ConWIP-based Packing Order Planning Software Prototype for Variant-centered Manufacturing

Markus Stopper, Bernd Gastermann, Franz Luftensteiner and Branko Katalinic

Abstract—**This paper is focused on the presentation of the concept, design, and implementation of a production planning software prototype built upon the methods of the constant work in process (ConWIP) manufacturing system. The paper discusses various aspects revolving around the field of application and system implementation itself. As an introduction, basics about ConWIP and the manufacturing processes of the company, in which this work has been conducted, are outlined. In subsequent sections, the decision to use ConWIP for production planning and various features and possibilities of the implemented software solution are illustrated. The paper concludes with a discussion about potentials and limitations of the system.**

Index Terms—**efficiency optimization, constant work-in-process, delivery reliability, packing order planning, variant-centered manufacturing**

I. Introduction

Manufacturing companies are confronted with increasingly challenging market factors, characterized by strong competition and rapid market changes as well as increased product variety. In order to remain competitive, manufacturing enterprises need to respond quickly to changing requirements without losing sight of costs and quality. When broken down to the level of production, this general perspective implies that on one hand production has to increase in speed and flexibility. On the other hand, however, improvements of quality and reduction of costs need constant attention.

Effective production planning and control strategies (PPCS) can support companies in satisfying the needs of their customers and to achieve their own objectives as well. Thus, selection and application of an appropriate PPCS becomes a crucial task for many companies.

This paper outlines the decision making process for the PPCS and the implementation of an additional software application prototype used for production planning and control (PPC) as well as stock management of a medium-sized manufacturing company operating in the sanitary branch of plastics industry. The particular focus of the company's optimization process is on strong customer orientation and reduction of work in process (WIP). In this case, customer orientation means that the production is based on actual customer orders and the company is able to respond economically to large fluctuations in customer demand.

Together with well-known PPCS the ConWIP method will be presented and investigated regarding the special circumstances and requirements of this specific company. Furthermore, the concept and development of a ConWIP-based production planning application software prototype, which integrates seamlessly into the company's enterprise resource planning (ERP) infrastructure, will be introduced in this paper.

II. Applied Production Planning and Control Systems

Preceding any meaningful discussion about the implemented production planning software, some fundamental knowledge of the topic is required. In order to allow for a better understanding, both ConWIP as well as the production hall layout and processes of the manufacturing company, in which this work was done, are introduced.

The following section about ConWIP remains solely introductory, as other publications like [2] or [7] already covered this topic to a greater extent. Please refer to one of these papers for a more in-depth view on ConWIP and other related PPC systems. Following an explanation of the company's manufacturing processes, which is mandatory for the understanding of the prototype's field of application, the reasoning behind choosing ConWIP as its underlying production planning system is discussed.

A. Constant Work-In-Process

Constant Work-In-Process (ConWIP) describes a rather uncommon production planning and control (PPC) system that was first presented by Spearman et al. [6] in the year

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1990. In their publication the authors characterized ConWIP as an enhanced and generalized form of Kanban. Its intended purpose is to ensure a constant level of work in process (WIP) for a whole manufacturing system – hence the name ConWIP. Despite the fact that it shares several similarities with Kanban, ConWIP is not a pure pull-based system but also incorporates aspects of push-based approaches [3]. It extends the advantages of Kanban in regard to demand-driven production with the push-based approach of Material Requirements Planning (MRP). Just like Kanban, ConWIP uses authorization cards that help to create a demand-driven system by signaling depletion of components or products between two production workstations. However, while Kanban uses individual card sets for each pair of manufacturing stations, ConWIP only employs a single global card set that is used for the whole production process [4]. This approach results in an almost constant level of WIP that holds the advantage of easily predictable flow times [6] and improved delivery reliability [1]. Furthermore, production systems based on ConWIP are typically easier to manage due to the fact that only a single card set has to be maintained for the whole manufacturing process.

