

Diverse Planning for Consecutive and Loosely Interrelated Production Stages in Manufacturing

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Abstract—An implementation case study is presented in this paper, which demonstrates the segmentation of the production process in order to achieve highly flexible variant management, increased processing throughput and reduced inventory size. At the beginning, fundamentals of each of the relevant concepts and systems are briefly introduced. Then, after some facets of product classification the important aspects of variant management and mastering complexity have been discussed. These aspects hand in hand with product configuration have a direct influence on costs or the cost structure respectively and may represent the crucial competitive advantage or disadvantage. The following case study and its implementation of a multi-stage manufacturing process are illustrated in detail. Consequently, the interaction of underlying software processes with specific focus on Infor ERP and a propriety Constant Work-In-Process (CONWIP) planning tool are clarified.

Index Terms—delivery reliability, inventory downsizing, variant management, reduced throughput times, customer order decoupling point

I. INTRODUCTION

A production planning and control (PPC) system is an essential part of production processes of each manufacturing company around the world. Although various manufacturing technologies exist to help with these processes to create products, it is important to make use of only those that are most suitable for the respective production field. Globalization has led to a dramatic change within the competitive environment of the manufacturing ecosystem and as a consequence it became vital to incorporate agile and lean production techniques that increase efficiency, flexibility, quality, and cost-effectiveness in order to satisfy quickly changing customer demands and keep up with increasing global competition.

Manuscript received December 12, 2012. This work was supported in part by the Automation Research & Development (ARD) Department of MKW@ Austria & MKW@ Slovakia as well as the Department of Intelligent Manufacturing Systems, Institute of Production Engineering, Vienna University of Technology, Vienna, Austria.

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Considering that, one approach to accomplish these quality characteristics is discussed by this paper. In form of a case study, the realization of a multiple stage production process for plain manufacturing environments is presented.

Due to the vast upcoming relevance of variant management and complexity mastering also for small and medium manufacturing companies, an overview of important basic aspects is given in a separate section. The explanations here center on the important customer order decoupling point.

The paper briefly introduces the reader to the relevant fundamental concepts and then discusses aspects of the implemented production process with focus on Constant Work-In-Process (CONWIP) and influence on management of variants for plastics industry.

II. FUNDAMENTALS

With regard to PPC, a multitude of manufacturing processes exist. However, if broken down into their basic elements and then examined for commonalities, only a few fundamental principles remain. In this section of the paper, some of these basic concepts, from which even complex manufacturing systems are constructed, will be discussed. Although most of these topics here were already covered in-depth by previous papers like [2], [3] and [8], those that are particularly relevant for this paper are briefly recapped for the sake of completeness.

A. Push and Pull Strategies

In supply chain management, it is common to classify manufacturing systems as either push- or pull-based system. Both of them are essential production strategies.

Manufacturing systems are considered push-based, if they release work units according to a master production schedule (MPS). As such, production is triggered by forecast demand and/or historic demand. Actual demand, however, is not being considered. If the release of new work is determined, it is then subsequently pushed through each step of the production line until the work is done and the final product will eventually be stored at the finished goods inventory. This implies that products are always produced in advance, regardless of actual demand. Jodlbauer used to call these products “anonymous”, which means that they are not associated with an actual consumer [4]. Therefore, push systems could also be described as “make-to-stock” (MTS). It is self-evident that such a build-ahead approach heavily relies on accuracy and reliability of demand forecasts.

Contrariwise, pull-based systems do depend on actual demand for the release of new work, though it is irrelevant where it originates from.

In other words, the presence of demand, whether it is a customer order or internal demand from other manufacturing stages, pulls raw materials and components through the manufacturing process. Because of this, such systems could also be referred to as “make-to-order” (MTO). With this approach, problems of excessive inventory, which is quite 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]. Generally, pull-based systems allow for more flexibility and product customization.

B. Re-Order Point Planning

Re-Order Point (ROP) Planning is a method of inventory control used to automate inventory and to minimize total inventory holding costs. ROP itself represents a certain level of stock at which signals to refill the inventory are triggered. Considering a certain lead time, the ROP must be high enough to allow ordered materials to arrive at the inventory before it is completely empty. The problem of this approach, however, is that replenishment orders are inferred from historic data and demand is expected to not show heavy fluctuations.

