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# Successful implementation of an order release mechanism based on workload control: a case study of a make-to-stock manufacturer

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This paper deals with improving the lead-time performance of a large crystal manufacturer that uses a state-of-the-art commercial Enterprise Resource Planning system. Since the company encountered some limitations of the standard production planning and control (PPC) system it sought for improvements by implementing an order release mechanism based on workload control (WLC). WLC employs certain rules for releasing orders in order to maintain a certain level of work in process to achieve a certain utilisation of the production system and thus control the flow times in order to meet the required due dates of the orders. We describe the successful implementation of an order release mechanism based on the WLC concept in this make-to-stock company. The paper describes the implemented order release mechanism, the implementation process and its impact on the company's performance. We show that the core function of WLC – the order release mechanism – can be integrated successfully into an existing PPC system. Furthermore, this study highlights the applicability of WLC to a wider range of companies, especially to make-to-stock manufacturers.

**Keywords:** workload control; make-to-stock production; production planning; order release; lead-time reduction

## 1. Introduction

Production planning and control (PPC) systems are of great importance for the competitive position of manufacturing firms. PPC systems are designed to efficiently manage the flow of materials and goods and the utilisation of people, equipment and capacity (Jacobs, Whybark, and Vollmann 2011). In order to handle the complexity of this planning and control problem, it is often advantageous to decompose this problem into sub-problems coordinated within a hierarchical structure. Especially in discrete manufacturing, as in our case study, the detailed sequencing and scheduling decisions are usually performed at the shop floor level, which constitutes the lower (base) level of this hierarchical structure. The upper (top) level coordinates these production units by coordinated releases of production orders (for conceptual issues see Bertrand, Wortmann, and Wijngaard [1990] or De Kok and Fransoo [2003]). This task of the top level requires generating production orders and their required due dates from customer orders and/or demand forecasts. Over the last 50 years several PPC concepts were designed and implemented in practice, such as the standard architecture of PPC systems based on MRP (see Jacobs, Whybark, and Vollmann 2011) or Advanced Planning Systems (Stadtler and Kilger 2005; see Zäpfel and Missbauer [1993] for alternative PPC concepts developed mainly in the 1980s). This paper focuses on the *workload control (WLC) concept*. The main idea of WLC is to limit the workload in the manufacturing system (more precisely: in the production units) and thus control flow times (see Wight 1970; Bechte 1988; Hendry and Kingsman 1989; Wiendahl, Glässner, and Petermann 1992).

The idea of WLC dates back to the conceptual work of Wight (1970) who was probably the first to understand and describe the importance of controlled order release (see Bergamaschi et al. 1997, 402). Definitions of WLC vary within the literature, but common for all WLC approaches is the essential role of order release for controlling WIP and flow times, which implies the use of a pre-shop pool of unreleased orders and an order release mechanism or model. In practice, the pre-shop pool is situated in the office of the production planners who decide which orders to release to the shop floor. In a recent literature review by Thuerer, Stevenson, and Silva (2011) the literature on WLC is divided into four categories: conceptual, analytical, empirical and simulation-based research and they conclude that most research belongs to the latter category (see Thuerer, Stevenson, and Silva 2011). With regard to implementations of the WLC concept

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(empirical research), only few studies were published (e.g. Fry and Smith 1987; Wiendahl, Glässner, and Petermann 1992; Hendry, Elings, and Pegg 1993; Park et al. 1999; Riezebos, Korte, and Land 2003; Silva, Roque, and Almeida 2006; Hendry, Stevenson, and Huang 2013; Silva, Stevenson, and Thurer 2015).

