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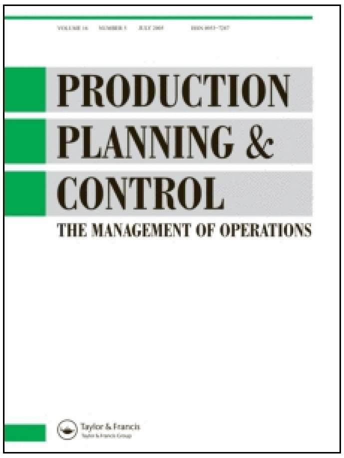

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A lean production control system for high-variety/low-volume environments: a case study implementation

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A lean production control system for high-variety/low-volume environments: a case study implementation

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Due to the success of lean manufacturing, many companies are interested in implementing a lean production control system. Lean production control principles include the levelling of production, the use of pull mechanisms and takt time control. These principles have mainly been applied in high volume flow shop environments where orders move through the production system in one direction in a limited number of identifiable routing sequences. This article investigates how lean production control principles can be used in a make-to-order job shop, where volume is typically low and there is high variety. We show how production levelling, constant work in process, first in first out and takt time can be integrated in a lean production control system. A case study is presented to illustrate the design and phased implementation of the system in a typical dual resource constrained production environment. The case study demonstrates that lean production control principles can be successfully implemented in a high-variety/low-volume context. Implementation led to a reduction in flow times and an increase in the service level achieved, with on-time delivery performance improving from 55 to 80%.

Keywords: lean manufacturing; make-to-order (MTO); CONWIP; takt time; job shop

1. Introduction

In today's marketplace, there is an increasing demand for customised products. As a result there has been large growth in the number of companies that choose to operate on a make-to-order (MTO) basis (Stevenson *et al*. 2005). Following an MTO strategy, production is not started until a customer order is received. This strategy allows firms to produce a high variety of products in small quantities. The globalisation and intense competitiveness of the current marketplace forces MTO companies to reduce flow times, improve quality and reduce the costs of their products in order to survive.

Production planning and control (PPC) concepts are important tools for realising increasingly high customer demands and expectations (Stevenson *et al*. 2005). A popular way of improving the performance of a production system is through the implementation of lean production control principles. Three lean production control principles that have shown to be successful in identifying and eliminating unnecessary sources of variability are (i) production levelling, (ii) pull mechanisms and (iii) takt time control. Production levelling reduces the input variability of the production system and is an important requisite for gaining a stable and constant flow of material on the shop floor. The key to the effectiveness of pull mechanisms is that they explicitly limit the amount of work in process that can be in the system (Hopp and Spearman 2004); this is typically supported by the use of production signals such as Kanbans. Takt time control sets a fixed production pace equal to the rate of customer demand.

Empirical literature reports significantly more implementations of these lean production control principles in make-to-stock (MTS) flow shops than in MTO job shop environments (White and Prybutok 2001). White and Prybutok (2001) explain this by noting that lean was designed in and has its roots in a repetitive MTS production system, i.e. the Toyota production system (TPS). Production levelling and the Kanban pull system – two important components of the TPS – were specifically designed for repetitive production environments. Literature discussing the integration and implementation of new (lean) production control principles in MTO companies are still few and far between.

This article intends to make a contribution towards filling this gap in the literature by demonstrating the

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applicability and appropriateness of a lean production control system for a dual resource constrained MTO job shop. The lean production control system discussed in this article integrates production levelling, constant work in process (CONWIP) and takt control principles. The system facilitates a clear distinction between the responsibilities of the various actors involved in production control. It does not require any advanced decision support. As Muda and Hendry (2002) note, small companies prefer simple solutions for their control problems, not requiring more than spreadsheet support.

The case study presented in this article concerns a relatively independent production unit in the part manufacturing department of a large company. In isolation, the production unit can be seen as a typical small MTO job shop. The unit, consisting of several types of machines, produces a large variety of part types in small batches. Each part type has its own routing through the production unit. The case study provides rich insights into the problems many MTO companies face in planning and controlling the flow of materials on the shop floor. Furthermore, our study indicates how MTO companies can deal with the complex task of implementing lean control principles in order to improve the performance of their production systems.

The central research question of the article is: how can principles of lean thinking be applied to a high-variety/low-volume environment? More specifically:

(i) How can a pull mechanism, controlled by takt time, be effectively applied in a high-variety/low-volume environment?
(ii) How can production levelling be effectively applied in a high-variety/low-volume environment?