C. Constant Work-In-Process

Reference [7] presented the concept of Constant Work-In-Process (CONWIP) as an enhanced and generalized form of Kanban. As the name implies, its basic notion is to ensure a constant level of work-in-process (WIP) throughout the whole production system. It is, however, neither pure pull nor pure push system, but incorporates aspects of both of them [4].

Although already presented in 1990, CONWIP is still quite unknown and hardly ever used within Europe. A reason for this could be the lack of actual CONWIP implementations for PPC applications. In its most simple form, CONWIP operates as a list-based system where demand triggers the release of new work units, which is a characteristic of pull-based systems. Each of these work units is then, similar to Kanban, assigned an global authorization card from a single global card set, which remains associated to that item until it is complete. Released work units are then pushed through each step of the manufacturing process. As soon as a product is finished, its authorization card is released. This allows another work unit to enter the production cycle. Under the assumption that all work units are of equal size, WIP remains constant for the whole production system as the total amount of authorization cards within the CONWIP system is also unchanged. Nonetheless, changes in the quantity of cards are allowed. In case of a bottleneck, for example, cards could be reduced. On the other hand, they could also be increased in order to raise WIP and to ensure higher throughput [5].

As a practical example, it is relatively easy to perform CONWIP-based production planning by means of a production order list [1]. Such a list (as illustrated in figure 1) needs to be filled and maintained by a MPS system that acts independently from the production control system. This list is then sequentially processed by the CONWIP manufacturing system.

An interesting aspect of such a list is that it does not require equal lot sizes for all work units. The list is basically divided into four status groups: The topmost section groups completed production orders that are already in stock. Typically, this serves informational purpose only. Below is the second group that contains items currently in production. The next two groups are for scheduled and pending work units. They appear in either of these two groups, depending on their respective target dates and some other list parameters, which will be discussed now in a few words to provide an overview. For a more detailed disquisition, refer to [3].

Index	Amount	Status	Target Date	Other Data
1	2070	completed	11.10.2012	...
2	940	completed	13.10.2012	...
3	5400	in production	13.10.2012	...
4	1750	in production	16.10.2012	...
5	3200	in production	17.10.2012	...
6	7000	in production	17.10.2012	...
7	2550	in production	21.10.2012	...
8	4750	scheduled	23.10.2012	...
9	6500	scheduled	25.10.2012	...
10	1500	scheduled	25.10.2012	...
11	8775	scheduled	02.11.2012	...
12	2100	scheduled	06.11.2012	...
13	4120	pending	07.11.2012	...
14	9300	pending	09.11.2012	...
15	3600	pending	10.11.2012	...

Fig. 1. This illustration shows an example of a CONWIP order list and highlights the scope of its parameters.

With regard to a simple CONWIP production order list, there are various important parameters that influence the arrangement and release of work units [1].

The work-ahead-window (WAW) is the timeframe in which work units are scheduled or released for production according to their respective target dates. The purpose of this parameter is to avoid the release of too much work is in low-selling periods. With this, the system is able to automatically reduce WIP and output quantity to the level of actual demand.

The capacity trigger parameter defines the maximum amount of work the production line can handle within a certain timeframe without the allocation of additional working resources. Consequently, it helps to detect capacity bottlenecks.

Dispatching and processing rule determine the order in which list items are ordered and processed. The dispatching rule affects the sequential arrangement in which scheduled work units are released. By default, the rule is based on the date of delivery, which causes the item with the earliest delivery date to be released next [7]. However, it is also possible to use different dispatching rules. Similarly, the processing rule determines the order in which released work items are processed by the production line. Although the order of items is defined by these rules, it is still possible to override this order manually and prioritize certain work items. But, doing so may have a negative effect on due dates.

At last, a WIP cap limits the maximum amount of work on which the production system is allowed to concurrently work on. It prevents the release of new production orders if the amount of work exceeds the currently set WIP cap. The value for this parameter is usually determined by the bottleneck of the production line.