Furthermore, most (especially more recent) literature on WLC concentrates on small- and medium-sized make-to-order (MTO) production systems since they argue that WLC was mainly designed for MTO companies (see Kingsman and Hendry 2002; Stevenson et al. 2011; Hendry, Stevenson, and Huang 2013; Silva, Stevenson, and Thurer 2015). Research on WLC in *make-to-stock (MTS)* production systems has been largely neglected in the last two decades, although earlier studies (e.g. Zäpfel and Missbauer 1993; Bechte 1994) suggest an application for both MTS and MTO companies. To the best of the authors' knowledge, there is no study that implements a WLC mechanism to a MTS company. Additionally, there is a lack of studies that incorporate *order release mechanisms* based on WLC into existing PPC systems, that generate the production orders and their approximate timing by MRP based on a master production schedule (Jacobs, Whybark, and Vollmann 2011) and/or by reorder point (ROP) systems, often integrated into Enterprise Resource Planning (ERP) systems which are mostly used in practice.

To the best of our knowledge, only the study by Hendry et al. (2008) describes an implementation project of WLC into an existing ERP system and the study by Fry and Smith (1987) may also be an exception although they do not give information on the PPC system in use at the company under study.

Therefore, this research projects' contribution is twofold. Firstly, it presents a case study of a successful implementation of an order release mechanism based on the WLC concept at a MTS company. Secondly, this paper shows that the core function of WLC – the order release mechanism – can be implemented successfully within an existing (non WLC based) ERP system which highlights the applicability of WLC to a wider range of companies than suggested by recent empirical WLC literature. More precisely, at the case company orders are generated by a ROP system (at the final product level) and by the master planning function of an Advanced Planning System that generates additional orders required for production smoothing

The remainder of this paper is organised as follows. Section 2 provides an overview of the empirical WLC literature before Section 3 describes the background of the case company. In Section 4 we describe the pre-implementation phase followed by the details on the implemented order release mechanism and its impact on the performance in Section 5. Finally, we summarise and conclude in Section 6.

## 2. Literature review: empirical WLC literature

Before describing the company under study in detail, we first provide a review of the most relevant prior empirical studies within the WLC literature. Our structure of the literature builds on and extends earlier literature reviews from Hendry et al. (2008) and Thuerer, Stevenson, and Silva (2011). We define empirical WLC literature as studies that present (or at least refer to) implementations of WLC concepts to real industry cases which means that we exclude studies that 'implement' WLC mechanisms to simulation models (e.g. Thuerer et al. 2012, 2013; Fernandes, Land, and Carmo-Silva 2014; Thuerer, Stevenson, and Land 2016; Thuerer, Stevenson, and Qu 2016a, 2016b). Furthermore, we did not include concepts such as Kanban and CONWIP (which can be considered as WLC techniques) in this literature review since they are not applicable to companies facing a complex material flow and demand pattern.

The empirical literature on WLC can be divided into three categories:

(1) Empirical studies that focus on the success of implementations of various WLC approaches,
(2) Empirical studies that analyse the applicability of WLC and the implementation process,
(3) Empirical studies that propose an implementation strategy for WLC.

The papers within the first category show the positive effect of WLC on the performance in practice (Bertrand and Wortmann 1981; Fry and Smith 1987; Bechte 1988; Wiendahl, Glässner, and Petermann 1992; Bechte 1994; Ulfers 1991; Park et al. 1999; Riezebos, Korte, and Land 2003). Bertrand and Wortmann (1981) present a WLC approach that calculates the workload by aggregating individual operation times. The 'aggregate workload' is calculated by summing up all operation times of orders waiting in front of a capacity group (direct load) and the operation times of orders upstream that need to be processed by this capacity group (indirect load; see Oosterman, Land, and Gaalman 2000; Henrich 2005; ). The authors successfully implement their approach in a diffusion department of a semiconductor plant. Fry and Smith (1987) present a successful implementation of an order release mechanism based on the ideas of Wight (1970) to a tool manufacturing job shop. Furthermore, Bechte (1988, 1994) and Wiendahl, Glässner, and Petermann (1992) report successful implementations of their Load-Oriented Manufacturing Control (LOMC) in small- and medium-sized make-to-order (MTO) companies. The LOMC approach determines the workload of a capacity group by adding a discounted indirect load to the direct load. They use a discount factor that represents the probability that an order upstream will reach the downstream capacity group in the corresponding planning period.

