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Research paper

Shop Floor Planning and Control in Team-based Work Processes

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Abstract

Production planning and control at the level of shop floor operations requires robust methods that are able to cope with variation in processing times, routing sequences, disturbances, resource allocation, et cetera. Nowadays, many organizations have invested in complex and expensive ERP systems, but the applicability of their shop floor control modules still lags behind the required performance and flexibility. Modern production concepts such as Lean Production and Quick Response Manufacturing advocate the use of team-based work processes and simple production control methods to manage the flow of orders at the shop floor. This paper investigates some of the fundamental principles that are behind this type of methods. We start with the concepts of Period Batch Control and Kanban, both of which were developed before the MRP crusade started. Next we will describe some recent developments in the use of shop floor control methods in Lean and Quick Response Manufacturing, such as Polca, M-Conwip, and Work Load Control.

Key words: *Conwip, Kanban, Period Batch Control, Polca, Work Load Control*

1. INTRODUCTION

Companies need to fulfil many requirements from the market in order to add value to the customer and survive in the global competition that they face. We may distinguish processes that focus on developments for future requirements, such as research and innovation, as well as product design and marketing. The second type of processes are generally denoted as the primary processes and focus on delivering products and services for current market requirements. This type of processes consist of sales, purchasing, engineering, order preparation, production, expedition, distribution, invoicing. In order to control these processes and take the required measurements, functions exists that manage quality, safety, cost, and delivery. Finally, there are processes that focus on maintenance and development of the resources, such as finance, human resource development, and maintenance.

All these processes need to be managed and controlled. They should be oriented towards the same direction that the company aims to tae for current and future developments. Planning and control are important managerial tasks in order to manage and control these processes. Planning and control refer to the Plan and Check phases of the Plan-Do-Check-Act circle that is fundamental in most of the modern production concepts, such as Lean production, Six Sigma, and Quick Response Manufacturing. However, we may expect huge differences in the way the various processes are planned and controlled. Some of them may be scheduled in detail, based on information regarding the expected demand, batch size, processing times, setup times, routing, et cetera. Others may just receive information on the scheduled due date, but have to decide during the execution ("Do") what resources to use and how much time to spend on the various tasks. We denote these differences as either an aggregation level difference (planning a combination of tasks instead of single tasks) or abstraction level difference (do not specify beforehand some of the resources, tasks, locations, et cetera). Due to the fierce competition that companies face and the continuing developments in technology and methods, companies have to rethink their choices for planning and control of the various processes periodically. Have they still been designed at the desired aggregation level? Is the abstraction level still correct for the complexity these operations face? Will the level of planning and control be sufficient to achieve the required objectives and synchronization with the other processes within the company?

These questions make clear that planning and control in companies is a very dynamic field that need to be reviewed periodically in order to adapt the system towards the changing environment. The availability of new technology for planning and control (e.g., software, methods) may enlarge the number of options when selecting an appropriate planning and control system, but does not need to dictate the choice. It is therefore wise to review some of the fundamental principles that are behind the planning and control methods in order to find out which approach suits best the requirements of the company.

This paper aims to review some of these fundamental principles by discussing two typical examples of planning and control approaches that have been developed before computerized methods such as MRP and ERP emerged. Section 2 will discuss the concepts of Period Batch Control and Kanban, mainly in the context of team-based work processes, which are fundamental in most of the modern production concepts. Section 3 will explore recent developments in the field of shop floor control methods, such as Polca, M-Conwip, and Work Load Control. Section 4 ends with conclusions and discussion of future research possibilities.

2. FUNDAMENTAL PLANNING AND CONTROL PRINCIPLES

This section discusses some fundamental principles behind planning and control methods. We selected two methods, one for planning and one for control, that have been developed before the well-known computerized planning methods of Material Requirements Planning and Enterprise Resource Planning emerged. Both methods were developed in the context of team-based work processes, such as cellular manufacturing, group technology, team production, et cetera. Period Batch Control and Kanban may not directly be suitable for all processes that we may encounter in a company, but some of the fundamental principles may still be applicable in non-shop floor situations. However, in the remaining part of this paper, we will primarily discuss the methods when applied to planning and controlling shop floor operations, as for this type of operations we noticed rather different directions that the available methods take in order to plan and control the operations.

