Exploring applicability of the workload control concept

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Peter Henrich*, Martin Land, Gerard Gaalman

Abstract
To be successful in companies, a production planning and control (PPC) concept should fit to the production environment. Essential elements of the concept should correspond with the characteristics of the production system. For classical concepts such as MRP these elements have become common sense. For example BOM-explosion and constant lead times make MRP known to perform best in environments with high material and low capacity complexity. For many other concepts the situation is less clear. In this paper the Workload Control (WLC) concept is considered for which the requirements for a successful application have never been investigated. A framework is proposed to explore the applicability of WLC in small- to medium-sized make-to-order (MTO) companies. It supports an initial consideration of WLC in the first phase of a PPC selection and implementation process.

As a first step in developing the framework the inherent characteristics of the WLC concept and the relevant MTO production characteristics are identified. Confronting the indicators of the company characteristics with the WLC elements results in best-fit indications for the WLC concept. Contrarily to other PPC evaluation schemes the framework considers variability indicators besides averages.

Use of this framework for a medium sized MTO company demonstrates its suitability in getting a systematic and quick impression of the applicability of WLC. Essential elements are treated and assessed.

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I. Introduction

Small- and medium-sized enterprises (SMEs) in the make-to-order (MTO) sector are of great interest, as they are a relevant part of the industrial infrastructure. These companies have to react on turbulent environments: they have to cope with changes in product mix and volume, production rate changes, a high number of rush orders, and lot of internal uncertainty. As a consequence the production planning and control (PPC) in MTO companies is rather complex and often based on insecure data. Since a good functioning of the production planning and control concept is crucial for the economic success of the enterprise, the selection of a fitting PPC concept is an important decision process. While selecting and implementing a suitable shop floor control concept different stages can be distinguished. Figure 1 roughly sketches these stages.

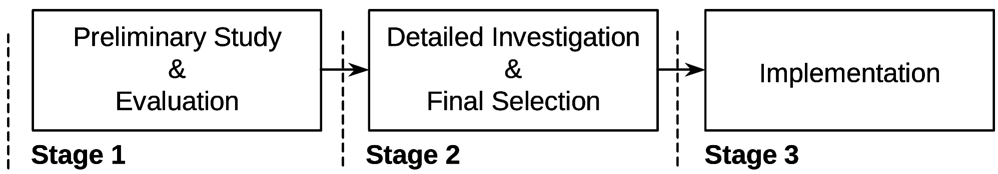

Figure 1: Stages in selecting and implementing a PPC concept

1. **Preliminary Study & Evaluation:** In this stage a pre-selection between alternative PPC concepts takes place. All possible concepts are considered without collecting detailed information.
2. **Detailed Investigation & Final Selection:** Before implementing a chosen concept a detailed investigation of relevant company characteristics and planning and control tasks is necessary. Also the characteristics of possible PPC software systems are evaluated. The huge amount of data retrieving and processing in this stage provides the motivation for pre-selection in stage 1.
3. **Implementation:** The production planning and control tasks of the shop floor have to be adapted according to the chosen concept. The selected software package is parameterised and embedded into the company.

In practice mostly external consultants support companies in selecting a suitable concept in the 'Preliminary Research & Evaluation' stage. This decision-making process is frequently based on intuitive reasoning rather than on an objective evaluation of the company characteristics and the considered production planning and control concepts. Moreover the selection is based on the experience of the advisor, collected in prior projects. There is a big need to make this initial selection procedure more transparent.

Several operations management textbook (e.g. Vollmann, Berry, & Whybark 1997, Silver & Peterson 1985) show diagrams relating control concepts to product and process characteristics of companies. The example in figure 2 is taken from Silver & Peterson (1985).