Finally, some studies demonstrate that WLC can be successfully implemented when part of a hybrid PPC system, meaning that different PPC concepts are used for different hierarchy levels within a PPC system. (Fry, Karwan, and Steele 1992; Park et al. 1999; Riezebos, Korte, and Land 2003). Fry, Karwan, and Steele (1992) successfully implement an Input–Output Control mechanism (see Fry and Smith 1987) within the Drum–Buffer–Rope (DBR) approach at a bearings manufacturer. Park et al. (1999) and Riezebos, Korte, and Land (2003) outline successful implementation cases of the customer enquiry stage only. Both studies maintain the order release policy already used in the company (a DBR mechanism) and combine it with an order acceptance mechanism based on WLC principles. In detail, Park et al. (1999) implement a decision support system to aid due date quotations based on the Lancaster University Management School (LUMS) approach (introduced by Hendry and Kingsman [1989]) at a large rotating machinery shop and Riezebos, Korte, and Land (2003) introduce an order acceptance mechanism based on a load-oriented procedure similar to the approach described in the LOMC literature at a small manufacturer of corrugated cardboard packing material.

Note that not all implementations of WLC have been successful. For example, the WLC systems implemented by Hendry, Elings, and Pegg (1993) and Stevenson (2006) were neglected and abandoned over time (see Silva, Stevenson, and Thurer 2015, 283). However, it is clear from the literature reviewed above that if the concept is correctly implemented, either as a comprehensive PPC system or as part of a hybrid PPC system, it can lead to performance improvements.

All of the above-mentioned studies focus on the result of implementation and the used WLC concept rather than on the implementation process itself which is the focus of the studies in the second category (Hendry, Elings, and Pegg 1993; Henrich, Land, and Gaalman 2004; Hendry et al. 2008; Stevenson and Silva 2008; Soepenberg, Land, and Gaalman 2012; Hendry, Stevenson, and Huang 2013; Silva, Stevenson, and Thurer 2015). In order to determine the fit between WLC and the company under study, Henrich, Land, and Gaalman (2004) develop a contingency-based framework for assessing the applicability of WLC by presenting 12 product- and process-related characteristics that indicate the match. The early work by Hendry, Elings, and Pegg (1993) reports some pitfalls in the implementation process and highlights the importance of usability and training of the end user. A more recent paper by Hendry et al. (2008) investigates issues that arise from implementing WLC and identify 17 implementation issues. They use a comparative case study analysis of a capital goods manufacturer and a precision engineering subcontractor and categorise the identified issues into five main areas: market, primary manufacturing process, WLC system, information flow and organisational embedding related issues. This list is validated and expanded by three issues by Hendry, Stevenson, and Huang (2013). The latter study also describes how most of the issues can be addressed. A relatively similar study was conducted by Stevenson and Silva (2008). They present a comparative case study between two implementation projects in MTO companies (Silva, Roque, and Almeida 2006; Stevenson 2006) and focus on the refinements both companies make to the WLC concept. Additionally, Soepenberg, Land, and Gaalman (2012) present a longitudinal study of a WLC implementation and highlight issues of WLC approaches in dynamic (practical) settings. Finally, a very recent study of Silva, Stevenson, and Thurer (2015) shows that WLC can be implemented successfully by practitioners as well (mostly without researcher intervention). They report a successful practitioner-led implementation of a WLC concept at a company producing aluminium rails on a MTO basis.