The remainder of the article is organised as follows. Section 2 presents the theoretical foundations of the lean production control system implemented in the case study company. It reviews the literature on pull and takt time control principles and discusses the applicability of these principles to an MTO job shop environment. Section 3 describes the case study company and the problems initially encountered. Section 4 focuses on the first research question and shows how a pull system controlled by takt time has been implemented. Section 5 is devoted to the second research question and shows how system stability is gained by means of production load levelling. Section 6 evaluates the implemented lean production control system before, finally, Section 7 concludes by summarising the main results of the study.

2. Theoretical background

The applicability of production control principles depends on the characteristics of the production environment. In this article, we focus on the applicability of lean production control principles to dual resource constrained (DRC) job shops, which are characterised by highly variable demand, large product variety, low volumes and variable order processing times. In such an environment, neither the original Toyota Kanban pull system nor the pure takt time control principle is considered to be appropriate (Suri and Krishnamurthy 2003).

Since the introduction of the TPS, new pull systems such as CONWIP (Spearman *et al.* 1990) and paired-cell overlapping loops of cards with authorisation (POLCA; Suri 1998) have been developed which have greater applicability to an MTO environment than Kanban. Similar to the Kanban system, CONWIP and POLCA use cards to constrain the number of orders on the shop floor. However, in the CONWIP and POLCA systems, cards are not specific to any order and stay with an order through more than one stage in the production process.

In many ways, the CONWIP system is the simplest card-based pull system to implement and to control. In a CONWIP system, an order may only enter the shop floor if a free card can be attached to it. Upon completion, the order leaves the shop floor to fulfil customer demand while the attached card is placed in a card box, where it waits until it is attached to another order in the order book. In this system, a card stays with an order throughout its time on the shop floor; each time an order leaves the shop floor the order book receives a signal to authorise the release of a new order. Because no order can enter the shop floor without a card attached to it, the number of orders on the shop floor is limited by the number of cards circulating on the shop floor and in the card box.

The effective use of CONWIP requires an order release mechanism, which takes the workload on the shop floor into account. Substantial research has been conducted in the area of workload control (WLC), which is focused on releasing orders in such a way that a balanced load is realised on the shop floor and due dates can be met; see Stevenson and Hendry (2006) for a concise overview of WLC systems. In the CONWIP context, as described above, the release mechanism is responsible for production levelling to reduce the load variability on the shop floor.

Most MTO job shops can be characterised as DRC systems where both workers and machines are constraining factors with respect to the flow times of orders. A DRC job shop usually has fewer workers

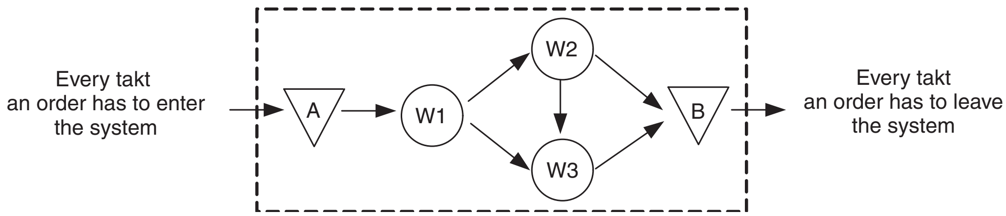

Figure 1. Illustration of generalised takt time control.

than machines. Therefore, the throughput of the DRC production system is mainly determined by the capacity and capabilities of the labour force. The capacity of machines plays a less important role, unless particular machines are overloaded. If workers are multi-skilled and flexible (Bokhorst and Slomp 2007) and the allowed lead times are sufficient, then a simple release mechanism for production levelling, which only focuses on the load of workers, may be sufficient in order to create a balanced workload on the shop floor.

Takt time is a concept predominantly used in final assembly production to accomplish levelled production throughout the factory (see e.g. Linck and Cochran 1999, Miltenburg 2001). The following equation defines takt time:

$$\text{Takt time} = \frac{\text{Available production time}}{\text{Customer demand (i.e. current backlog of orders)}} \quad (1)$$

The takt time gives the ideal pace of production to which workstations in a flow shop need to be balanced, in order to minimise inventory build ups and keep up with customer demand. 'Takt-paced' production can improve control over the production system and make it more predictable. Given that the approach fixes the pace of production, the system flow time of an order can be determined using Little's law:

$$\text{Flow time} = \frac{\text{Work in process}}{\text{Throughput}} = \text{Takt time} \times \text{Work in process} \quad (2)$$