Demand-driven ConWIP systems basically correspond to pull-based systems in which demand at the end of the production chain triggers the release of new work at the beginning. Each released work unit is required to have approximately the same size in terms of time or work required to process a package. As soon as a work unit enters production, it is assigned an authorization card from the global card set. Card and work unit remain associated until the manufacturing process for this package is completed, at which point the card is released and put back into the card stack. Once a work package is released to production, it is pushed through the manufacturing chain until it is fully processed and its outcome leaves production. In case all available cards are assigned, no additional work is allowed to be released. This mechanism ensures a constant level of WIP 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 also allows to raise the level of WIP and to ensure higher throughput by increasing the number of authorization cards.

Despite having shown improvements to inventory levels, lead times, and output rates in various studies such as [1], [4], and [5], ConWIP rarely made it beyond its theoretical approach. Actual implementations of ConWIP for PPC systems are scarce, which is why it still remains relatively unknown especially within Europe. Nonetheless, a definitive statement about the actual performance of ConWIP in comparison to other more established PPC systems cannot be made at this point as other studies came to conflicting conclusions. This area remains the subject of ongoing research.

B. Manufacturing Processes and Production Hall Layout

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. These general conditions need to be considered in order to understand the entry points for the later discussed software solution.

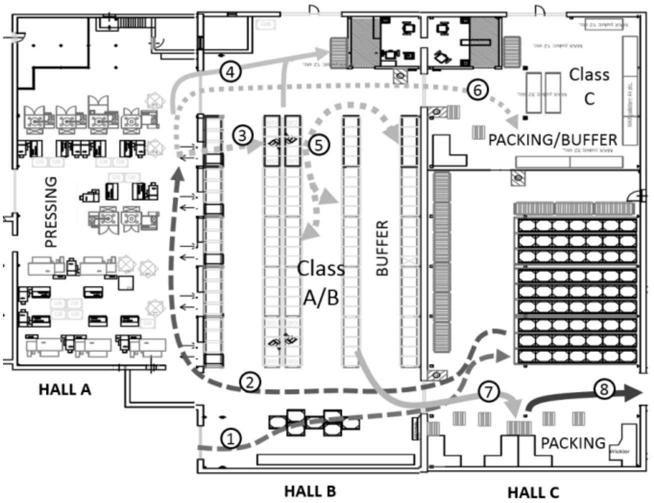

Fig. 1. An overview of the production hall layout including respective flows of raw materials, components, and end-products of various categories.

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, components are packed into a box together with hinges and other parts, according to customer requirements. Fig. 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 dashed arrow with the number 1 at the bottom of Fig. 1, raw material enters the production in so-called octabins at 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. There, 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 solid arrow with the number 4, according to Fig. 1. Otherwise, they are disposed of.

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 molding presses are therefore able to continuously produce these without further interruption. Category A represents approximately 20% of the total production volume whereas category B represents about

60% of the total production volume. Category C combines all other variants of low volume and minor importance. Typically, category C comprises of more than 50 different variants whereas category A and B only contain 18 different component variants altogether.

After the grinding station the material flow is split up into two different paths. Only flawless parts of categories A and B are put into the buffer storage for semi-finished products at hall B (see arrow number 5). Following the dotted arrow with number 6, 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 customer order decoupling point (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/packing stations downstream of the CODP need to be fast and flexible. The ConWIP planning method supports this customer-oriented pull-based approach for packing 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.

C. System Properties and Requirements

This chapter discusses the main aspects for choosing the ConWIP method as the adequate production planning and control strategy (PPCS) for the assembling stage of products based on category A and B components.

General requirements of the company are the reduction of required production capital, which means low WIP levels, thereby simultaneously reducing delivery lead times and finally a customer-oriented production. The last point in particular means that every customer order is processed as a single production batch.

Additional to more or less standardized products, customers are constantly demanding new and more individual products. This directly leads to an increasing number of variants in the company's product range. Furthermore PPCSs have to be able to deal with the high variability of customer demand. In times of lower demand, WIP levels have to be adjusted proportionally. Otherwise, production lead times as well as the risk of sorting out products, that have already been released for production when customer requirements change, will increase.