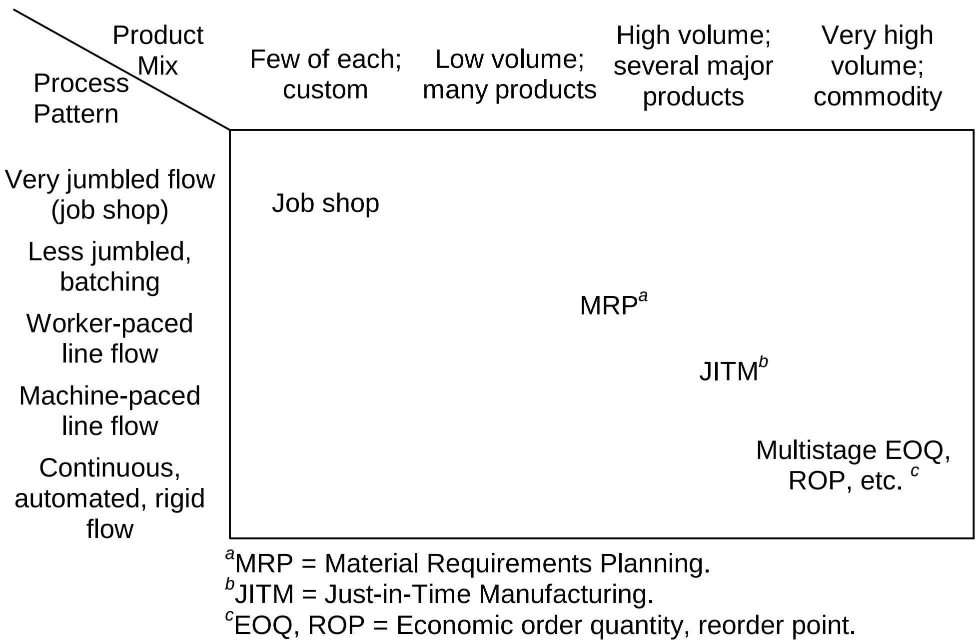

Figure 2: Positions of PPC concepts in the Product-Process Matrix (Silver & Peterson 1985)

Remarkably little seems to be known about the applicability of PPC concepts for the area that is indicated in figure 2 as ‘job shop’. Exactly this part of the matrix reflects the environment that can be found in most SMEs in the MTO sector. Hendry &

Kingsman (1989) suggest amongst others that the workload control (WLC) concept is particularly suitable in this environment. As for JIT manufacturing and MRP, WLC also imposes certain requirements on the production environment to guarantee a successful implementation. The inherent characteristics of the concept have to match up with the company characteristics. For classical concepts such as MRP these requirements have become common sense. For example BOM-explosion and constant lead times make MRP known to perform best in environments with high material and low capacity complexity.

In this paper we identify these inherent characteristics of the WLC concept, particularly those that can be seen as distinguishing elements. The possible match between the distinguishing WLC elements and the company characteristics is analysed, and, based on the resulting insights, a framework is developed that supports the consideration of WLC in the 'Preliminary Study & Evaluation' stage of a selection process (figure 1).

The structure of the paper is as follows: Section II discusses the distinguishing elements of the WLC concept. Section III analyses the relevant company characteristics to be considered in the preliminary selection. A compact set of indicators is proposed to describe these characteristics. In section IV the framework is set-up by relating each indicator to the distinguishing elements of WLC. Section V discusses the use of the framework in a MTO company. Finally, in section VI some concluding remarks are provided.

II. The characteristics of workload control (WLC)

This section gives a comprehensive analysis of the WLC concept. For a more extensive and formal description, we refer to Kingsman (2000).

The WLC concept is based on principles of input/output control. Input control relates to both accepting orders and releasing them to the shop floor. Once released the orders remain on the shop floor. Simple priority dispatching rules will direct the orders along their downstream operations. In our discussion, we will assume that each operation relates to a specific capacity group consisting of one or more machines and operators. Both the acceptance and the release of an order can be accompanied by output control decisions in terms of capacity adjustments. Typical for the WLC concept is the control of the work in progress (WIP) by means of order release. Order acceptance and output control decisions are based on the implications of this approach. Therefore, the release approach will be discussed in more detail.

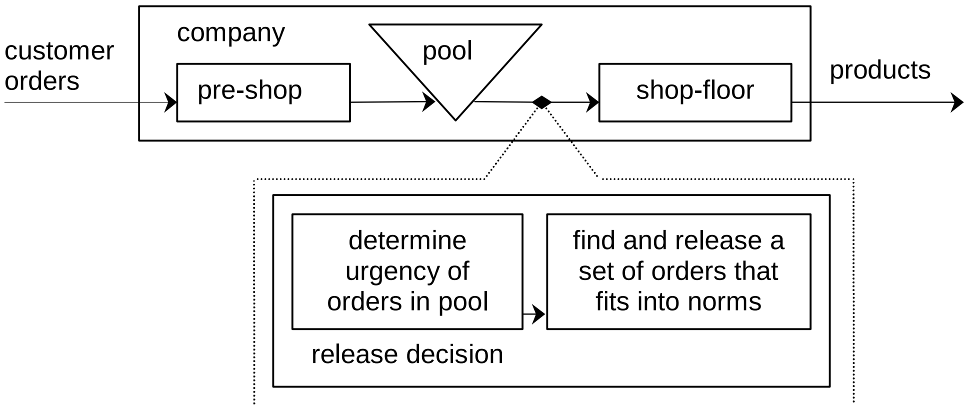

Figure 3: Order release within the WLC concept

As depicted in figure 3, after the acceptance of an order some pre-shop operations (engineering/process planning) may be necessary before the order is ready for release to the shop floor. Then the order will generally have to wait before it is selected for release. Waiting before release takes place in a so-called order pool.