In a job shop, multiple products with different customer demand rates and requiring different operations are produced in the same production system. This makes the implementation of pure takt time control rather complicated. But takt time control can be applied in such an environment by seeing the whole (or parts of the) production system as a production unit and requiring that orders arrive and leave the unit according to the takt time, in a first in first out (FIFO) sequence. We refer to this type of control as generalised takt time control. Figure 1 shows a small job shop consisting of workstations W_1, W_2 and W_3. For example, under generalised takt time control, illustrated in Figure 1, an order has to arrive at Buffer A and another order has to depart from Buffer B each takt.

Using generalised takt time control, the flow time of each order in the production unit is theoretically constant and can be determined by Equation (2). An important benefit of this takt time control principle in a DRC job shop is that it applies pressure to reduce the variability in the production system caused by worker preferences in assignment decisions. Generalised takt time control gives workers an incentive to work on the right order at the right time. We argue that this can have a positive effect on motivation by giving workers a clear performance target, namely realising takt time, which can be readily influenced by the workers.

3. The case study

Following the review, this article seeks to implement a lean production control system based on production levelling, CONWIP and takt control principles in a production unit of 'General Supplies'. General Supplies is an internal supplier to a company that develops, produces and sells electrical power distribution and control equipment for industrial, commercial and residual markets. The product range of the company consists of a wide variety of medium and low-voltage switchgear systems and switchgear components. The company comprises of five departments: Medium Voltage Systems, Low Voltage Systems, Low Voltage Components, Service and General Supplies. Low Voltage Components and General Supplies produce the components for the assembly lines of Medium and Low Voltage Systems. The Service department deals with the after sales service.

The components and semi-manufactured products of General Supplies are made from a wide range of metals, including steel, copper and aluminium. Based on product characteristics, General Supplies is divided into three independent production units: sheet metal, turning and milling, and copper bars. Each production unit has its own performance targets and its own PPC system to realise these targets. The production unit

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considered in our case study is the copper bars production unit, hereafter referred to as CB unit. We have focused on CB unit because its production environment combines all of the characteristics that are interesting for our research purposes. The production situation of CB unit can be seen as a typical MTO job shop, with a high variety of different part types, low volumes and small lot sizes, and a great variety in routings. Furthermore, CB unit is a DRC system.

The project team responsible for the introduction of lean production control principles to CB unit consisted of the logistics manager of General Supplies, the coordinator of CB unit and a production planner. Research students, undertaking projects in the firm, were highly involved and supported the introduction of the new lean production control system. The authors of this article were regularly consulted by the project team and/or research students and supported the project by generating ideas, doing simulation studies and creating a game based on computer animation (later described in Section 4.1). From the above it follows that some elements of the project have the characteristics of action research.

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3.1. *Description of the company*

CB unit produces a wide variety of conductor components for the assembly lines of low and medium voltage systems. A large proportion of the components are custom designed and fabricated. The components are made from large copper bars (also called copper strips), which can have different thicknesses. Due to customisation requirements, orders for copper bars can have very different demands within the production unit. The following operations take place within the production unit: punching, trimming, bending, drilling, milling and bench work. Figure 2 illustrates the position of the CB unit in the order flow. All operations, except punching, are grouped under the heading ‘strip manufacturing’.

The first operation in the routing of an order is always punching. Orders that require the same thickness of copper bars are nested on the same (type of) copper bar and are punched as one order to reduce copper waste and setup time. After the copper bars are punched, the routing of the orders through the subsequent operations can differ from order to order. Within the strip manufacturing part of CB unit, orders can start and finish at any operation, allowing complete freedom and customisation. However, the dominant flow within CB Unit is: punching → trimming → bending → drilling and/or milling → bench work. The shop floor configuration of CB unit can therefore be classified as a general job shop (Stevenson *et al.* 2005).

Some orders need an operation which takes place outside of CB unit. For example, some orders need a surface treatment, and this is undertaken by another company. External operations are often the last operation, so once they are completed, most orders are dispatched to the customer, but some have to return to CB unit for another operation; this re-entrance flow complicates the PPC of CB unit significantly.

In total 15–18 workers are working in CB unit, divided into a morning and an evening shift. Since there are more positions where workers can perform their tasks than there are workers available during any period in time, CB unit can be characterised as a DRC job shop.