Hereinafter the mature PPCSs MRP and Kanban together with the relatively unknown ConWIP method are taken into account. Regarding Kanban, every product variant has its corresponding containers. Size and number of containers determine the maximum WIP level for the specific product. According to the increasing number of variants, additional containers are needed, which in turn leads to higher efforts for the management of containers. Furthermore, it would be necessary to reduce the number of containers in times of lower demand, so that the WIP level declines accordingly. Summarized, Kanban is not meeting the needs for this specific production situation.

MRP and ConWIP are both able to adequately fulfill the requirements concerning customer orientated production, reduction of capital requirements, and delivery lead times. To choose the appropriate PPCS, further criteria have to be considered.

Once the decision for a specific PPCS is made, the optimal parameterization has to be determined. Typically MRP has different parameters for every single product, e.g. safety lead times, safety stock and eventually lot size. On the contrary ConWIP is operated with only few parameters for a production line. This means less effort for the calculation and maintenance of the parameters. Furthermore, in MRP, this calculation has to be done only once and not for each new product variant.

For a company it is absolutely necessary that the planning process is understandable and transparent. The MRP procedure determines release dates and times for production orders. The calculation itself is not transparent to the user whereas the ConWIP planning process can easily be performed with the help of a spreadsheet just by following some basic rules of this method. The main advantage is that even users who are not highly educated and familiar with the planning process are nonetheless able to achieve useful results (just after a short training period).

Overall, the ease of use, higher transparency, and low complexity are crucial in deciding for ConWIP as PPSC.

III. Development of a Production Planning Software Prototype

So far, this paper presented the theoretic background of ConWIP-based PPC systems, outlined the company's manufacturing processes, and highlighted the reasoning behind choosing ConWIP as the preferred system for planning of packing orders. Based upon this introduction, the following chapter is going to focus on technical aspects as it describes the design and actual implementation of the manufacturing planning software prototype.

The development of a proprietary software solution for ConWIP-based production planning systems was rooted in the need for a highly efficient, yet transparent and easily manageable system. The decision to use ConWIP for the last stage of the company's hybrid production approach was made because of its promising performance and other inherent advantages. A classical ERP system by Infor had

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already been adopted, but it neither satisfied the company's ambitious goals for the planning of packing orders out of the box nor did it incorporate any ConWIP mechanics. As a result, a custom-made proprietary solution for this production system stage had to be developed.

In order to make use of a custom planning tool, some fundamental requirements have to be met. For this specific production planning prototype, integration into the company's existing Infor ERP system, ease of use, and effective planning capabilities are essential. In order to meet these requirements, initial work focused on a ConWIP-based planning concept presented by Altendorfer and Jodlbauer in [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 effectively is but one fragment of the whole solution. Staff working with such a tool must also 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 company's manufacturing system: production of components, inventory levels, and packing of products. Considering these prerequisites, a tight integration with the data pool of the central ERP system is required in order to achieve these goals. However, integration with the ERP system was impeded by the absence of a public interface to the system and its high acquisition costs. Although full integration would be preferable, it was concluded that partial integration with the system would be sufficient for an initial prototype. Therefore, required data is directly accessed via the ERP system's underlying Microsoft SQL Server database in a read-only manner. As a result of this limited approach, some actions and changes done by this tool would also require manual data updates in the ERP system via its user interface. Unfortunately, without an accessible application programming interface (API) or precise knowledge about the system's internals, an automation of this step is not feasible. Refer to section 3B, "Packing Order Planning View", later in this paper for further details on the process affected by this limitation.

As already mentioned, transparency and usability are important aspects of a potential software solution that have to be taken into consideration during the application's 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, making transparency of the background software processes and ease of use especially important aspects. 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 adjournments thereof. Due to the fact that customer orders and packing orders are tightly interrelated, they could use this software to review the automatic creation of packing orders from new customer orders (see section 3B, "Customer and Packing Order Correlation View") and validate changes of delivery dates.