Release criteria

The decision to release an order is based on two aspects, namely the urgency of the order itself and its influence on the momentary shop floor situation (see figure 3). The latter is determined by comparing workloads with norms. Workload norms can be defined for each capacity group and are usually expressed in time units. They should guarantee a small but stable buffer of work in front of the resources within the capacity groups. A stable buffer allows for constant operation lead times. In turn these constant lead times are used for determining accurate planned release dates. The planned release date of an order is calculated as its due date minus the planned lead times for its operations. Thus the urgency of orders in the pool can be compared.

Release procedure

Most classical variants of the WLC concept take the release decision periodically according to the following procedures. Orders in the pool are considered for release in the sequence of their planned release dates. The order being considered is added to the release selection as long as its release will not cause any workload norm to be exceeded. Otherwise the order will have to wait in the pool until the next release opportunity. An order with a later planned release date may be selected when it does fit in the norms. After this procedure is completed, selected orders are sent to the capacity groups performing the first operation and remain on the shop floor until all operations have been finished.

The five most distinguishing elements of the WLC approach to shop floor control are the control point at release, the use of aggregate measures, resource buffering, shop floor buffering, and central load buffering.

1) Control point at release

The main control point of the WLC concept is the release decision. This decision precedes the first shop floor operation of the orders. At this point fitting the orders into workload norms should create predictable operation lead times. Downstream on the shop floor, simple priority rules at capacity groups are sufficient (Bechte 1994). Examples of priority rules are First-Come-First-Served, which guarantees the smallest variation of operation lead times, or due date oriented rules to correct for individual progress disturbances among orders. No sophisticated methods are used for controlling the downstream operations of the orders. Although some of the orders arriving at a capacity group may come directly from the pool, a significant amount may come indirectly via other capacity groups which perform the upstream operations of the order (see figure 4).

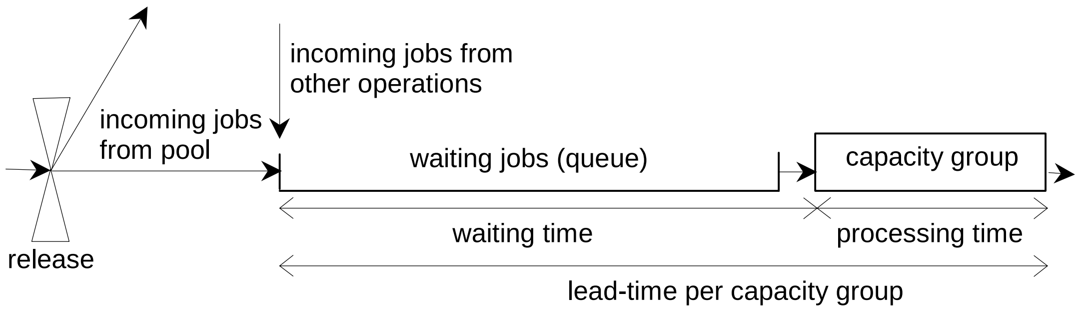

Figure 4: Control point at release

2) Aggregate measures

The decision to allow an order for release depends on the shop floor situation, which is reflected in workloads. Workloads are calculated as an aggregate of individual processing times. Most workload definitions also count up the processing times of orders waiting in front of a capacity group (direct load) and those of orders upstream (indirect load), as figure 5 shows. The general assumption is that variations within an aggregate measure of summed processing times will be relatively small. Therefore, decisions will be rather insensitive to individual processing time deviations.