D. Hybrid Production Strategies

When designing a manufacturing system, it is not always appropriate to adopt either the MTS or the MTO production approach. However, they are not mutually exclusive [7], so it is possible to combine both of them into a hybrid production system, which is often referred to as “make-to-assemble” (MTA). Hybrid manufacturing strategies are able to combine aspects of both push- and pull-based systems in the following way:

In a first step, basic components of a product are produced and stocked on an intermediate storage based on forecast or pre-defined schedules. As soon as a customer order is placed, the previously stocked components are then used to assemble the final product. With this approach, there is one point that splits the manufacturing chain into MTS and MTO production: The inventory of components clearly marks the point of transition between the two approaches. This point is either called the Order Penetration Point (OPP) [6] or Customer Order Decoupling Point (CODP) [4], though only the latter term will be used throughout this paper. The actual position of this spot may vary, but it is important to wisely choose its location in order to gain benefits from both push and pull strategy. Moving the CODP closer to the customer, for example, improves responsiveness, while moving it farther away from improves flexibility.

III. ASPECTS OF VARIANT MANAGEMENT

Mastering the steadily growing number of product variants and the resulting impact for the production itself increasingly represents the crucial competitive factor for production companies. Customer-oriented and customized products are the key for success in the manufacturing industry. It is an unbroken trend that customer wishes become dominant on the different markets. The more specific a company may fulfill the concrete needs and wishes of the customer the bigger is the advance. Standard products are by far not as requested as customized products. However, manufacturers find themselves in an area of conflict between fulfilling customer wishes and cost optimal production. Different customer needs must be on top of companies' priorities but it has to be taken into consideration that increasing numbers of variants and unique products are enormous drivers of costs. These significant cost increases can be contained through variant management by following approaches which eliminate a full parallel development like platform concepts or modular construction systems and by exactly defining the CODP as late as possible within the whole process chain. The CODP positioning relevance is described more detailed in the next section. Variant management must therefore be an integral enterprise wide paradigm for mastering variant diversity of products in the company.

Taking into consideration the initial cause for rising variant diversity in respect to growing competition, product complexity and market growth and the customer requests for shorter delivery times and product life cycles, the following major reasons can be pointed out [9]:

- escalating design orientation of products
- trend for individual ownership (unique products)
- different legal requirements in different markets or countries
- individual different requirements of customers for the same product
- significant different application for unique variants
- technical progress and development with limited forward/backward compatibility

For mastering variant diversity and complexity as indicated above standardization, modularization and application of platform as well as building block systems are immensely supportive. Additionally, in order to get ahead a logical description within different projection levels in which only a certain section or scope of the variant diversity matters is advantageous [10]:

- *product-level*: describes sales related characteristics of the manufacturer's variants
- *assembly-level*: describes the building block/modular construction system variants
- *structural-level*: describes the building block/modular construction system itself
- *material-level*: describes the single items/raw parts and half parts

Hand in hand with cost aspects of rising variant diversity the growing complexity level of the operational enterprise value chain results in lower process quality. Missing targets regarding product variety as well as insufficient variant diversity controlling and the lack of using advanced tools and methods to master the rising complexity represent a major challenge for companies. The critical aspect hereby is that the rise in complexity in real industrial environments takes place very quietly and mostly undetected for a while. Just flashes of problems appear which often results in creating island solutions to solve local complexity problems. However, this leads to a certain fragmentation which makes the company overall less efficient most of the times even though the locally optimized solution might be more effective. Especially small and medium sized companies are often not able to manage this issue thereby decreasing their effectiveness. Entire concepts which represent the whole added value process and further integral enterprise processes are therefore required.

Strategic main points of interest are reducing, mastering and avoiding complexity. Narrowed down to practical issues it requires:

- reducing the already available complexity
- mastering the non-avoidable complexity
- preventively avoiding emergence of complexity

Downsizing the product portfolio is often not or only marginally possible due to the variety of customer wishes. In fact, suitable methods like the above mentioned (platforms, modules etc.) are representing an effective measure for reducing product driven and process driven complexity.