A. Introduction to a ConWIP-based Planning Concept

Knowing the most important criteria that have to be met for such software, an appropriate planning concept based on ConWIP had to be found. Initial work centered on a concept first presented by Altendorfer and Jodlbauer in [1], which proved to be promising and therefore formed the foundation of the implemented software prototype. The purpose of this section is to provide the reader with a short overview of said concept. However, as [1] and [2] already provided a more comprehensive view on this matter, please refer to one of these publications for more details as it would exceed the scope of this paper.

Generally, the concept is a rather simple approach without much overhead and easy enough to work with even for unskilled staff. Considering its operating mode, the simplest way to perform ConWIP-based production planning is by means of a production order list. As depicted in Fig. 2, such a list consists of multiple work orders. Based upon this list, orders are planned and sequentially released to the production line. All orders within the list are arranged into four groups for easier manageability. The sequence of work orders and other list properties are influenced by various parameters. The scope of these parameters is highlighted in Fig. 2 by numbered vertical bars.

The WIP cap (see vertical bar #1 in Fig. 2) defines the maximum amount of work the system is allowed to perform simultaneously. The timeframe in which work orders are scheduled and released to production is defined by the work-ahead-window (WAW) (see bar #2). It avoids that too much work is released during low-selling periods. After all, it is not desirable to process certain orders earlier than scheduled just to bridge such a period. The capacity trigger (see bar #3) determines the maximum amount of work the production line can handle within a certain timeframe without the allocation of additional working resources. The processing rule (#4) determines the order in which released orders are processed within the production line. Similarly, 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 would also be possible.

Fig. 2 clearly illustrates the four areas in which orders are grouped. Groups are based on the status for each work order. The arrangement within a group is determined by the processing rule or dispatching rule (depending on the group) and is typically sorted by date. The four groups are, from top to bottom: completed, in production, scheduled, and pending. The first one only contains work orders that are

Index	Quantity	Status	Target Date	Other Data
1	940	completed	10.12.2013	...
2	5400	in production	11.12.2013	...
3	7000	in production	16.12.2013	...
4	2550	in production	20.12.2013	...
5	8775	scheduled	27.12.2013	...
6	2100	scheduled	27.12.2013	...
7	4120	pending	02.01.2014	...

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

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
23135	1	16.12.2013	Customer #08	S497V987	Product for Customer #08	1743	23135-001	16.12.2013	S497V987	Product for Customer #08	1743	Completed
99645	2	16.12.2013	Customer #08	S264V922	Product for Customer #08	992	99645-002	16.12.2013	S264V922	Product for Customer #08	992	Completed
36431	1	20.12.2013	Customer #11	S082V542	Product for Customer #11	521	36431-001	20.12.2013	S082V542	Product for Customer #11	521	Completed
23971	2	20.12.2013	Customer #11	S839V482	Product for Customer #11	347	23971-002	20.12.2013	S839V482	Product for Customer #11	0	Released
34441	3	20.12.2013	Customer #11	S013V904	Product for Customer #11	2394	34441-003	20.12.2013	S013V904	Product for Customer #11	2394	Released
38434	4	20.12.2013	Customer #11	S455V002	Product for Customer #11	1458	38434-004	20.12.2013	S455V002	Product for Customer #11	1458	Released
80247	1	23.12.2013	Customer #03	S726V463	Product for Customer #03	2880						
85305	2	23.12.2013	Customer #03	S934V823	Product for Customer #03	1833						
61439	1	23.12.2013	Customer #01	S134V988	Product for Customer #01	3180	61439-001	23.12.2013	S134V988	Product for Customer #01	3180	Released
96454	1	27.12.2013	Customer #02	S345V933	Product for Customer #02	5323	96454-001	27.12.2013	S345V933	Product for Customer #02	5323	Scheduled
64311	2	27.12.2013	Customer #02	S653V942	Product for Customer #02	2341	64311-002	27.12.2013	S653V942	Product for Customer #02	2341	Scheduled
39713	3	27.12.2013	Customer #02	S764V731	Product for Customer #02	3831	39713-003	27.12.2013	S764V731	Product for Customer #02	3831	Scheduled
44418	4	27.12.2013	Customer #02	S126V983	Product for Customer #02	9421	44418-004	27.12.2013	S126V983	Product for Customer #02	9421	Scheduled

Fig. 3. This is a part of the application screen used to correlate customer orders with packing orders.

already completed, that is, they are fully processed and their outcome has been put on stock. The second group contains orders that are currently being processed, while the third one comprises orders that are scheduled. Although already within the WAW, scheduled orders are not allowed to enter production due to the limiting WIP cap. All other work orders with dates beyond the WAW make up the fourth group serving solely informational purposes.