The papers discussed in category two above focus mainly on the implementation process. The third category of literature in this review (studies proposing implementation strategies) goes one step further and propose implementation strategies, meaning that they additionally outline a roadmap including the steps before the implementation process (pre-implementation) and (in some cases) the post-implementation phase. Within the third category (studies proposing implementation strategies) are the papers by Fry and Smith (1987), Fry, Karwan, and Steele (1992), Wiendahl (1995) and Stevenson et al. (2011). Fry and Smith (1987) provide a six-step implementation strategy for implementing a WLC concept (they only implement the order release stage) and they also apply this strategy to a bearings manufacturer (Fry, Karwan, and Steele 1992). The first five steps are pre-implementation or preparatory steps: (1) Worker incentives analysis (management related); (2) Identification of bottlenecks; (3) Norm setting; (4) Reduction of lot sizes; (5) Prioritisation of orders on the shop floor and the sixth step is the implementation of the WLC release stage. Wiendahl (1995) considers a comprehensive WLC concept and presents a six-step implementation strategy as well: (1) analysis of the manufacturing system; (2) manufacturing process improvement; (3) improvement of the feedback accuracy; (4) establish a monitoring system; (5) checking present manufacturing control and (6) implementation of the WLC concept. Finally, Stevenson et al. (2011) present an implementation strategy defining three phases: (1) Pre-implementation; (2) Implementation process and (3) Post-Implementation. Their outlined implementation strategy is the most complete to date and provides a good starting point for an implementation project which was used in this study as well.

This paper presents a new case study of a WLC implementation in practice, which has had a positive impact on the focal case study company: a crystal manufacturer for fashion, jewellery, lighting, architecture and interiors. Our interest here is not only on the performance impact, but we also discuss the implementation issues which are different to earlier studies since the case company works in a MTS environment. The two main research questions (RQ) of this paper are:

RQ1: To what extent is an order release mechanism based on workload control suitable for large make-to-stock enterprises?

RQ2: What are the main differences in the implementation process with regard to earlier studies?

This study pursues an engaged research project, using a case study. In engaged or action research, the researcher and the firm's personnel are co-researchers working to resolve or to improve the firm's issue, and to contribute to the body of knowledge (Pasmore et al. 2008). Case studies can be used for different purposes like exploration, theory building, theory testing and/or theory extension (Handfield and Melnyk 1998). With regard to the two research questions stated above, we pursue theory testing for our research question RQ1 since we test the theory by Zäpfel and Missbauer (1993) and Bechte (1994) that WLC concept is applicable to MTS companies. And we also extend/refine theory by answering research question RQ2 which calls for refinements of earlier theories on the implementation process of WLC concepts (at MTS companies). Furthermore, according to Yin (2014) a single case company can be appropriate under several circumstances. The main rationale of case studies is that it can be regarded as a revelatory case to analyse a phenomenon previously inaccessible to scientific investigation (Yin 2014). Here, it relates to a first and unique possibility to gain in-depth empirical insights into how applicable the core function of WLC – the order release mechanism – is to a large MTS company. The main criterion for selecting a company for this study was that it could be regarded as representative (Yin 2014). Therefore, we selected a large company that works in a (almost pure) MTS environment. In 2015, the company had more than 4500 employees at the site under investigation and a world-wide turnover of approximately 2.4 billion Euros. The main data source for our study was operational (empirical) data from the ERP system, but we also used data from unstructured interviews with key participants, formal debriefing meetings following design activities and other documentation (e.g. internal white papers) which were collected from 2012 to 2016, with the primary researcher employed full-time at the company which helped to establish a strong chain of evidence. In order to reduce an observer bias, the interviews were always conducted by two or more interviewers (Voss, Johnson, and Godsell 2016).

## 3. Case study company background

The company produces crystals (e.g. for the fashion industry) and the shop floor is configured as a general flow shop. Figure 1 describes the overall process flow.

The routing varies from order to order, but a dominant flow (solid line in Figure 1) generally exists as most orders will start with the grinding capacity group. But an order can also start at the refining (A) – or refining (B) capacity group. Thus, orders visit only a subset of the major processes depicted above. The routing and operation times are