CB unit receives three types of orders: material requirements planning (MRP), Kanban and project requirements planning (PRP) orders. MRP orders are for standard components, which are scheduled by a MRP system (Vollmann *et al.* 1997). Safety stock held by the customer provides the opportunity to balance the load over time. Kanban orders are also orders for standard components, but these components are ordered in a more repetitive manner by the assembly lines and are replenished using a Kanban system (Sugimori *et al.* 1977). Lead times for Kanban orders are short. PRP orders are for components for customer

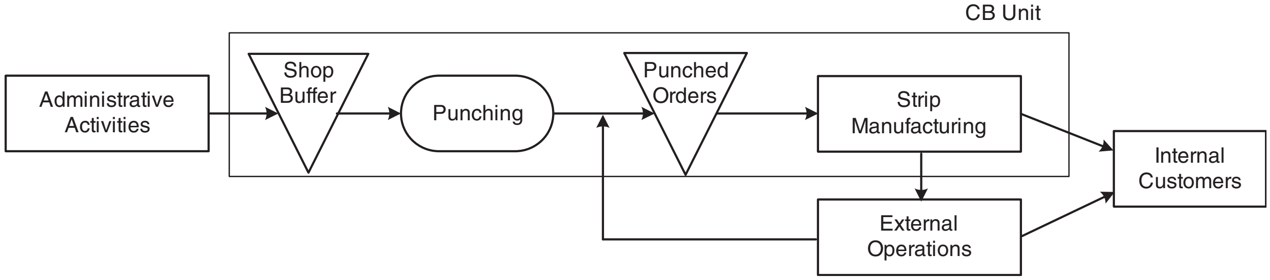

Figure 2. Schematic overview of the order flow of copper bars.

specific projects. These components may or may not have short delivery times. On average 40% of the orders are MRP, 35% are Kanban and 25% are PRP.

The production control mechanism currently used in CB unit can be characterised as 'push' because there is no explicit limit on the amount of work in process that is released to the shop floor. On the shop floor, CB unit tries to meet the promised lead times by means of a priority system that is meant to control the flow times of orders. The priority of orders ranges from rush orders (highest priority) to normal orders (lowest priority). If an order is behind schedule, its priority is increased by the planner until it is back on schedule. This means that orders are continually expedited and 'de-expedited' to satisfy customer demand on time.

3.2. *Problem description*

Both flow times and service levels are of strategic importance for CB unit. The performance target for CB unit is to realise an administrative flow time of 2 days, a production flow time of 3.5 days and a service level (i.e. orders delivered within promised lead time or by desired date) of 95%. Figure 3 shows how the administrative and production flow time are measured in CB unit. The figure shows that the time an order spends waiting before the first operation starts (i.e. punching) and the processing time of the punching operation are included in the administrative flow time. This is because the time when the administrative activities associated with an order are finished is not registered; only the time when an operation at one of the machines in the production unit is finished is recorded.

Prior to the project (i.e. before June 2007) none of the performance targets were realised: the average administrative flow time was 5.9 days, the average production flow time was 4.2 days and the service level was 55%. The flow times of the orders were also highly unpredictable, which made it difficult to quote reliable due dates to customers. This had a negative influence on the service level.

The long and unpredictable flow times were mainly caused by inefficiencies and poor control over the production system. With respect to production control, the push system caused high levels of work in process (WIP), which fluctuated greatly throughout the year. Also, the priority system did not work very well. Because of the large percentage of rush orders, it was unclear to the workers which of the rush orders were most important. Moreover, the expediting and de-expediting of orders resulted in increased variability in the system, inflated flow times and reduced the service level of orders. Next and related to these problems, according to management, the flexibility and motivation of the workers was low. Workers tended to remain at their 'own' machines if work was available irrespective of its priority; they were not focused on realising due dates. Also, workers tended to postpone less attractive bench work operations. There was also a feeling that the efficiency of the workers was far from optimal: too much time was spent on searching for orders.

To summarise, the main problem of the firm was: how can short and reliable flow times be realised? Our research questions, presented in Section 1, closely align with the objective of the firm to shorten and stabilise the flow times of orders, thereby improving the service level.