The core functionality of the implemented production planning software was built upon the concept shortly discussed in this section. Refer to section 3B, “Packing Order Planning View”, later in this paper for a discussion about a practical application and implementation of this concept.

B. Implementation Aspects and Components

With regard to the underlying technological aspects, the software prototype is a Windows Presentation Foundation application for the Windows desktop and was developed using the Microsoft .NET Framework. The decision for this specific software development kit (SDK) was made due to previous experience, but Java or any other SDK could have been used as well. 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 using plain SQL query commands. The application sends SQL queries directly to the ERP system’s backing database with each manually or periodically triggered update to request the latest data. Incoming results are then merged and transformed into custom data types for further processing. Eventually, everything is cached in a local Microsoft SQL Server Compact Edition database file solely used by this application. Caching is an important aspect 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.

In the final design of the initial software prototype the user is offered three main views, each of which will be explained in the upcoming sections. The user is able to switch freely between each of these views. It is also always possible to trigger an update of all displayed data. Apart from that, data is automatically updated from the ERP system in a customizable interval. The prototype also offers a configuration dialog in which various application parameters, like the ones mentioned in the previous section, are used. Please refer to section 3B, “Application Parameters for Production Planning”, for more information about available application settings.

Customer and Packing Order Correlation View

The first type of the three application screens is the correlation view. Though being of minor relevance for actual production planning, it is still very important with regard to process transparency and flawless operation. The purpose of this screen is to enable the user to correlate created packing orders with their respective customer order counterparts. Therefore, it lists all currently registered customer orders whose status is either active or unfinished. Of course, already processed and finished customer orders should not be listed here as they are no longer relevant and would only clutter the view unnecessarily. As the ERP system is responsible for the automatic creation of new packing orders based on incoming customer orders, a strong association between these two types of orders exists. The representation of this association is the intention of this screen, which is illustrated in Fig. 3.

Basically, the screen displays a list divided into two superordinate columns: the left column contains all registered and still active or unfinished customer orders; the right column displays their associated packing orders, if available. Each of the columns displays informational data relevant for the respective type of order. Some of these informations are order numbers, delivery dates, customer names, product numbers, and target quantities.

Due to the fact that packing orders are always derived from customer orders, values of shared properties must always be the same. For example, product numbers, quantities, and delivery dates should typically be the same for both order types. Any discrepancies here likely indicate either an error or outdated data. The application compares property values of each packing order with its respective customer order source values and highlights the row in red if any of these values mismatch. The same happens if there is no associated packing order for an already registered customer order. In this case, it is also highlighted in red and the respective row in the packing orders column remains empty. All of these incidents require attention of the user and need to be resolved manually through the ERP system’s user interface. The next time updated data is loaded from the ERP database, displayed information is being refreshed accordingly.

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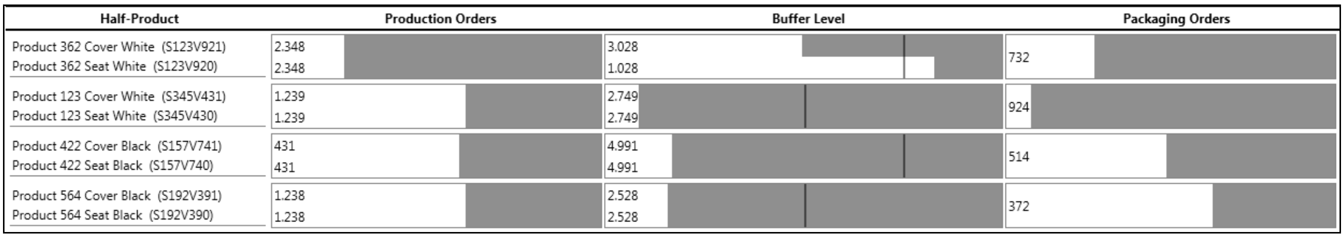

Fig. 4. This is a part of the application screen used to gain a holistic overview of production stages and buffer storage.

