important in regard to process transparency and flawless operation. This screen enables the user to list all customer orders that are registered at the company’s ERP system and whose state is currently active or unfinished. Of course, already processed and finished customer orders must not be listed here as this would only clutter the view unnecessarily. Being part of the process, the ERP system is responsible for the automatic creation of new packaging orders based on each incoming customer order. Consequently, a strong correlation between these two kinds of orders exists. The illustration of this correlation is the purpose of this application screen, which is shown below in figure 3.

Customer Orders							Packaging Orders					
Order No.	Order Pos.	Delivery Date	Customer	Product No.	Product Description	Quantity	Order No.	Delivery Date	Product No.	Product Description	Quantity	Status
8010005	1	28.11.2012		S012V010	UNISSET biela AB	150	8010005-001	28.11.2012	S012V010	UNISSET biela AB	150	Completed
8010006	1	06.12.2012		S153V535	DESKA DELFI ANTYBAKTER...	25	8010006-001	18.02.2013	S013V010	UNISSET biela AB metal	20	Completed
8010006	2	06.12.2012		S153V535	DESKA DELFI ANTYBAKTER...	180	8010006-002	18.02.2013	S153V535	DESKA DELFI ANTYBAKTER...	25	Completed
8010006	3	06.12.2012		S153V535	DESKA DELFI ANTYBAKTER...	300	8010006-003	04.03.2013	S153V535	DESKA DELFI ANTYBAKTER...	180	Completed
8010016	7	20.03.2013		S012V015	PRISMA Hanibal biela AB	550	8010016-007	13.03.2013	S012V015	PRISMA Hanibal biela AB	550	Released
8010015	1	27.03.2013		S062V017	DESKA EKO PLUS WOLNO...	2						
8010015	2	27.03.2013		S063V015	DESKA EKO PLUS ANTYBA...	2	8010015-002	20.03.2013	S013V010	UNISSET biela AB metal	2	Completed
8010015	3	27.03.2013		S063V016	DESKA EKO PLUS ANTYBA...	2						
8010015	4	27.03.2013		S065V530	DESKA EKO PLUS AB WOL...	2						
8010015	5	27.03.2013		S013V010	UNISSET biela AB metal	2						
8010022	2	10.04.2013		S012V010	UNISSET biela AB	120	8010022-002	27.03.2013	S012V010	UNISSET biela AB	120	Scheduled

Fig. 3. Part of the application screen used to correlate customer orders with packaging orders.

Basically, the screen displays a list divided into two superordinate columns: the left column contains all registered and unfinished customer orders; the right column displays associated packaging orders, if available. Each of the columns displays essential data relevant for the respective type of order. Some of these data are order numbers, delivery dates, customer names, product numbers, and target quantities. However, because of privacy protection reasons, customer names (the fourth column in figure 3) have been obfuscated. Due to the fact that packaging orders are always derived from customer orders, values of shared properties should always be the same too. For example, product numbers, quantities, and delivery dates should be the same for both order types, though delivery dates could be changed in the planning view introduced later in section 4.2.3 of this paper. The application compares packaging order property values with their respective customer order source values and highlights the row in red if any of them differs in a way that indicates system errors or manual planning mistakes. The same happens if

there is no associated packaging order for an already registered customer order. While still highlighted in red, the respective row in the packaging orders column remains empty in that case. All of these incidents require attention of the user and need to be resolved manually in the ERP system. With the next update, the application reads the updated data from the ERP database and refreshes the displayed information accordingly.

4.2.2. Production and buffer storage overview

The second screen offered by this production planning application provides a complete overview of the whole production process in regard to quantities. As described in section 3, the company's manufacturing process is a hybrid production system using buffer storage for semi-finished product variants as its CODP. This corresponds to a tripartite process that includes manufacturing of semi-finished products, the buffer storage where they are stocked, and assembly and packaging at the last stage before expedition. Each of these steps is included in this overview screen, broken down to available variants.

Product Name	Incoming (Production)	Buffer Storage	Outgoing (Packaging)
ACCESS biela AB dekel (S563P011)	0462	0752	0000
ACCESS biela AB brila (S563P010)	0462	0753	
ALASKA prinz AB dekel (S052P011)	0310	0079	0002
ALASKA prinz AB brila (S052P010)	0276	0178	
BALTIC biela AB dekel (S722P011)	0199	1636	1641
BALTIC biela AB brila (S722P010)	0250	3533	
EUROCLASS DINO biela AB dekel (S120P011)	0283	4034	2112
EUROCLASS biela AB brila (S120P010)	0263	4616	
IRYDA prinz AB dekel (S890P011)	0853	0347	0000
IRYDA prinz AB brila (S890P010)	0796	0121	
MIO biela AB dekel (S801P011)	0584	0000	3378
MIO biela AB brila (S801P010)	2651	0023	
PRIMA biela AB dekel (S940P011)	0079	5134	1536
PRIMA biela AB brila (S940P010)	0129	5422	
SENATOR prinz AB dekel NF (S513P531)	0472	0941	0000
SENATOR prinz AB brila (S513P530)	0328	1080	
TRENTO prinz AB dekel (S620P531)	1680	2418	0000
TRENTO prinz AB brila (S620P530)	1393	2605	

Fig. 4. Part of the application screen used to gain a holistic overview of production stages and buffer storage.