4. CONWIP/FIFO/takt time control of strip manufacturing

The implementation of the lean production control system started with the CONWIP/FIFO/takt time control system for strip manufacturing. In the proposed lean production control system, the amount of WIP in strip manufacturing is controlled by means of CONWIP combined with the generalised takt time control principle. According to the CONWIP principle, each order that enters strip manufacturing has a card

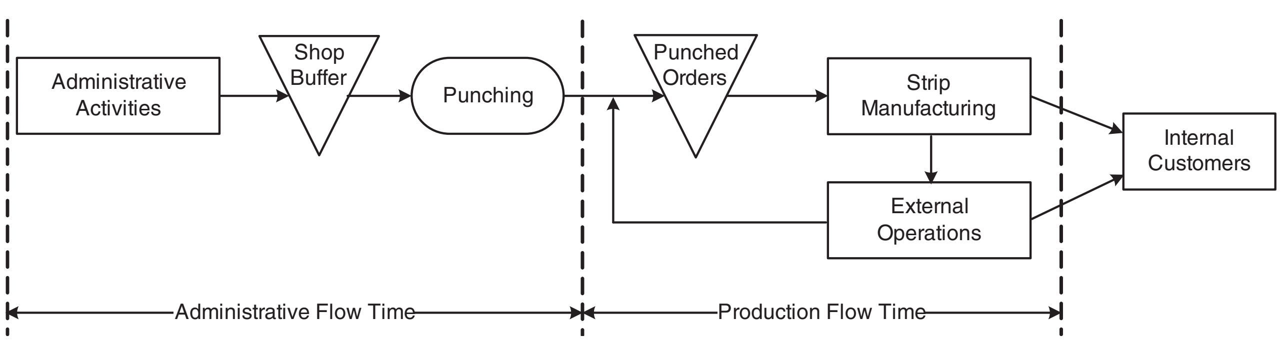

Figure 3. Administrative and production flow time of copper bar orders.

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attached to it. A card can only be connected to another order after a takt is finished and an order has departed strip manufacturing. Since the sequence of orders leaving strip manufacturing should be on a FIFO basis, the flow time of each order in strip manufacturing equals 'WIP $\times$ takt time'. The team of workers has to take care to ensure that orders are able to leave strip manufacturing in FIFO sequence and in takt. This governs priority dispatching on the shop floor.

Another characteristic of the system is that the amount of WIP needs to be larger than the number of active resources in the system. Within a traditional takt time controlled assembly line, the amount of WIP is fixed and equals the number of stations. Each station in the line contains one order that is transferred to the next station after each takt. With the generalised takt control principle, however, the fixed level of WIP needs to be larger than the number of active resources (workers) in the system. This is needed in order to deal with processing time and routing variability.

Since the proposed control system for strip manufacturing was quite different from the practices previously in use, management opted for a phased implementation. Furthermore, since not everyone involved fully understood the proposed system – it was met with some scepticism from supervisors and planners – we developed a game to give an insight into the basic workings of the system. The game will be briefly described in Section 4.1. Section 4.2 presents the different implementation phases and some initial results.

4.1. *User acceptance and training: gaming based on computer animation*

In order to gain the acceptance of supervisors and planners, we developed a game/animation in the object-oriented simulation software package Tecnomatix Plant Simulation 7.6 (Texas: UGS Corporation) to demonstrate the value of CONWIP/FIFO/takt time control. We organised a session with supervisors and planners to play the game. The aim was to give insights into the basic workings of the system and to convince the people involved that the lean production control system works in the high-variety/low-volume environment of strip manufacturing. The animation used real production data of orders (routing and processing time information) and was depicted on a large screen. The 'players' needed to dynamically decide which orders to work on to deliver the right order each takt and the simulation showed the outcomes of these decisions over time. If the takt time was exceeded, we looked at the causes together (e.g. a worker who continued processing orders at his/her machine instead of moving to an older, more urgent order at another machine) and discussed possible solutions.

The animation/game had a positive effect on the acceptance of the CONWIP/FIFO/takt time control proposal. So far the game had only been used with supervisors and planners but at the end of the game, management suggested that the game be used for the shop floor workers of strip manufacturing as well. We suggested an implementation plan consisting of three phases, which was developed in such a way that workers be gradually introduced to the new control system. We decided to play the game with workers only in the case that it was felt that training was required; ultimately this was not considered to be necessary.

4.2. *Phased implementation and initial results*

The three defined phases for the implementation of the CONWIP/FIFO/takt time control system were chosen such that each phase would show certain performance advantages. Furthermore, the phased implementation would help workers to gradually learn the features of the system. We named the three phases after the element of the control system added in that phase: 1 – CONWIP phase, 2 – FIFO phase, 3 – Takt phase.