Production and Buffer Storage View

The second view offered by the application provides a complete overview of the whole production process with regard to quantities. As described in section 2B, 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 stock, and assembly and packing at the last stage before expedition. The overview screen includes each of these stages, displaying quantities for each available variant.

Fig. 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 gets 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. However, 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 right 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 packing 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.

Using this information, the user is provided with a holistic overview of production and its stages. This allows an evaluation of 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.

Packing Order Planning View

Although still very useful, none of the functionalities presented so far served the originally intended purpose of a production planning software yet. This area is covered by the third and last screen and is being discussed in this section of the paper. As already mentioned in section 3A the concept of a ConWIP-based work order list is used for planning of packing orders. The screenshot in Fig. 5 shows an actual implementation of such an order planning list, which slightly resembles the schematic illustration depicted in Fig. 2.

Based upon the concept of section 3A, the implemented planning list is split into four retractable groups that contain packing orders based on their status and acknowledged delivery date. Even though customers usually express desired delivery dates at the time an order is placed, these dates still 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 packing of orders whose delivery dates are too far in the future, because doing so would tie costs to end products that may not be sold due to a short-term change of a customer order. Such a situation would be highly disadvantageous and must be avoided. The implemented production planning application facilitates this process for the production manager by dividing packing orders into four groups, according to the ConWIP-based planning concept of Altendorfer and Jodlbauer [1]:

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 include all those orders that are scheduled for packing but are not yet being processed. The difference between both groups is the WAW parameter, which specifies a timeframe in which planning of orders is allowed and reasonable. Settings like these are adjustable in the application's configuration dialog, which is being described in the upcoming section called "Application Parameters for Production Planning". By limiting the amount of orders to deal with, the user also gets a more concise view on the current production situation.

The primary group for planning of packing orders is the third group. The sequence of orders is determined by the dispatching rule, which typically sorts by acknowledged delivery date. When a new customer order is registered and, consequently, a new packing order is created, 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

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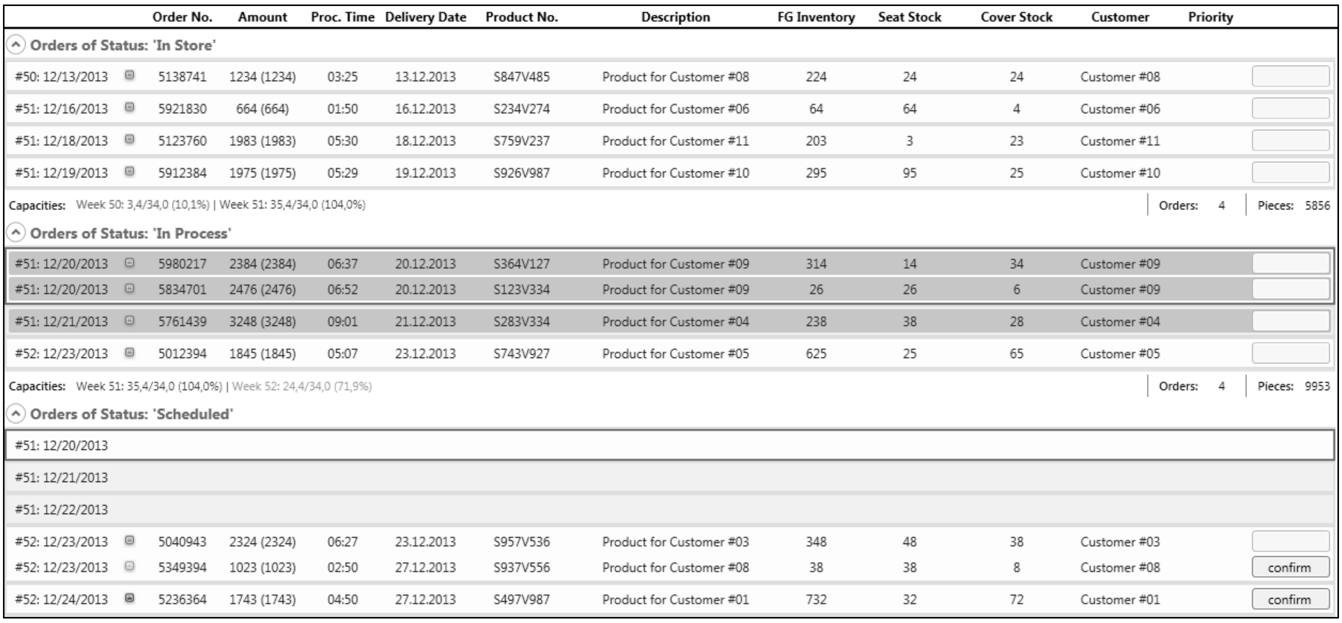