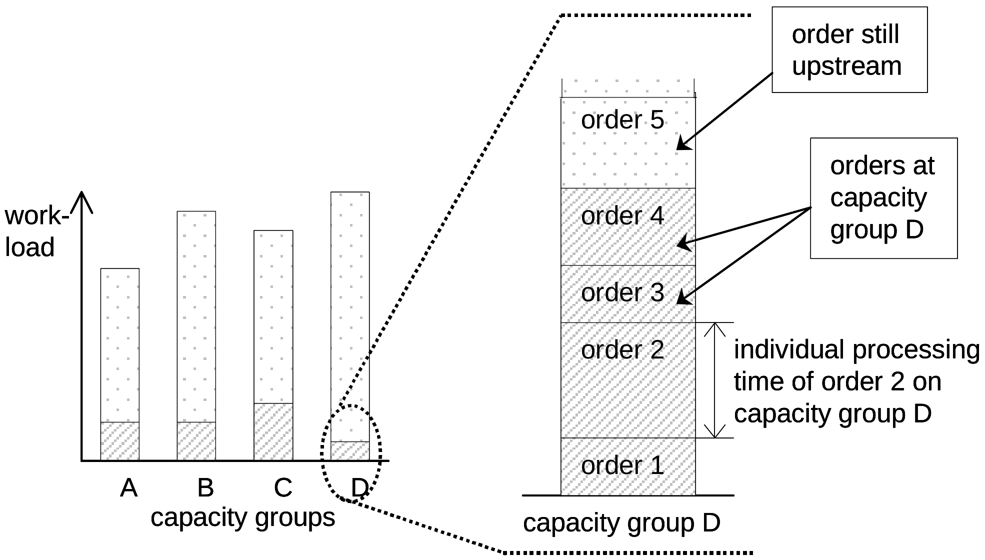

Figure 5: Use of aggregate measures - summing individual processing times

3) Resource buffering

Control within the WLC concept is not based on filling the capacities of resources in a time-phased plan as for finite loading or deterministic scheduling approaches. Instead it is based on maintaining a buffer for the resources in a capacity group, by keeping workloads at norm levels. Although different types of workload norms can be used, the orders allowed on the shop floor after release will normally contain more work than the capacity groups can handle before the next release moment (see figure

6), resulting in queues of orders in front of the capacity groups. WLC is essentially designed for situations where queues are inevitable, coping with variations in order arrival and processing times.

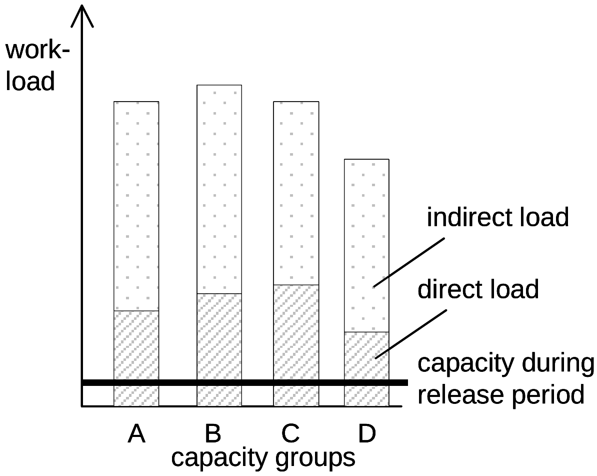

Figure 6: Resource buffering

4) Shop floor buffering

Even though resources are buffered by queues, these queues are kept small. As far as possible the waiting time is placed before the first operation in the form of pool waiting time. Thus, the main buffer is placed before the shop floor (figure 7). The pool should absorb all kinds of fluctuations in the arriving order flow in order to keep the resource buffers small and stable. Pool waiting times of orders may vary according to their urgency, which is reflected in the slack to planned release dates, and whether they fit well into the shop floor situation, which is reflected in the workloads.

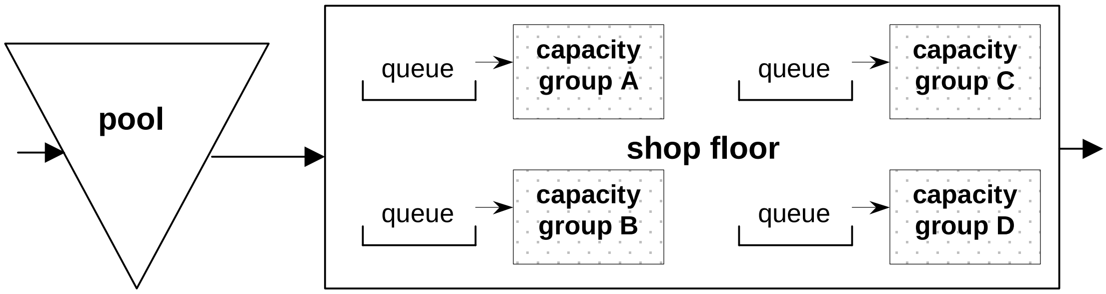

Figure 7: Shop floor buffering

5) Central load balancing

The main decisions of WLC are made centrally. The release decision compares the urgency of orders and balances loads among capacity groups. This requires a global view of the shop. As mentioned before, local decisions at individual capacity groups can be based on simple priority dispatching rules not requiring global information. The central balancing of loads by fitting the orders from the pool into workload norms (figure 8) will keep the resource buffers stable, despite variations in the arriving order flow.