Mastering complexity goes far beyond pure reduction of product variety. Here intelligent concepts for job control, order tracking, disposition, production planning, logistics etc. take effect (e.g. CONWIP and manufacturing segmentation). Avoiding emergent complexity can be handled by strict and clever controlling of new variants. The strategies hereby focus mainly on restrictive process controlling when treating existing variants or creating new variants (approval for new variants is necessary) and on the support of a suitable enterprise wide software infrastructure.

Previous statements gave a rough outline about coherence between variant diversity and complexity. It is obvious that versatile causes and effects of variant diversity take effect on the complete chain of order fulfillment. Hence the request for an integrated and in all phases of order fulfillment comprehensive variant management derivate.

There are many approaches for variant management. However, in this paper section only the issue of internal and external variant diversity is the focus because of special relevance regarding manufacturing segmentation.

The general target of variant management is minimization of internal variety while providing external variety requested by the customers or markets respectively. Thus the difference between these two kinds of variety is described as follows [11].

External variety is fully usable variety of product variants for the customer. These variety must be entirely visible or recognizable for the customer to be sales-related and contributes to fulfill customer wishes as well as to increase customer product benefits. In general, external variety by trend is useful for a company as long as the variety is not exceeding the market requested variety.

Internal variety in the frame of order fulfillment describes the recurring variety of parts and component groups, products and processes. This variety causes increasing complexity and missing transparency in indirect fields within the processes and therefore acts as an overhead cost driver. Overall the expenses in manufacturing increase and the internal variety affects the enterprise in a disadvantageous way. In industrial practice internal variety often results from internal inventive creativity, in many cases not controlled and not useful if not initiated by customer requests or market requirements. The increase of internal variety regarding these aspects must be avoided with emphasis.

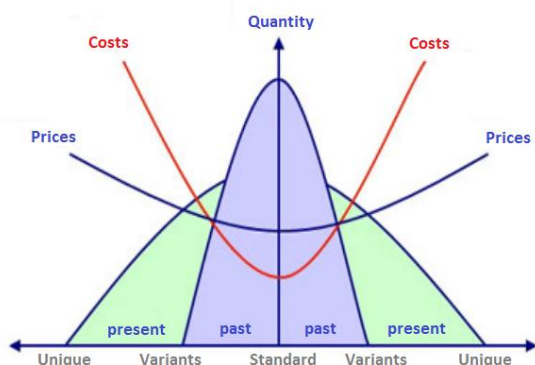


Fig. 2. Coherence between quantity, prices and costs regarding growing variants in past and presence.

Internal variety resulting from external variety has to be economically evaluated. Beside of immediate cost-benefit considerations also tactical and strategical market aspects have to be taken into account.

As mentioned before, aspects of variant management hand in hand with product configuration have a direct influence on costs or the cost structure respectively and may represent the crucial competitive advantage. Figure 2 above shows the coherence between quantity, prices and costs [11].

As easily can be seen variants have an enormous negative effect on economic considerations because of the impact to the existing cost structure. Hence the target must be to produce variants as almost as economical efficient as standard products, like described in Figure 3 [11].

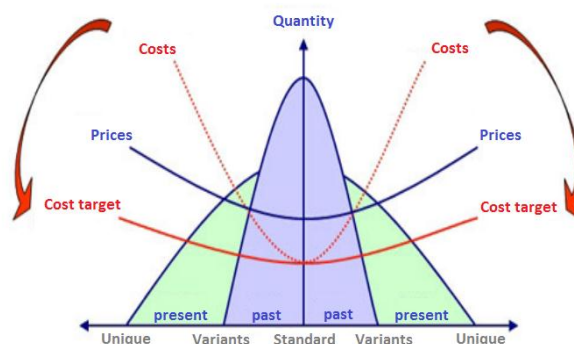


Fig. 3. Cost target: moving variants costs in the direction of standard products costs to be competitive.

As outlined in this section variant management and mastering complexity are the major issues of survival in current competitive situations. The impact on the enterprise cost structure is the key point to consider. Hereby the most important point is to implement the CODP as late as possible in the process chain. The significance of this topic will be outlined in the next section.