Fig. 5. This screenshot shows the application screen used to plan packing orders based on the ConWIP planning mechanism.

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 packing orders, the row representing that day remains empty. This allows the user to drag orders to certain dates, thereby also changing their delivery dates. However, due to the lack of full integration, changes like these are not automatically sent back to the ERP system. Modified delivery dates need to be entered manually into the ERP system. However, each row contains a status light that supports the user in this process. Status lights could be either green, yellow, or red. All new orders that have never been modified by the user are marked red. As soon as they are modified or updated, the color changes to yellow. Updates happen every time the user drags an order to a different date, thus changing its delivery date, or if a customer requests a change of an already placed order. The yellow warning light is important because it shows the production manager that something has changed, which requires his attention. The user is responsible to adapt the current production plan to any customer-originating changes, be it changes of volumes or delivery dates. If the user is done planning, the delivery dates of each unconfirmed order needs to be confirmed by pressing the respective button. By doing so, the row's status light switches to green. Acknowledged dates of such orders then need to be entered back into the ERP system, if they were changed.

Furthermore, the application displays the degree of capacity utilization per calendar week and highlights potential shortages in yellow or red. The user needs to monitor these values during his planning process and to adapt accordingly in order to avoid capacity conflicts. Another helpful feature of the order planning list is that all delayed packing orders are highlighted. The application observes delivery dates for all packing orders and as soon as any of them are late or have missed their deadline, the represented row is highlighted in red (as can be seen by the three dark rows in the center of Fig. 5). Again, this draws the attention of the user and requires manual resolution.

Application Parameters for Production Planning

The functionality of the presented software prototype implementation offers various parameters that allow for adaption to changing production planning needs. Especially the employed ConWIP-based planning concept makes use of several such parameters. This is why the implementation of a configuration dialog was necessary.

The most recent version of the prototype incorporates a configuration dialog that is divided into three areas: a general area that comprises of some application-wide settings, a ConWIP area that is made up of settings primarily used by the order planning list, and a capacity-related area in which weekly resource capacities are set.

As seen in Fig. 6, the section for general settings incorporates mostly time-based parameters that limit the amount of data loaded from the ERP system's database based on the data's timestamp. For instance, orders that are too old or too far in the future need not be loaded as they are not relevant at present. Furthermore, it is also possible to