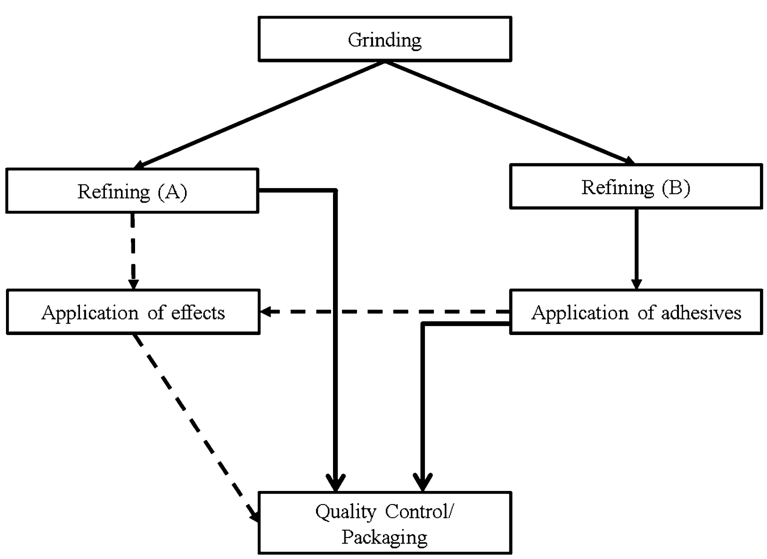


Figure 1. Overall process flow at the case company.

known for each planned order. The vast majority of orders are made to stock (for the order generation procedure see Section 3.1), the rest are customer orders which are handled separately. Bottleneck work centres can occur in all of these processes. The company uses a state-of-the-art ERP system that stores data on the orders, monitors the production process and is used to create production orders. The company generates a few hundred orders per day having a high variety of products (several thousand different final products).

These company characteristics indicate that implementing a WLC-based planning and control system is a reasonable choice although theory on selecting PPC concepts is far from mature: A centralised scheduling solution, either for the entire shop or for the bottleneck work centres in the spirit of drum–buffer–rope, would be far more complex, the latter suffering from shifting bottlenecks as described above (see also Stevenson, Hendry, and Kingsman [2005] for a discussion of DBR in MTO industries). Due to the dynamics of the situation that leads to frequent rescheduling the potential benefits of such a solution are questionable in practice. Therefore, a hierarchical planning and control system that leaves detailed scheduling to the dispatchers at the shop floor and allows utilising the specific knowledge at the shop-floor level seems more appropriate. The high number of orders (several thousands of orders simultaneously in the manufacturing system on average) allows working with planned WIP levels and release quantities that are substituted by specific work orders in the order release run. Given this hierarchical structure, WLC is often superior with respect to control of WIP and flow time as worked out in the WLC theory cited above (see Missbauer, Hauber, and Stadler [2011] for an analogous reasoning in favour of a centralised scheduling solution in the steel making industry – where the characteristics are entirely different). Note that we analyse the fit of WLC to the company under study in Section 4.1.

### 3.1 *Mid-term capacity planning*

In the case company mid-term production planning is made as follows: At first, demand forecasts for product groups are made (for six months up to three years). Thereafter, the forecasts are disaggregated using historical data on the shares of products in the product groups and are fed into the Advanced Planning System module which creates a provisional production plan by applying an optimisation model or a heuristic planning method (both are used). The resulting provisional production orders are the input to a (uncapacitated) MRP-run. Given this production plan, capacity requirements planning and load levelling are performed. Several scenarios are 'simulated' until a team of managers either decides to increase the capacity of a work centre or to authorise the generated provisional production plan. Finally, this provisional production plan may lead to an additional creation of orders in the pre-shop pool: The pre-shop pool is constantly filled with planned orders that are generated by the Reorder-Point (ROP) system which is in place at the shop floor. If the quantity of a product in the provisional production plan is greater than the planned quantity (generated by the ROP system) the discrepancy is added to the pre-shop pool. This procedure is repeated every three months.

### 3.2 *Short-term production planning*

Prior to the WLC implementation project, the company only pursued a detailed scheduling approach for the gateway work centres (grinding machines) without taking into account the downstream work centres. Urgent orders (about 5% of the orders) were expedited and short-term capacity adjustments were made by assigning overtime or extra shifts to some capacity groups. Due to the varying product mix, the prevailing planning system led to time-varying workloads and thus to changing utilisation levels at the capacity groups and as a consequence to shifting bottlenecks. Thus, high WIP levels and therefore long flow times were observed which, as a consequence, led to a poor service level. The dispatching rule First-Come-First-Serve was (and still is) used throughout the whole company.