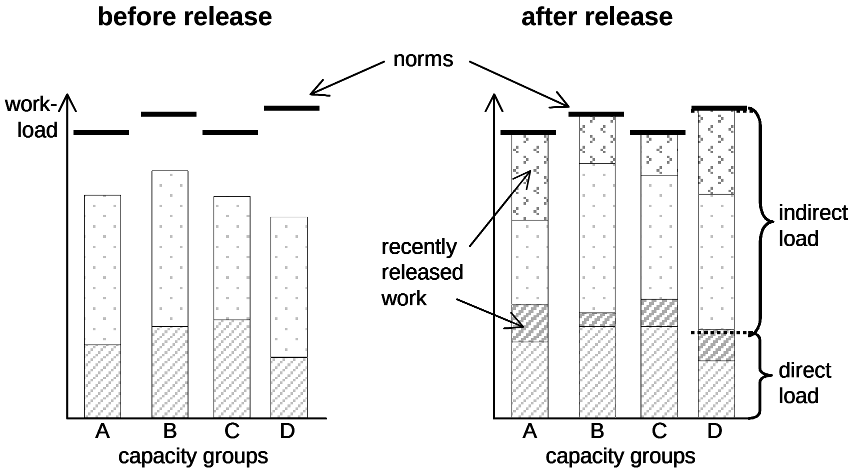

Figure 8: Central load balancing

The preceding five elements of WLC are supposed to give a rather complete picture of those elements that can be considered distinguishing for the WLC concept. Having identified these elements of WLC the next step in the development of the framework is the description of relevant company characteristics.

III. Company characteristics

To explore which company characteristics comply with the distinguishing elements of the WLC concept, a structured overview of relevant characteristics must be developed. Since the basic function of a shop floor control concept is to match order requirements with the available capacity, the overview will be derived from order requirements. We will start by identifying the relevant characteristics of one single order and use this to structure the characteristics of the order flow.

Principally, each order can be characterised by an arrival date, a due date, and technological requirements. The technological requirements result in a set of operations, each on a certain capacity group, to be performed according to a certain routing along the capacity groups (see figure 9).

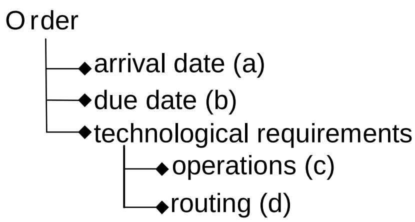

Figure 9: Order characteristics

The simplest approach would be to indicate some kind of order flow average for each, in order to elaborate these characteristics of a single order to a spectrum of characteristics that typify the complete order flow. In most cases this will be sufficient for a preliminary evaluation of a concept's applicability. However, in small- to medium-sized MTO companies control complexity results from all kinds of variability that should be handled. Therefore variability indicators have been added in the characterisation of order requirements. The complete set of indicators for exploring the applicability of WLC is given in table 1.

Table 1: Characteristics and indicators

Characteristic	*Indicator*
a) order arrival dates	(a_1) arrival intensity
	(a_2) inter-arrival time variability
b) due date requirements	(b_1) due date tightness
	(b_2) variability of due date allowances
c) operations	(c_1) processing time lumpiness
	(c_2) processing time variability
	(c_3) set-up/processing time ratio
d) routing	(d_1) routing sequence variability
	(d_2) routing length
	(d_3) routing length variability
	(d_4) routing flexibility
	(d_5) level of convergence

Besides indicating averages and variability, operations and routings have been elaborated in more detail. For operations one can discriminate between processing and set-up time. Within the routing characteristics sequence variability, routing length, routing flexibility, and routing convergence have been discerned.

It must be noticed that the specified set of indicators cannot fully describe the dynamics of the incoming order flow. Indications of variability may depend on the time fence chosen, patterns such as cycles and trends could be observed, and finally the order characteristics may show internal relationships. But since we aim at a preliminary evaluation of WLC applicability the evaluation framework will be restricted to table 1.

IV. Building the framework

The framework for evaluating the applicability of WLC will be completed by indicating a 'best fit area' for each of the indicators in table 1. For other shop floor control concepts similar frameworks have been published in literature. For instance Vollmann, Berry, & Whybark (1997) show a framework determining the applicability of MRP-based and JIT-based shop floor control approaches (table 2), splitting the list of company characteristics into 'Market requirements' and 'Manufacturing'.

This example, like many studies, tries to discriminate between two concepts, where our framework will just indicate the best fit for one concept, that of WLC. Similar to the framework of Vollmann, Berry, & Whybark (1997), the indicators will not be numerical, as they must be based on a qualitative assessment of the distinguishing elements of the concept. A qualitative evaluation complies with the purposes of the preliminary selection phase.