IV. PRODUCTION PLANNING FOR MID-RANGE VOLUME PRODUCTS

Many companies are facing a hybrid production situation. Customer requirements are increasingly moving towards individual products and so the total product volume spreads across a growing number of product variants. By analyzing the product range (for example by means of an ABC analysis), characteristics of MTS, MTO and MTA can be found. Few major products with high volume and a well-known standard design are produced to stock. The customer demand for these products is widely stable and predictable. Companies often refer to these products as A-class products. At the other end of scale we can find C-class products characterized by low volume even down to one-of-a-kind. In an ideal situation the customer accepts longer delivery lead times so that the production orders are based on a customer order. Actually products and components are stocked as well, so that C-class products have a disproportionate share of the total inventories of a company. In this paper we are focusing on a third category (that of B-class products), which are characterized by a significant share of the total volume and a customer-driven amount of variants.

Furthermore the customer demands delivery lead times for these products, which are much shorter than the production lead time. Starting the production with the presence of a customer order, it is not possible to meet customers' needs in terms of delivery lead time. Due to the amount of variants it is also not possible to stock products in every different variant economically. Thus, the MTS approach is not feasible as well.

As discussed above we now have a MTA situation for B-class products in which the CODP divides production into two parts. On the one hand there is the customer orientated stage triggered by actual customer orders. And on the other hand there is a stage where components or parts are produced customer anonymously. Typically the CODP is a stocking point. The production lead time downstream the CODP now is shorter than the delivery lead time. Provided that the right parts are present at the stocking point, customer orders can be delivered in time. Activities upstream the CODP have to ensure the availability of the right parts at the intermediate store.

In terms of PPC we now have two stages of production with different objectives.

Downstream the CODP production is customer orientated where the focus is on delivery speed, delivery reliability and flexibility concerning volume and product variants [6]. Not to forget the overall objectives like low price and high quality. The company has to provide flexibility and speed and even be able to respond to demand fluctuations quickly. At the same time inventories have to be low.

Upstream the CODP objectives are to maintain high stock availability and to produce at low costs. To meet these different objectives on both sides of the CODP the company has to find an appropriate combination of PPC strategies for every single stage based on an appropriate set of criteria.

In summary, the main criteria for the selection of a PPS strategy are the ability to deal with numerous variants and with demand fluctuation as well as the support of the customer orientated production. Additional criteria are the transparency of the planning process and ease of use.

Material Requirements Planning (MRP) is very popular and has helped many companies reducing inventory levels and improving customer service level in many cases [7]. It is, however, disadvantageous that there are several parameters for every single variant which have to be determined and kept up to date. In opposite to MRP, CONWIP uses only few parameters for a single production line, regardless of the number of variants.

In short this means that CONWIP requires less effort for data maintenance. In terms of ease of use and transparency, CONWIP has major advantages compared to MRP. The plain CONWIP list of production orders provides an overview "at a glance" and the planning process follows certain easy-to-understand rules. The results are comprehensible to the production control staff.

The first stage, in which components are produced customer anonymously for the intermediate store, is characterized by high volume and few variants. Additionally fluctuations are much smoother than in the second stage. Based on these assumptions ROP is the PPC strategy for the first stage.

Summarized, the combination of CONWIP and ROP planning is appropriate to address the companies' objectives for the PPC of B-class products.

V. CASE STUDY: IMPLEMENTING CONWIP

In this section, focus lies on the case study, in which ROP and CONWIP have been implemented for evaluation in a separated area of a manufacturing plant. The plant is part of a medium-sized manufacturing company operating in the sanitary branch of plastics industry. The motivation of this case study is based on the fact that said company did not incorporate an efficient production planning and control system. Until then, manufacturing planning had been carried out solely by manual methods. This approach may work under certain circumstances, but in order to keep up with competition and increasing demand it became necessary to incorporate an approved and more 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 required type of production. Classical ERP solutions, for example, provide an extensive range of functionality, but are therefore also mostly afflicted with high complexity. However, high complexity was not a desirable objective, so other production strategies had to be assessed as well. In the end, the decision to make use of a hybrid production strategy has been made because of the inherent advantages of such a manufacturing system.