2.1 **Planning method: Period Batch Control**

Period Batch Control (PBC) was developed by a British consultant, R.J. Gigli, and has been advocated by J. Burbidge (e.g., [1], [2]). PBCs most fabled application is the production control for aircraft during World War II [3]. The alloy that the UK needed to produce extruded aircraft parts was largely imported from overseas. As alloy supply was not reliable, the approximately 5,000 individual parts makers and 48 aircraft manufacturers each placed large orders to make sure that they would be able to deliver. Consequently, total demand could not be met and supplies were distributed unevenly. Whereas some sub-contractors had alloy in stock, others had insufficient raw material.

To face the situation, the government created the Ministry of Supply, which had authority over the allocation of raw material. The first and most important step was to persuade the manufacturers and sub-contractors to declare the material stocks they already had and to prepare master parts lists of all details of extrusion in every type of aircraft being made. On calculation strips the quantities of each craft for the month were set out and then extended against the master list, and the total quantities were entered against the manufacturers and sub-contractors to receive them.

It took much persuasion and much hard work, but in a short time a Period Batch System was working well, based on the Air Ministry's monthly list of aircraft required.

A one-month cycle was strictly maintained according to a predetermined procedure. Later supplementary allowances were arranged on a daily basis to repair planes.

Period Batch Control is a cyclical planning system. It operates with fixed cycles (periods) during which the parts are produced that are required in a succeeding period in the next stage. In this way it coordinates the various stages of transformation that are required in order to fulfil the demand of the customers. Effective coordination of the supply chain makes it possible to avoid or reduce decoupling stocks or other types of inefficiencies between successive steps in the transformation processes.

PBC differs from other planning systems in the way it accomplishes this coordination, and more specifically, in the three principles it applies in configuring the planning system: single cycle ordering, single phasing, and single offset timing [4].

Single cycle ordering refers to the frequency of releasing work orders. Each part has the same ordering frequency as its parent product.

Single phasing refers to the release moment of work orders. Work orders are released to the production system at the same moment (defined as the start of a period).

Single offset timing refers to the lead time of work orders (per stage). All work orders have identical lead times per stage. As the number of stages per work order may differ, total lead times may vary, but in a predetermined way.

The combination of the latter two principles leads to work orders in the production system having all both identical release dates and identical due dates per stage. The time available for completion of a work order, the offset time, is equal to the period length. In order to obtain the required amount of an end product, often several transformation processes are involved in sequence. Subsets of these processes may be combined into a work order for the same stage, which means that these processes will be performed during the same time period. Activities that can be performed in parallel generate extra work orders for the stage.

PBC aims at short throughput times as well as effective coordination of the stages in the process. Now if we look at the fundamental principles of this planning method, then we observe that the lot sizing decision (how many items are included in a single work order) is a result of the choice of period length and is synchronized for different product levels. Longer periods would cause larger batch sizes. The choice of period length causes synchronization amongst the various levels of a product, i.e. components, sub-assemblies, final products. This is a very fundamental

principle in echelon inventory management and lean manufacturing. The lot-for-lot rule may be extended to a power-of-two rule ([5]), but this will cause waste in the system, as the system needs storage space for items that are not needed during an entire period. The PBC system will avoid this type of inventory stock-keeping and focus on time-phased ordering in the right quantities. Other planning methods, such as MRP, allow for economic order quantities at every product level, which is clearly suboptimal from the perspective of echelon inventory management. Synchronized production will eliminate this type of waste and have everyone focus on the same tact time of the system. The principle of synchronization is advocated in various modern systems, such as Lean [6], Drum-Buffer-Rope (Optimized Production Technology (OPT) or Theory of Constraints (TOC) [7], [8], Period Batch Control [9], [10], and Quick Response Manufacturing (QRM) [11], [12].