## 4. Pre-implementation

Within this section, we describe the procedure before our implementation project started. The section starts with the assessment of the fit of WLC to the (almost pure) MTS company under study (4.1) and thereafter describes the differences to earlier WLC implementations with regard to implementation issues (4.2) and how we addressed the social and managerial implementation barriers (4.3).

### 4.1 *Assessing the fit*

We assessed the fit of WLC to the company under study using the framework by Henrich, Land, and Gaalman (2004) and Hendry, Stevenson, and Huang (2013) which was developed for implementing a comprehensive WLC concept in MTO driven companies (see Table 1 below).

Table 1. Assessing the fit of WLC to the company (adapted from Hendry, Stevenson, and Huang 2013).

| Contextual factors | LUMS WLC 'best fit' | Evidence in company | Assessing the applicability |
|---|---|---|---|
| Order arrival intensity | A high arrival rate of many relatively small jobs allows greater flexibility at job release and for workload balancing | Make-to-stock production with a periodic reorder point system that orders a few hundred order/day on average | Not applicable for MTS manufacturers |
| Inter-arrival time variability | WLC pre-shop pool typically absorbs high inter-arrival time variability | No variability in the inter-arrival times but only in the amount of orders per day since the MPS generates the order list at the beginning of each day | |
| Due date (DD) tightness | Low tightness (adequate slack) provides flexibility at the job release stage | Low tightness as there is a large difference between average shop flow throughput times and delivery lead times which are defined for each product group | |
| Variability of DD allowances | Shop floor buffering using the pre-shop pool suits high variability of DD allowance | Low variability of DD allowances as only 5% of all orders are rush orders | |
| Processing time lumpiness | Short processing times on average allow greater workload balancing and the use of aggregate workload measures | An average order processing time of a few hours which is considered as short. Thus, we consider low lumpiness because large orders only rarely occur | Poor fit • Best fit |
| Processing time variability | High variability of processing times provides flexibility to balance workloads; and to provide resource and shop floor buffers | Moderate unit processing time variation (varies between 50% and 300% of the average order processing time) | Poor fit • Best fit |
| Set-up/ processing time ratio | A low ratio between set-up and processing times is expected for WLC to be effective because joint release due to sequence dependent set-up times is not required | A low ratio between set-up and processing time | Poor fit • Best fit |
| Routing sequence variability | High variability provides a greater number of options and a greater mix of jobs for job release and workload balancing | High variability, about 80 of possible routings through the general flow shop | Poor fit • Best fit |
| Routing length | WLC best serves short routing lengths, on average, so that simple priority rules after order release are sufficient | Orders have four operations in their routing, on average, priority rules are predominantly FIFO | Poor fit • Best fit |
| Routing length variability | High routing length variability provides flexibility for load balancing; and resource and shop floor buffers | Varies from one to six operations | Poor fit • Best fit |
| Routing flexibility | High flexibility is good for balancing workloads across work centres | High flexibility, since nearly all machines are inter-changeable and semi-skilled people can move across sections | Poor fit • Best fit |
| Level of | convergence | Using the release stage as the main control point works best if there is a low level of convergence for parts that need to be assembled | No sub- |
| assembly/ assembly structures for the products | Poor fit | • | Best fit |

Note that the framework depicted in Table 1 was developed based on case studies that implement a whole PPC system to SME MTO firms (see Henrich, Land, and Gaalman 2004; Hendry, Stevenson, and Huang 2013). The first column of Table 1 depicts 12 different contextual factors which were identified by Henrich, Land, and Gaalman (2004) and Hendry, Stevenson, and Huang (2013). The second column shows the 'LUMS WLC best fit' which was adopted from the study of Hendry, Stevenson, and Huang (2013). The third column depicts the characteristics of our case company with regard to 12 contextual factors and finally the fourth column shows the assessment of the expected fit of WLC to the company. Thus, the first four contextual factors (order arrival intensity, inter-arrival time variability, due date tightness and due date allowance) are not applicable to our case company since the order arrival stream is determined by the Master Production Schedule (MPS) and MRP module in a MTS setting (therefore shaded in grey in Table 1). Note that in the beginning of the project, we filled out the whole framework since it was very much appreciated by the company representatives and proved to be helpful to convince managers of the applicability of WLC-based concepts.