4.2.1. *The CONWIP phase*

Before the implementation started, the current situation (base situation) at CB unit was recorded. Starting from the base situation, the first phase involved creating a CONWIP system with an acceptable, but limited, level of WIP in strip manufacturing. Starting from an initial situation of about 150 orders in progress, the research team involved in the project gradually reduced this number in the first phase. Each order received a unique number and a card; after an order was finished, the card was free to be used for a new order. Workers were informed not to start with a new order, but to proceed with current orders already in the system. Free cards that were not used for a new order indicated the possibility to reduce WIP. Finally, it was decided that 60 orders in progress, about 1 day's worth of work, would give workers sufficient overview and opportunities to continue with their work. This much lower level of WIP, compared to the previous situation, has reduced the flow time in strip manufacturing significantly from about 4.2 days to about 1 day. It has to be noted that this did not reduce the overall flow time of orders in CB unit. The saving of flow time has simply been moved to a pool delay. Workers, as well as supervisors, however, preferred the new

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situation and noted several advantages, such as a better overview of the situation and less time spent trying to find urgent orders.

4.2.2. *The FIFO phase*

In the second phase, FIFO was introduced. This phase required the team of workers to focus on the oldest orders in strip manufacturing, since orders now needed to depart strip manufacturing in order of arrival. The reason why this was introduced is that it gives a clear priority to orders. Workers are stimulated to work on the right orders; they cannot ignore tedious or difficult orders anymore, which was one of the causes of poor delivery performance in the previous situation (and which could still be a cause in the CONWIP phase). Only when the oldest order in strip manufacturing is finished is a new order allowed to enter. This restriction reduced the likelihood of an order that needs to be finished urgently still being in-process within strip manufacturing while all the operations of a less urgent order are finished and able to leave the system. The constant amount of WIP determined in the first phase is the maximum amount of WIP in the system starting from the FIFO phase. In order to support the FIFO phase, we developed a 'production progress screen', see Figure 4, which indicates the sequence in which the orders should leave the system. The screen was initially programmed in Excel and Visio Basic but the screen was later re-programmed in html so it could be linked with the firm's BAAN ERP system. Workers have to enter start and finish times of orders into a computer. The screen then shows all numbers/cards linked to orders and the time that the orders have been in the system. Workers and supervisors responded well to the screen and found it helpful for prioritising orders. The variability of flow times reduced significantly at this phase.

4.2.3. *The takt phase*

In the takt phase, orders need to leave strip manufacturing in order and in takt. In the case of strip manufacturing, the takt time was 20 min (in the period of implementation). Therefore, according to the takt time rule, an order had to be ready to leave strip manufacturing every 20 min, and in FIFO sequence. The passing of the takt time before a new order can be released in the system is an additional restriction compared to the situation in the FIFO phase. As a consequence, the total time that an order spends in the system would ideally be equal to WIP x takt (or 60 $\times$ 20 min = 20 h). These fixed flow times of orders support supervisors and workers in controlling the timely flow of orders through the system. Note that in Figure 4, only 57 orders are in strip manufacturing, which simplifies the realisation of short flow times.

The production progress screen was used to indicate late orders. These orders were marked red (highlighted in Figure 4). In the figure, we see that five orders are late. When finishing a late order, the worker who performed the last operation is asked to give a reason for the order being late. For this purpose, the team of workers identified 10 possible reasons.