Table 2: Existing framework for evaluating MRP- and JIT-based shop floor control (Vollmann, Berry, & Whybark 1997, p. 368).

<table>
<tr><th colspan="3" rowspan="2">Strategic variables</th><th colspan="2">Shop-floor system approach</th></tr>
<tr><th>MRP based</th><th>JIT based</th></tr>
<tr><td rowspan="7">Market requirements</td><td rowspan="2">Product</td><td>Design</td><td>Custom</td><td>Standard</td></tr>
<tr><td>Variety</td><td>Wide</td><td>Narrow</td></tr>
<tr><td colspan="2">Individual product</td><td>Low</td><td>High</td></tr>
<tr><td rowspan="2">Accom-modating demand changes</td><td>Total volume</td><td>Easy/incremental</td><td>Difficult/stepped</td></tr>
<tr><td>Product mix</td><td>High</td><td>Low</td></tr>
<tr><td rowspan="2">Delivery</td><td>Speed</td><td>Achieved by schedule change</td><td>Achieved through finished goods inventory</td></tr>
<tr><td>Schedule changes</td><td>More difficult</td><td>Less difficult</td></tr>
<tr><td rowspan="6">Manufacturing</td><td colspan="2">Process choice</td><td>Low-volume batch</td><td>High-volume batch/line</td></tr>
<tr><td colspan="2">Changeover cost</td><td>High</td><td>Low</td></tr>
<tr><td colspan="2">Organizational control</td><td>Centralized</td><td>Decentralized (shop floor based)</td></tr>
<tr><td colspan="2">Work in process</td><td>High</td><td>Low</td></tr>
<tr><td rowspan="2">Source of cost reduction</td><td>Overheads</td><td>Low</td><td>High</td></tr>
<tr><td>Inventory</td><td>Low</td><td>High</td></tr>
</table>

The matrix structure of figure 10 is followed in the assessment whether the WLC concepts fits better to a high or low level of an indicator. For each cell in the matrix we consider the functional relationship between the distinguishing element of WLC and the company characteristic indicated. The relevant relationships are marked and will be discussed below.

Characteristic	Indicator	Control point at release	Aggregate measures	Resource Buffering	Shop floor buffering	Central load balancing
a) arrivals	(a_1) arrival intensity		x			x
	(a_2) inter-arrival time variability				x	
b) due dates	(b_1) due date tightness			x	x	
	(b_2) variability of due date allowances				x	
c) operations	(c_1) processing time lumpiness		x			x
	(c_2) processing time variability			x	x	x
	(c_3) set-up/processing time ratio	x				x
d) routings	(d_1) routing sequence variability	x		x	x	x
	(d_2) routing length	x				
	(d_3) routing length variability			x	x	x
	(d_4) routing flexibility					x
	(d_5) level of convergence	x				x

Figure 10: Relevant relationships

1) Control point at release

The release decision has been indicated as the main control point of the WLC concept. Once released, simple priority rules must control the progress of jobs on the shop floor. Though quite common in typical job shops, this may be insufficient for capacity groups with a downstream position in certain production structures, as the results of Oosterman, Land, & Gaalman (2000) show. As a consequence, long routings, particularly when combined with little sequence variety, may conflict with this distinguishing element of the WLC concept. Also highly convergent routings as typical for assembly situations may require more emphasis on control of the downstream assembly, though van de Wakker (1993) has suggested some solutions for controlled release in an assembly environment. In addition, sequence dependent set up times on resources ask for useful joint progress control of associated jobs on the shop floor. Considering the above, WLC best supports high routing sequence variability, short routings, little routing convergence, i.e. no dominant assembly structure, and small set-up times.

2) Aggregate measures

Workloads, being aggregates of individual processing times, reflect the shop floor situation within the WLC concept. The detailed composition of these workloads is not considered, which may become relevant if the shop floor is loaded by a small number of large jobs. In this situation one may consider jobs as projects rather than anonymous contributors to workloads. According to Adam (1988) and Breithaupt, Land, & Nyhuis (2002), the WLC approach is designed to function optimally when workloads consist of a large number of small processing times. This condition supports the presumed relationships between workloads and throughput times. Robustness is supported by not reacting to details. Therefore, a best fit will be realised with high arrival intensities and relatively small processing times.

3) Resource buffering

WLC is based on maintaining a buffer for the resources in a capacity group, and as such it is designed for situations where queues are inevitable. Main determinants of these queues are internal arrival variability and processing time variability. The internal order arrival process for a certain capacity group is regulated by the release decision within WLC but also depends on the output process of other groups. Therefore internal arrival variability will typically occur in situations with high routing variety in terms of sequence and length. Thus, WLC best fits to high variability of processing times, routing sequences and routing lengths. Besides, the possibilities for resource buffering depend on how much due date allowances allow for queuing. Relatively tight due dates will conflict with buffer waiting times and require high capacity flexibility to avoid queues.