Figure 4 clearly shows the partitioning of the production process, with the leftmost column enumerating component combinations (variants), and the remaining three columns specifying the current quantities of components at each of the previously described manufacturing stages. The first of the horizontal-bar graph columns corresponds to the production of semi-finished products. Each of these bars corresponds to the total amount of parts for a specific component type that is already scheduled for production. In other words, a single bar denotes the quantity of a certain kind of semi-finished product that is still being produced and expected to enter the buffer storage upon completion. With each batch of components that are being produced and booked into the buffer, this bar becomes smaller. As the maximum amount of components per type is limited within the buffer, these values can be used to assess the current rate of production and thus avoid buffer overflows. But in order to avoid overflows of the buffer storage, the user also has to know its current fill level. This information is itemized in the adjacent column. It displays the current buffer inventory fill level per variant and component type. Next to this, the total amount of remaining components still required for packaging is shown in the last and rightmost column of this screen. With each batch of final products that are packaged and stocked for delivery, the displayed value decreases.

By use of this information, the user is provided with an overview of relevant production stages and is thus able to evaluate the further progression of production. Depending on the flow of incoming and outgoing components to and from the buffer, the production manager is able to adjust manufacturing parameters in order to avoid buffer overflows or buffer shortages, which is important for a flexible and smooth production.

4.2.3. Packaging order planning view

Although all of the previously introduced functionalities are useful from the perspective of a production manager, none of them served the originally intended purpose of this application yet. The primary function of the presented

solution is production planning and this is the topic the third and last screen deals with. As already mentioned in section 4.1, the concept of a ConWIP-based work package list is used for planning of packaging orders. The following screenshot in figure 5 shows an implemented version of such an order planning list, which slightly resembles the schematic list depicted in figure 2.

Order No.	Amount	Proc. Time	Delivery Date	Product No.	Description	FG Inventory	Seat Stock	Cover Stock	Customer	Priority
^ Orders of Status: 'In Store'										
04.07.2013	5010736	636	10601	04.07.2013	S042V010	DESKA KOMP PRESIDENT...	967	473	469	
05.07.2013	5010742	128	21:21	05.07.2013	S473V010	DINO, LYRA compact NF...	1536	4616	4034	
06.07.2013	5010750	1280	21:21	06.07.2013	S723V010	BALTIC biela AB metal	4608	3533	1636	
10.07.2013	5010761	128	21:21	10.07.2013	S723V011	BALTIC click on biela AB	0	3533	1636	
10.07.2013	5010766	128	21:21	10.07.2013	S472V012	DINO, LYRA compact NF...	257	4616	4034	
13.07.2013	5010806	128	21:21	13.07.2013	S473V010	DINO, LYRA compact NF...	1536	4616	4034	
17.07.2013	5010818	256	42:41	17.07.2013	S593V010	UNISET PLUS biela AB metal	3892	2946	839	
26.07.2013	5010882	420	70:01	26.07.2013	S801V010	MIO biela AB metal	3456	23	0	
26.07.2013	5010893	985	164:11	26.07.2013	S801V010	MIO biela AB metal	3456	23	0	
27.07.2013	5010915	50	08:21	27.07.2013	S082V010	WEGA biela AB	3081	2946	175	
Capacities: 31: 64.0/100.0 (64.0%) 32: 111.4/100.0 (111.4%) 34: 196.4/100.0 (196.4%)										
										Orders: 10 Pieces: 4139
^ Orders of Status: 'In Process'										
10.07.2013	5010769	236	39:21	10.07.2013	S940V010	PRIMA biela AB	1977	5422	5134	
24.07.2013	5010864	2432	405:21	24.07.2013	S723V010	BALTIC biela AB metal	4608	3533	1636	
25.07.2013	5010877	512	85:21	25.07.2013	S940V010	PRIMA biela AB	1977	5422	5134	
26.07.2013	5010886	1024	170:41	26.07.2013	S473V010	DINO, LYRA compact NF...	1536	4616	4034	

Fig. 5. Application screen used to plan packaging orders based on ConWIP mechanisms.