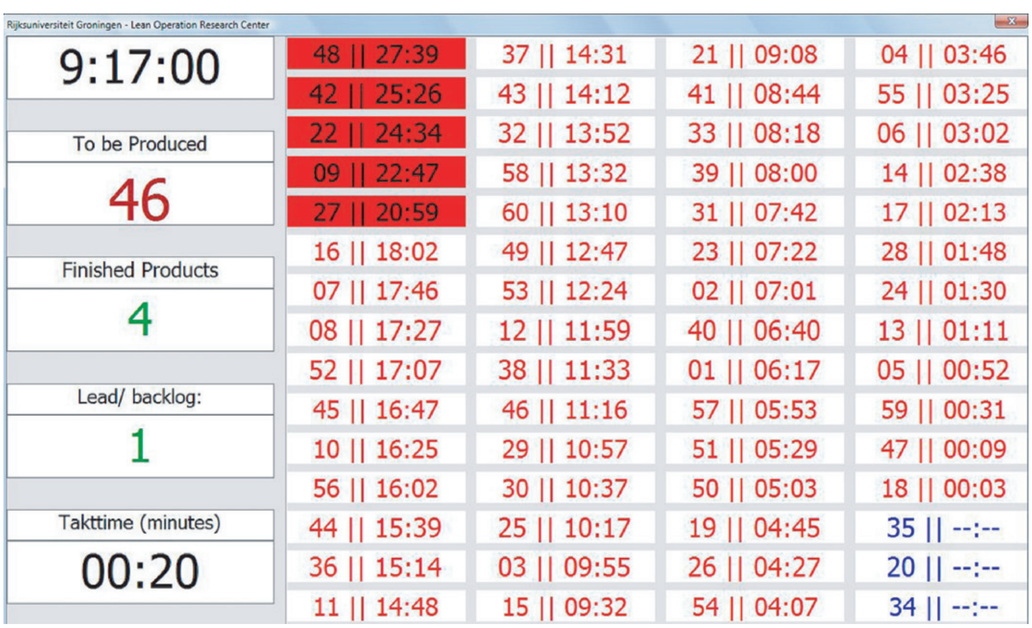

Figure 4. Production progress screen.

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These reasons are stored in the computer and the workers indicate the main reason of lateness, sometimes after a short discussion with other workers, by simply clicking on one of the 10 predefined reasons. In a period of 5 months (3 July 2007 till 5 December 2007), the main reasons were insufficient attention (40%), limited worker flexibility (30%) and technical problems (25%). Fluctuating and long order processing times were only mentioned in 5% of all cases, indicating that these fluctuations and varieties can be easily absorbed by the team of workers and by the WIP in the system. It is possible for workers to work 'in advance' to some extent, so some orders will be finished earlier than required. These orders, however, only formally leave the system at their associated takt time. The 'buffer' of orders that are finished too early is helpful in periods where orders are relatively large, or where there are temporarily few workers. As indicated by the outcomes of the reasons for lateness, the workers did not experience problems with balancing the load over time.

At the moment, the team of workers in strip manufacturing is busy improving their performance. Measures are taken to reduce the number of 'red' (or late) orders. Some workers, for instance, are cross-trained to operate machines, which can currently only be operated by a single worker each shift. Also, the maintenance of some machines has been intensified. Supervisors have been asked to stimulate and teach workers to perform the correct orders. Furthermore, a set of performance indicators has been developed (quality, delivery performance, efficiency) to be used at the shop floor level.

The production progress screen, as presented in Figure 4, provides interesting information about the way CB unit deals with the CONWIP/FIFO/takt time control system. This will be discussed in Section 6, which concerns, among other things, a critical evaluation of the whole lean production control system. Beforehand, Section 5 will describe the approach taken to production levelling in the CB unit.

5. Production levelling in the CB unit

The CONWIP/FIFO/takt time control system for strip manufacturing resulted in short and controllable manufacturing flow times in strip manufacturing. However, limiting the amount of work released into strip manufacturing naturally leads to an increase in the level of WIP in the buffers that feed strip manufacturing (Figure 2). Without any further changes to the production control system, this increase in WIP would lead to long waiting times for orders before strip manufacturing. Therefore, we also developed and included a levelling function in the new lean production control system to control the loading of the shop buffer (Figures 2 and 3) and the subsequent release to strip manufacturing.

The levelling function works as follows. The planner is made responsible for fulfilling the shop buffer up to a level of about 2.5 days of work in CB unit on a daily basis. A set of available orders of only a few days of work is sufficient for the planner to be able to balance (level) the load of CB unit over time. Orders need to be released to the shop buffer at least 3 days before the customer due date. The internal due dates of orders released at day x are set at day $x+3$. Each work day is associated with a particular colour and the orders released at day x are filed in a folder with the colour of day x. It is the responsibility of the puncher to punch the orders based on colour sequence and deliver them to the punched orders buffer in time. The puncher also takes nesting efficiency into account when selecting orders. The puncher is also responsible for the sequence of orders entering strip manufacturing; colours do not play a role in the control system in strip manufacturing.

The levelling function increased the planner's ability to control the loading. It resulted in short, constant and reliable flow times (of 3 days). This is a significant improvement compared to the old situation in which the total flow time (administrative + manufacturing flow time) was, on average, 10.1 days.