4) Shop floor buffering

The main buffer within WLC is the pool of jobs waiting for release to the shop floor. This pool is meant to absorb all kinds of fluctuations in the arriving order flow. Like resource buffering, it supports the handling of processing time and routing variability and it conflicts with relatively tight due dates. Besides, the shop floor buffer typically serves a function in the absorption of inter-arrival time variability. Shop floor buffering further suits situations with a diverse mix of urgent and non-urgent orders, i.e. a high variability of due date allowances. The differences in due date allowances can be compensated by longer and shorter pool waiting times, reducing the need for interventions on the shop floor.

5) Central load balancing

The centrally taken decision of order release aims at load balancing, besides considering the urgency of jobs. Combined with the pool buffer this function should smooth the influence of variability in arrivals, processing times, routing lengths and routing sequences. However the possibilities for load balancing diminish when only a small number of jobs with lumpy processing times is available. Therefore, it will function best in environments with high arrival intensity and relatively small processing times. Particular characteristics that should be considered with respect to central load balancing are set-up times and routing flexibility. Sequence-independent set-up times could be treated as part of the operation processing time and need not been considered separately (Allahverdi, Gupta, & Aldowaisan 1999). Basically, two possibilities exist to cope with sequence dependent set-up times: considering them centrally within the release decision or locally within the priority dispatching decision. However, central load balancing reduces queue lengths and thus restricts the effectiveness of local dispatching rules, while the objective of load balancing within the release decision may conflict with requirements of set-up reduction. Therefore, WLC fits best in environments with relatively small sequence-dependent set-up times. For a more extended discussion on sequence-dependent set-up times the reader is referred to Missbauer (1997). In contrast, routing flexibility may support central load balancing. The flexibility in terms of routing alternatives can be used to further balance the load across capacity groups.

The above considerations can be translated into ‘best fit’ areas for each characteristic. Based on the conclusions of Hendry and Kingsman 1989 we may assume WLC to be appropriate in an ‘average’ MTO company. The framework in figure 11 shows the consequences for WLC applicability if characteristics move to more extreme values.

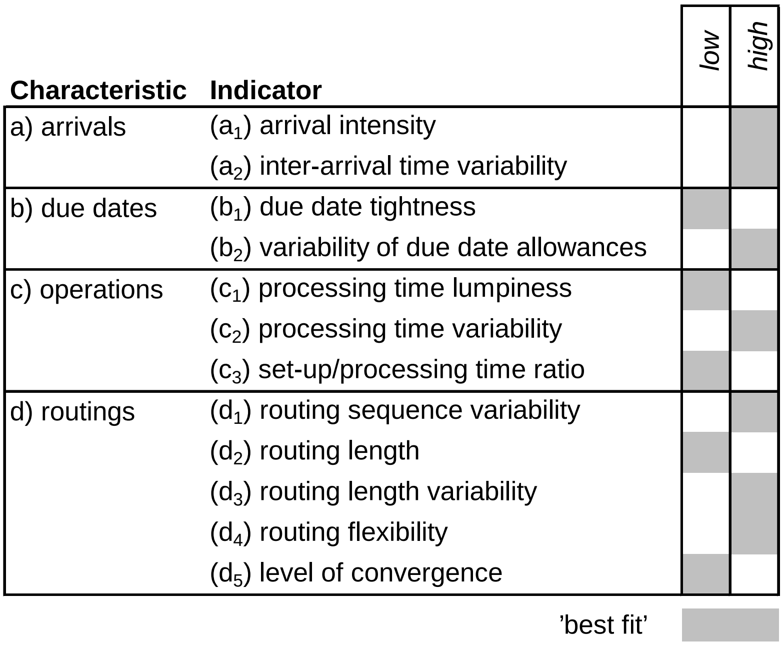

Figure 11: Evaluation framework indicating ‘best fit’ for WLC

V. Using the framework

The presented framework has been applied in a medium-sized MTO company. This section starts with a short description of the company. Then the characteristics of the company are depicted and projected on the framework.

The MTO company produces conveyor belts for agricultural purposes, among others for combined harvesters. The conveyor belts simultaneously transport the products and sift all soil remainders out of them. During the last couple of years this company has grown from a small- to a medium-sized company. This has lead to increased workload, work in progress and lead times. Moreover the due date performance deteriorated greatly. In the past the production planner could easily overview the shop floor. Due the higher WIP levels and the increasing number of urgent jobs the intuitive manner in which the shop is (still) controlled by the planner can no longer successfully be used. Therefore, the company is looking for a new production planning and control concept that supports the planner in employing a more structured approach.