A second fundamental principle of the PBC method is to focus on an aggregation level that suits the organization of work processes. Most computerized planning systems model the operations at the highest level of detail, i.e. at the task level. This puts an enormous pressure on the quality of data and maintenance of this data within the company. PBC suggests modelling it at the correct level of organization within the stages, i.e. at the team level. The planning system does not need to prescribe who will work at the various tasks and when they have to start within a period, it suffices to know that there will be enough capacity at the team level to accomplish all tasks that are scheduled within this period. See [13] for more details.

Finally, the PBC system directs the attention of the planning towards the main trade-off that the company has to make: external performance (time, quality) versus internal (efficiency). All activities are directed towards completing them within the end-of-period due date, but during the period itself, teams may address quality and efficiency-related issues. However, if the activities have not been completed within the period, the manager has to be informed in order to coordinate the remaining activities and identify the root cause of not finishing within time. This is a very effective way of assuring that the balance between external and internal performance objectives is maintained.

2.2 Control method: Kanban

The other method that we examine to identify some additional fundamental principles is Kanban. The paper of Sugimori et al. [14] on the Toyota Production System presented a fundamentally different way of organizing production logistics as Western companies did during the seventies. Many Western companies relied on the new technological developments in IT and implemented MRP systems. Sugimori et al. criticized the lack of respect for human in production organizations controlled by computerized planning. They stated: "It is not a conveyer that operates men, while it is men that operate a conveyer, which is the first step to respect for human independence" [14:559]. In the Kanban system, control decisions are delegated to foremen and workers, instead of centralized in a control department.

Their choice for a different approach and no involvement of computers in the Kanban system are motivated as follows: (1) Reduction of cost processing information. (2) Rapid and precise acquisition of facts. (3) Limiting surplus capacity of preceding shops. This shows that the first fundamental principle of Kanban is "respect for human". The persons who are to be supported using planning and control methods should still be in charge of these methods and understand as well as trust the outcomes. They will decide on the number of kanbans and modify this number if required. Only then the system will be used, adapt itself to changing circumstances, and will provide real support.

The Kanban system chooses to use small transfer batches, resulting in a small variance of order sizes and processing time. An irregular loading of the production system would result in more complex planning or additional capacity. Hence, small transfer batches result in less waste, although they make it necessary to setup the equipment more frequently. Investments are therefore directed to improving the production system in order to produce with less waste instead of enabling the control system to cope with all complex issues related to a non-optimized production organization. This is the second fundamental principle that we also encounter in PBC, OPT and QRM. Optimization should be directed towards standardizing, simplifying, and optimizing the production system itself, as this is a more fundamental and robust approach than investing in managing high variety that could have been avoided or eliminated. Otherwise, coordination costs will be too high in the long term.

Table 1. Fundamental principles of planning and control

1	Synchronization of all processes in organization
2	Aggregation level of planning fits work organization
3	Balance external and internal performance requirements
4	Respect for human
5	Optimize the processes before attempting to control
6	Visual management
7	Chaining
8	Discipline and Division of Authority

A third fundamental principle of Kanban is visual management. In order to direct the behaviour of people in the overall desired direction (i.e., timely delivery), a control system should provide visual clues and easily interpretable information on what to do. Kanban and other tools implemented at Toyota, such as Andon, strongly emphasis the value of visual feedbacks at the shop floor, which directs the behaviour of people.

A fourth fundamental principle of Kanban is chaining, i.e., the connection of production steps. PBC uses a similar approach, but at a higher level (stages), while Kanban implements this at a more detailed level (production tasks). However, the principle remains the same: avoid sub-optimization by connecting a chain towards the final customer. Polca and the drum-buffer-rope concept apply the same type of principle.

A final fundamental principle of Kanban is discipline and division of authority. A planning and control system will only be effective if its outcomes are respected and followed by all stakeholders in the system. If the CEO of the company does interfere with the outcomes of the system and does not respect the authority of the operator who uses a Kanban system, the Kanban system will never be effective. The same holds true for operators who do not give priority to the products that – according to the Kanban system- need to be produced.