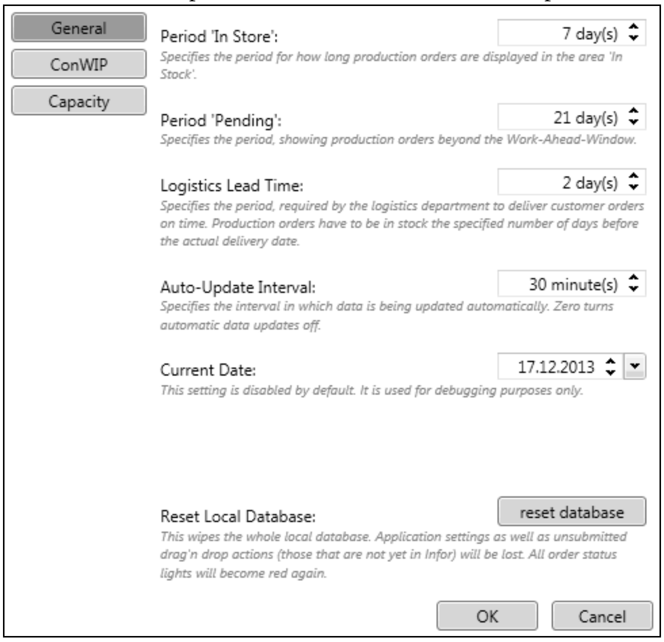

Fig. 6. This is a part of the application configuration dialog that displays various general application settings used to adapt the tool to specific needs.

calibrate the interval in which automatic data updates are made.

The second area includes all those parameters that have already been discussed in section 3A of this paper. Users are allowed to adapt the WAW parameter, choose dispatching and processing rules, or set the capacity trigger or the WIP cap. However, in this initial version of the prototype, the latter two settings are not yet implemented.

Finally, there is a capacity area in which hour-based capacities for each calendar week are set. The user is able to set capacity values for the next seven weeks. As time passes and no new values are entered, the application assumes the last entered value for all upcoming weeks. Values here influence the capacity utilization displayed below each group of the planning order list. Here, it is also possible to define thresholds that are used to color certain utilization degrees. For example, a weekly capacity utilization degree below 70% is marked as green, while values above 95% are shown in red.

IV. Conclusion

This paper describes an innovative software solution for both PPC as well as for stock management of a medium-sized manufacturing company in plastics industry. Within the general settings of this company, variants are produced in two distinctive stages: The pressing stage delivers numerous semi-finished products (components), which are then assembled at a second manufacturing stage. As a consequence, the ConWIP method was selected as PPCS for the relevant second production stage. It is recommended, however, to investigate possibilities for improvement in the area of production and logistics processes first, before a particular PPCS is being taken into account.

The basic concept of this PPC method as well as the company's production process were presented. Based on a sales volume analysis and the comparison of production lead times versus desired delivery lead times a hybrid production situation was determined, in which the make-to-stock (MTS) and make-to-order (MTO) sections of the production are separated by the CODP. The PPCS for the relevant MTO section downstream of the CODP was selected in accordance with the company's objectives, considering the following criteria: The appropriate PPCS must have the ability to provide customer-oriented production, which implicates that production orders are based on actual customer orders. Furthermore, both large fluctuations in customer demand and great product variety have to be supported. The particular challenge was to significantly reduce the number of components in stock.

Both MRP and ConWIP have major advantages over Kanban concerning the relevant criteria. But ConWIP exceeds MRP if efforts and complexity of achieving optimal performance are taken into account, as it offers a more succinct number of system parameters.

To ensure customer-oriented production the second manufacturing line has to be fast and flexible. Therefore, the planning staff needed an adequate software solution. As the ConWIP PPCS is not supported by the company's ERP system, a customized solution had to be developed.

The proposed solution applies comprehensible and transparent rules and processes that are easy to use and understandable for the whole target user group. A customized solution also offers additional options by extending core functionality in such a way that additional information, like inventory levels, is provided, thereby further facilitating the planning process. As is the case with all in-house developments, dedicated resources are still required to stabilize and maintain the current version of the software prototype. After all, further adaptions and refinements are expected as part of an ongoing evaluation.

The presented system is suitable for combining customer-oriented production lines with a greater number of product variants. Especially if the reduction of component inventories is required the ConWIP method will be able to achieve this goal. This system does not only comply with variant production, it also suits the needs of production lines in serial production. The software application is basically designed independently from any ERP systems. Therefore most ERP systems, which provide an interface for data exchange, could be extended by this solution.

The software described in this paper is neither a ubiquitous nor a definite solution for production planning using the ConWIP approach. At this stage, an ultimate 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 implementations and scenarios remain the task of further research in this context.

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