An important change, which the firm is yet to perform, is to adjust the lead times in the external order acceptance (MRP) system to reflect manufacturing reality. Currently, the lead times are dependent on processing times, setup times and the number of operations required. Without changing the external delivery times, the new production control system will not lead to shorter flow times. It will only increase the number of orders from which the planner can make his/her selection. With the help of the lean production control system proposed in our study, the firm may take important decisions by which the lead times of orders can be reduced. After the implementation of the lean production control system, the lead times of orders to be performed at strip manufacturing can be set equal in the overall planning and control system of the firm. Equal and short lead times offer important opportunities; for example, they may enable an increase in the number of orders controlled by Kanban. It is argued that long lead times are no longer an adequate reason to reject Kanban deliveries. Short and reliable lead times also support efficient material flow to the assembly lines. Equal and short lead times, furthermore, may reduce the overall lead times of customer orders.

6. Evaluation of the lean production control system

As indicated in previous sections, management of the firm is enthusiastic about the new lean production control system. The system was implemented between October 2007 and March 2008. The delivery performance of CB unit has since been improved significantly, from 55% to more than 80%.

Although the new production control system offers substantial benefits and improvement possibilities, some critical aspects should also be mentioned. Figure 4 presents the status of the production progress screen at a particular moment, some months after the implementation of the system. Several interesting observations can be made. The screen shows five late orders, caused by workers deviating from the input sequence of orders. Reasons for this behaviour could be the breakdown of a machine or material problems. According to the principles of the lean production control system, the workers should focus on solving these problems and should not deviate from the input sequence of orders. Although the actions of the workers are understandable, since they want to continue producing, there is a certain risk that 'red orders' will get less attention than needed. Another observation is that there are less than 60 orders, the predetermined WIP in the system. As can be seen, the Kanban cards 35, 20 and 34 are not connected to an order. We asked why and the workers explained that it was not necessary to connect these cards to a new order because there were enough orders in the system to work on. In the lean production control system proposed here, this is not a correct way to deal with the cards. Having a lower level of WIP in the system reduces the chance of 'red orders' since workers are responsible for fewer jobs in the system, while each job entering the system is still assigned a fixed flow time based on the predetermined (higher) WIP level. The daily throughput, however, may not be realised by the manufacturing team.

7. Conclusions

In this article, we have presented the development of a lean production control system for a high-variety/low-volume production unit. The main contribution is the illustration that lean control principles, such as levelling, pull and takt time, can be used in such a context. We have translated these principles into a concise production control system for a particular manufacturing system. The lean production control system consists of two important elements. Firstly, a levelling or loading function, to control the loading of the shop buffer and the subsequent release to strip manufacturing. Secondly, a CONWIP/FIFO/takt time system to control the flow of orders within strip manufacturing. The lean production control system has led to short and reliable flow times on the shop floor. As a result, planners and workers have improved control over the flow of orders; gaming and the phased introduction of the system have been factors critical to success. In Section 6, we showed that the system, although successful, requires continuous attention. Workers and managers can still deviate from the rules of the lean production control system.

After the implementation of the control system in the CB unit, the firm decided to also implement the control system in other production units. By September 2008, the system was successfully running in the turning/milling unit. Initially, there was substantial resistance against the system in this production unit. Supervisors and workers had the opinion that the system would not work in their production unit because of the even larger variety of routings and processing times. Management, however, successfully introduced the production progress screen and workers soon appreciated the benefits. The supervisor was stimulated to reduce the work in progress. This led to a substantial reduction in flow times in the turning/milling unit. Next, the coloured folders were introduced by the planner. This brought similar benefits to those attained in the CB unit. The firm is now implementing the system in the sheet metal unit. Management strongly believes that the lean production control system is robust and can be used in a variety of manufacturing circumstances.

The success of the lean production control system at this particular firm has motivated us to suggest the system to other companies. The control system is now also being used in the 'test unit' of a centrifugal pump manufacturer. It has supported the identification and quantification of reasons why pumps sometimes stay in the test unit for an excessive amount of time. In this particular case, the production progress screen has also motivated the workers to reduce flow time variety as much as possible.

We have also conducted simulation studies to investigate the applicability of the lean production control system in various situations (Bokhorst and Slomp 2008). Among other outcomes, we found that the level of WIP is a key factor for the success of the system. As an initial outcome, we suggest that a relatively low level of WIP can be sufficient to absorb even substantial processing time variability. More empirical and simulation studies are needed for generalisation purposes. This is the objective of our future research.

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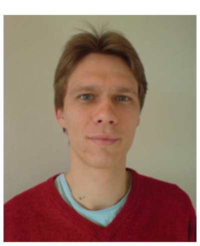

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