The fundamental principles that we discovered when discussing PBC and Kanban are listed in Table 1.

3. RECENT DEVELOPMENTS IN SHOP FLOOR CONTROL

This section will explore recent developments in the field of shop floor control methods. Most of these developments aim to address typical issues discussed in the Introduction section, such as variability in processing times and routing. The key principles of section 2 have been developed and applied in relatively stable production environments, such as the automotive industry. In order to make these principles applicable in other industries with different types of variability, some of the methods need to be modified. This section discusses three methods that may be applied in the context of team-based work processes: Polca, M-Conwip, and Work Load Control. All three methods focus on control instead of planning. The reason is that for PBC applications in less stable areas have been described, see e.g., [1], [2].

3.1 Polca

Polca is an acronym for Paired-cell Overlapping Loops of Cards with Authorization [15]. It is a material control system that authorizes the flow of orders at the shop floor [16]. Polca controls the flow of work between cells. The main problem of planning in such cellular systems is related to insufficient synchronization of the processes between these cells. At the same time, another cell might face a lack of work to be done, which we denote as unbalance. Polca not only aims to increase the speed of job transfer between cells, but also to reduce these unbalances in the system. In order to achieve this, it uses chaining between subsequent segments of the job routing. Polca uses visual signals (cards) to authorize the progress of an order. Hence, we see that Polca uses many of the fundamental principles that we discussed in Table 1.

Polca not only operates at the shop floor itself, but does also decide on the release of orders to the shop floor. It affects the timing of release. The decisions when and what to release to the shop floor have both a high impact on shop floor throughput time and delivery performance [17]. If jobs are released too early, they often wait a long time on the shop floor before being completed. This enables the shop floor employees to allow low-priority orders to be produced before high-priority orders. This behaviour will lead to a higher standard deviation of lateness, with possibly negative effects on due date performance. By limiting the amount of work on the shop floor and regulating the inflow of work, Polca aims to achieve short and stable throughput times.

The Polca system is a replacement for the Kanban system in production situations with a large variety in routings. The authorization signals (cards) are namely not specific for a single product (as is the case in Kanban, but may be used for any product that has to visit the two production cells in the specified sequence. The cards manage the amount of work in progress in this loop and many others, which causes a balance in work load in the overall system.

3.2 M-Conwip

M-Conwip is an extension of the single Conwip system as described by [18]. Conwip aims at a constant level of work-in-progress at the shop floor. Whenever a job leaves the shop floor, a new job may enter. This type of system can be very effective, as it both controls the release of new jobs and the throughput time of existing jobs. However, one of the main drawbacks of Conwip is the lack of work order balancing capability ([17], [19]). Simple extension of the Conwip system is to introduce Conwip loops for every different routing that may be encountered, even if these loops partially visit the same resources. In two large simulation studies, we showed that the M-Conwip system outperforms the single Conwip system as well as the Polca system in terms of throughput time performance. However, the cost of implementing a loop for every possible routing, even the very rare routings that sometimes have to be used, may be extensive. Hence, a more robust approach of Polca, which is able to construct even these rare routings based on simple chains of two cells or teams may be preferred.

M-Conwip is also a replacement of the Kanban system in situations where processing times vary and multiple routings occur. A Kanban system would not be able to cope with this variety, while an M-Conwip system will. Still it is based on the same fundamental principles.

3.3 Work Load Control

The last system that we describe is not that recent, as the first publications on Work Load Control stem back from the input-output control literature in MRP systems [20]. However, some recent developments (i.e., [21], [22]) may make it a very attractive approach, especially if combined with a visual management approach as developed in Lean and Quick Response Manufacturing. Work Load Control (WLC) aims to control the release of work load instead of work orders. If the total work load for a single team (as estimated beforehand) is larger than a specific norm, no new work is being released if it has to visit this team at the shop floor.