The list is split into four retractable groups that contain packaging orders based on their system status and acknowledged delivery date. Even though customers usually express desired delivery dates, these dates need to be confirmed by production. For example, a lack of resources within a certain timeframe could cause some orders to be postponed. The challenge for the production manager here is to comply with as many customer-proposed delivery dates as possible while trying to utilize available resources and maintain a balanced workload. However, he must not begin packaging of orders whose delivery dates are too far in the future, because doing so would tie costs to end products that may be specific for only a single customer. But customers sometimes request to change their orders in some way until shortly before delivery, which could eventually result in a situation where a certain amount of finished products is put on stock even though none or only few of them have definitive buyers. Running into this situation would be highly disadvantageous and must be avoided. The proposed production planning application facilitates this process for the user by the division of orders into the following packaging order groups:

The first group includes completed orders whose end products have already been put on the dispatch stock. Everything within this group solely serves informational purposes and is typically not required for planning. The second group only contains orders that are currently being worked on. The third and fourth group includes all those orders that are scheduled for packaging but are not yet being processed. The difference between both groups is the WAW parameter of ConWIP, which specifies a timeframe in which planning of orders is allowed and reasonable. For instance, it makes no sense for the user to plan or schedule orders that are far too distant in the future. Settings like these are adjustable in the application's configuration dialog, though. By limiting the amount of orders to deal with, the user also gets a more concise view on the current production situation.

Actual planning of packaging orders is mostly done in this third group. The sequence of orders is determined by their acknowledged delivery date. Initially, the values of acknowledged and customer-requested delivery dates are equal. In the course of production planning, the user is able to adjust the order sequence by means of drag and drop. The application highlights the actual date with a red frame and displays a continuous timeline to the maximum specified date. Weekends are colored differently than work days and in case a certain day contains no planned packaging orders, that day is simply displayed empty. This gives the user the possibility to drag orders to certain dates, thereby also changing their dates of delivery. However, due to the lack of full integration, changes are not automatically propagated back to the ERP system. All modifications of delivery dates have to be entered manually into the ERP system, but small status lights in the second column support the user. New and untouched orders from the ERP system are marked red, modified or updated orders are yellow, and confirmed orders exhibit green lights. On the very first application start-up, all packaging orders are expected to show red lights as no changes have been performed yet. But over time and as orders are adjusted and confirmed, all of them are supposed to become green. In case customers request changes to volumes or delivery dates, affected orders are highlighted by yellow lights.

Hereupon, the user is responsible to adapt the current production plan to such changes. The application also displays the degree of capacity utilization per calendar week and highlights shortages in yellow or red. The user has to monitor these values and adapt accordingly. Furthermore, the application continuously observes delivery dates. As soon as any packaging order is late or has missed its deadline, the represented row is highlighted in light red (as can be seen in figure 5). Again, this draws the attention of the user and requires manual resolution.

5. Conclusion

This paper described the concepts, design, and implementation of a customized and innovative production planning solution based on the ConWIP manufacturing system. The resulting PPC software prototype is currently being evaluated in the course of a field test at the manufacturing facility of a plastics processing company. Production halls, manufacturing processes, and material flows were redesigned into modular units and optimized in such a way that they result in minimum distances and closed working cycles. Thereby, the buffer storage for semi-finished products represents a key component of the employed hybrid production system as it increases flexibility, improves lead times and manageability of variants, and eventually leads to a reduction of finished products stock.

ConWIP was adopted for the final production stage, in which components from the buffer stock are assembled and packed. It is able to satisfy the company's requirements for a customer-oriented production as well as a reduction of inventory and work-in-process. Other benefits include, among others, easy manageability of production planning processes and an improved capability to deal with fluctuations of customer demand. However, its use also led to some challenges: The corporate ERP system does not support production planning using ConWIP, so a proprietary solution had to be developed, which resulted in the software prototype presented in this paper. The proposed solution applies comprehensible and transparent rules and processes that are easy to understand for the entire target user group. A customized solution also offers the possibility to extend core functionality in a way that additional information like inventory levels is provided, thereby further facilitating the planning process. As with all in-house developments, dedicated resources are still required to stabilize and maintain the current version of the software prototype. After all, further adaptations and refinements are expected as part of an ongoing evaluation.

The software described in this paper does neither represent a ubiquitous nor definitive solution for production planning using the ConWIP approach. At this moment, a final statement about "real-world" performance cannot be made. In order to come to a final conclusion, the assessment of applicability, efficiency, and other aspects as well as a comparison with different other implementations and scenarios remain the task of further research in this context.

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