In advance this company seemed well suited for using WLC. In order to get a quick and structured indication our framework has been used. In discussions with the planner and the operations manager indicator levels of the characteristics have been established.

a) Arrivals

About 20 orders arrive per day. With a current lead time of 15 days about 300 orders have to be considered simultaneously by the planner. From this perspective the arrival intensity of orders (a_1) can be considered relatively high. The inter-arrival time variability (a_2) is not extremely high or low.

b) Due dates

On average (b_1) the due dates allow for a moderate slack. However, two different groups of customers need to be serviced. One group consists of the farmers, the users of harvesting machines. These customers order repair parts during the harvesting period and demand very short due dates. The other group consists of the producers of harvesting machines, who tend to place orders more in advance. The aggregate due date requirements of the two customer groups lead to a high variability of due date allowances (b_2).

c) Operations

Both the lumpiness (c_1) and variability (c_2) of the processing times are not considerable extreme for this type of situation. In contrast, extremely large sequence dependent set-up times (c_3) can be recognised at four resources. Realising good order sequences therefore requires a lot of co-ordination between the planner and the foremen on the shop floor. It is difficult to handle urgent orders first and balance workloads, as disturbing the set-up sequence leads to large inefficiency losses on machines.

d) Routings

The indicators d_1, d_2, d_3 did not show extreme values. Routing flexibility (d_4) was relatively high. Alternative machines allow different routings for operating the same order. One assembly stage exists where two or three flows come together, leading to a moderate level of routing convergence. Under the given circumstances this hardly causes synchronisation problems between orders on the shop floor.

Figure 12 summarises where extreme values have been observed.

Characteristic	Indicator	*low*	*high*
a) arrivals	(a_1) arrival intensity		x
	(a_2) inter-arrival time variability		
b) due dates	(b_1) due date tightness		
	(b_2) variability of due date allowances		x
c) operations	(c_1) processing time lumpiness		
	(c_2) processing time variability		
	(c_3) set-up/processing time ratio		x
d) routings	(d_1) routing sequence variability		
	(d_2) routing length		
	(d_3) routing length variability		
	(d_4) routing flexibility		x
	(d_5) level of convergence		x

'best fit'

more extreme values of the company x

Figure 12: The actual situation at the conveyor belt manufacturer

According to this quick scan it might be beneficial to consider the WLC concept in this company. Nevertheless, the set-up/processing time ratio (c_3) forms a serious obstacle for the WLC concept, as it cannot cope with the large impact of sequence dependent set-up times. To a limited extent the assembly phase needs attention for a fruitful application of the WLC concept. Based on these insights the company started a program for reducing the set-up times before going into the phase of detailed investigations for a particular production planning and control concept.

VI. Conclusions

The paper proposes a framework that supports the consideration of WLC in the 'Preliminary Study & Evaluation' stage of selecting a suitable shop floor control concept. The paper started with a concise analysis of the WLC concept, from which five distinguishing elements have been identified:

1) The main control point is the decision to release orders to the shop floor;
2) Control is based on aggregate measures of summed processing times;
3) Small and stable buffers are maintained in front of capacity groups;
4) A pool of orders buffers the shop floor against fluctuations;
5) The central release function balances loads across capacity groups.

The match between these typical elements and the relevant company characteristics, results in a framework that indicates best-fit areas for WLC. Indicators are not only based on average values but also on the variability of the company characteristics.

In general, it can be concluded that the applicability of WLC concept increases with raising variability, indicated by increased arrival rate fluctuations, due date differences, processing time variability, routing sequence and routing length variability. While routing flexibility has not been widely reported in WLC literature, it can contribute to the applicability of WLC. Assembly operations and sequence dependent set-up times may cause problems when applying the WLC approach.

The framework has been tested in an MTO company and one of the outcomes was that, despite WLC's potential attractiveness, barriers concerning set-up times had to be removed first. The framework helped in getting a systematic, objective and quick impression of the applicability of WLC in a situation where management and planners hardly had any knowledge of PPC concepts. As an indirect effect, the use of the framework gave the management of the company much insight in the way the shop floor was currently controlled.

The framework contributes to a more objective decision-making process regarding WLC in the first stage of selecting a production planning and control concept. One future research direction may focus on the quantification of the indicators, which offers the possibility to compare different small- and medium-sized MTO- companies regarding the applicability of WLC.

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