The WLC system requires an up-to-date information flow to the release decision maker if teams have finished working at a work order, even if the order is not yet complete. The WLC system does not use visual signals to guide the flow of orders. It focuses on the

planner/controller as decision maker. Hence, the system doesn't apply all fundamental principles of our Table 1. However, if the variation in processing times increases, WLC might be better suited to decide on the release of new jobs to the shop floor than systems such as Kanban, Polca, or M-Conwip.

4. CONCLUSION AND FUTURE RESEARCH

This paper has examined some fundamental principles that are behind planning and control methods for team-based work processes. Two approaches that have specifically been designed to accommodate team-based work processes in production were examined, namely Period Batch Control and Kanban.

The Period Batch Control method focuses on synchronization and balancing the external and internal performance measures a company has to aim for. It aggregates the planning decision to the allocation of a set of tasks (possibly of a single team) for a work order to one or more periods of time. By effectively planning the successive activities, PBC avoids waste of intermediate stocking of inventory during a whole period of time. The PBC system aims for a simple, easy to use method that may also be applied to other processes in an organization, such as new business development. In fact, popular approaches such as the Stage-Gate approach ([23]) use important elements of the PBC approach. However, more research needs to be done in order to make PBC a suitable planning approach in other processes, or even in other fields, like health care and maintenance services.

The Kanban system focuses on simple visual control and very short feedback loops between successive stages of production. It is based on the respect-for-human principle, which sees human operators (or teams of employees) as the entity responsible for maintaining the planning and control system. Hence they should be able to modify it according the changing circumstances in their work place. Another fundamental principle of Kanban is to optimize the system before implementing a control system. However, in the philosophy of modern manufacturing systems, optimization is not a one-time exercise, but a continuous process. Hence, control systems need to change accordingly over time. It is a fundamental principle that planning and control systems should accommodate such a continuous improvement process instead of hindering it.

Kanban systems also introduced chaining and visual management in shop floor control. These principles have a huge impact on the behaviour of people working with these systems, as it continuously signals - clearly visible for everyone in the factory- what action is required. This helps people to work according to the right priorities.

Finally, Kanban systems cannot operate without discipline and respect for the division of authority. Responsibilities should be put there where action can be taken. Planning and control are there to support the employees to accomplish their tasks, and discipline is required from them as well as from every other internal stakeholder in the company.

In order to make Kanban systems and their underlying principles applicable in other industries than the automotive, modifications have been suggested that resulted in different systems, such as Polca, Conwip, M-Conwip. Some of these developments make the principles applicable in industries that face a lot more variability such as processing time variability and routing variability. However, more research is needed, as the type of variability faced by industry is much larger and will make it possible to develop other alternative control methods for these situations.

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Planiranje i upravljanje proizvodnom jedinicom primenom procesa timski zasnovanog rada

Jan Riezebos

Rezime:

Planiranje i upravljanje proizvodnjom na nivou proizvodnih operacija u radnim jedinicama zahteva robusne metode koje omogućavaju izbor varijante vremena izrade, redosleda operacija, poremećaja, alokacije resursa i slično. Danas, mnoge organizacije investiraju u složene i skupe ERP sisteme, ali primenljivost njihovih modula na nivou upravljanja pogonom još uvek zaostaje za potrebama obezbeđenja performnsi i fleksibilnosti. Savremeni koncepti proizvodnje kao što su Lean proizvodnja i QRM preporučuju korišćenje procesa timskog rada i jednostavne metode upravljanja proizvodnjom kako bi se uspešno upravljalo radnim nalozima na nivou pogona. Ovaj članak istražuje neke osnovne principe koji su sadržani u datim metodama. Početak istraživanja se odnosi na koncept Upravljanje periodičnim serijama (PBC) i Kanban koje su razvijene pre MRP sistema. Sledeći korak je opis skorašnjih istraživanja upotrebe metada upravljanja progonom Lean prilazu i QRM prilazu u kome su razvijene metode Polca, M-Conwip i Work Load Control.

Ključne reči: *Conwip, Kanban, PBC, Polca Work Load Control*