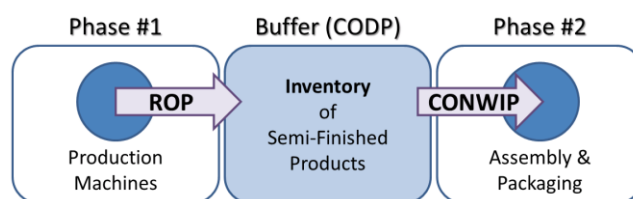


Fig. 4. This schematic drawing depicts the new production process.

Figure 4 illustrates the layout of the new production process. It is inspired by a typical hybrid production approach that is divided into two manufacturing stages.

For the first stage, a typical MTS production system is used. In this stage, raw materials are processed by plastic molding presses, which produce generalized components based on ROP planning. These components are stocked on a buffer, which is an intermediate storage for semi-finished products. The buffer represents the CODP of this whole hybrid system. Using ROP implies that whenever the stock level of the buffer drops below a certain level, production order are automatically created that induce molding presses to produce the missing parts and refill the buffer. It is generally no problem to realize this stage by means of an existing ERP system, which is required anyway. The Infor ERP, which is used at that manufacturing company, supports this approach. The second stage is implemented as a MTO system. Here, CONWIP is used for planning and control. As soon as a customer order is placed, an internal assembly and packaging order is created and then scheduled by a CONWIP planning tool, which might just be an order list as described in the previous section.

For each released order, components are taken from the buffer and a specific variant of the product is constructed. Eventually, the final products are packaged and sent to the customer. Unlike in the first phase, assembly and packaging is initiated only by actual demand, that is, customer orders.

However, difficulties arise from the fact that CONWIP is not a well-known approach to work with. As already mentioned, it was no problem to use the existing Infor ERP system, for ROP-based planning. But as expected, CONWIP was not supported. Because of this, the decision to develop proprietary planning software was made. Details on this software are planned to be published in a subsequent paper.

VI. PROCESSES OF PLANNING SOFTWARE

As seen above, the presence of new production orders represents the starting point in the CONWIP planning process. Basically, customer orders are captured and converted to production orders in the existing ERP system and transferred to the CONWIP software. According to its desired delivery date, every single production order appears in the CONWIP list together with relevant data like amount, required capacity, and availability of materials.

On a weekly basis sums of capacity utilized by the current planning situation are calculated. In order to take planning decisions, these calculated capacity sums are then contrasted with currently provided capacity. If necessary, production orders are allowed to be moved within the WAW. Once the delivery date of an order fulfills relevant criteria, it is acknowledged and its changed target date is transferred back to the ERP system to allow for a notification to the customer.

With CONWIP, production orders should be released as late as possible. On one hand, work stations must not run out of work, provided that production orders are present within the WAW. On the other hand, very late production orders have to be taken into account, which provides a maximum of flexibility.

Status changes, like orders that are released for production, are transferred to the ERP system as well. All further steps until completion of the production order are conducted within the ERP system. Finally, the status change of completed orders is transferred to the CONWIP software again, which moves the respective list item to the area of completed production orders.

VII. CONCLUSION

Companies having a product range with variants are facing an ambitious production situation. Depending on product volume and the number of available variants, characteristics of MTS, MTO and MTA can be found. In this paper it is pointed out that different PPC approaches have to be implemented for every different area to bring together customer requirements and the companies' objectives. Based on an ABC-analysis it is shown that there is a group of B-class products, which consists of numerous product variants and represents a significant share of the total product volume.

The position of the CODP yields a MTA situation. In the customer orientated part of the production, flexibility and speed are essential. Additionally, demand fluctuations are significant. In the customer anonymous part of production the most important point is to reduce costs. Also, ease of use and transparency are considered as an important criterion for selecting a PPC system.

The excursion of aspects of variant management with the look at facets of mastering complexity focuses on crucial theoretical background of variant diversity difficulty to understand the importance of the CODP issue. Due to the broadly outlined mandatory economic reasons the variant creation must take place as late as possible in the production process chain, or in other words, the CODP has to be positioned in the process chain as far back as possible.

The presented combination of CONWIP and ROP is just one approach on how manufacturing companies could achieve ambitious objectives for B-class products. It is able to reduce WIP, but also able to increase flexibility and speed and to deliver numerous product variants demanded by the customer.

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