The scale for measuring the fit of the WLC mechanism to the case company consists of four levels: (1) 'poor fit', (2) 'moderate fit', (3) 'high fit' and (4) 'best fit'. One can see in Table 1 that the fit of the case company to use WLC was quite high for most indicators identified by Henrich, Land, and Gaalman (2004) and Hendry, Stevenson, and Huang (2013). Only one category yielded a moderate fit: processing time variability (see Table 1). Hendry, Stevenson, and Huang (2013) argue that high processing time variability is most suitable for WLC since it provides more flexibility to balance workloads. With regard to our case company, we defined the processing time variability as being moderate (variation between 50% and 300% of the average order processing time). However, we were confident that this factor does not reduce the load balancing function of the WLC mechanism too much and thus concluded a high level of fit for WLC at the case company. Note that none of the other prior studies that used this framework have had a 'best fit' across all of the criteria.

### 4.2 *Implementation issues*

With regard to implementation issues, we follow Hendry et al. (2008) and Hendry, Stevenson, and Huang (2013) who categorise implementation issues into five main areas: market/customer (A), primary manufacturing process (B), WLC system (C), organisational embedding (D) and information flow (E) related issues and identify 20 implementation issues (see first column of Table 2). Additionally, we list all 20 implementation issues identified by Hendry et al. (2008) and Hendry, Stevenson, and Huang (2013) in column two of Table 2 and indicate in column three whether we encountered these issues as well. Finally, in column four we shortly comment each issue with regard to the situation at the case company. In the course of our implementation study, we only encountered nine implementation issues. Eight out of 11 issues were not relevant to our case due to the following 3 reasons:

- The major difference between earlier studies that implemented WLC concepts and our study is that the company under investigation works in a MTS environment. Therefore, five issues (A1, A2, A3, B5 and C2) were not relevant (shaded light grey in Table 2).
- We 'only' implemented the order release mechanism (and not a whole PPC system). Therefore, one issue (C1; 'blue' (dark grey) in Table 2) was only a minor problem in our case company.
- Our case company is a large company (earlier case studies were mostly done with SMEs) and thus two issues (E1, E2; shaded 'orange' (light grey) in Table 2) were no problem since the IT-department is used to adaptions of the ERP system (which may be the case at most large companies).

Finally, we did not encounter the remaining three issues (B1, B2 and C3) due to the production process in our case company (see Table 2).

As one can see in Table 2 only 9 out of 20 implementation issues were relevant to our implementation project. In detail, four (A5, B3, B4, D1) can be classified as being minor and five as being major implementation issues (A4, D2-D5). The minor issues of having both MTO and MTS production (item A5: 'Hybrid production' in Table 2) and of inter-changeable machines (item B3: 'Alternative shop floor routings' in Table 2) were addressed by (1) simply giving MTO orders higher priority and (2) by grouping inter-changeable machines to work centres (as described in Hendry et al. [2008, 2013]) .With regard to the 'industry specific process' issue (item B4 in Table 2) we only had a minor issue of integrating minimum lot sizes (for the first production stage) into our WLC mechanism (see Section 5.1 for a detailed description). Finally, we only encountered a minor issue with the 'awareness of the concept of WLC' (item D1 in Table 2) since nearly all managers knew the concept of WLC (since LOMC is quite popular in German speaking countries). Note that we nevertheless agree with earlier studies on WLC implementations (e.g. Hendry, Stevenson, and

Table 2. Implementation issues at the case company.

| Category | Key implementation issues (Hendry, Stevenson, and Huang 2013) | Confirm (y/n) | Description | |
|---|---|---|---|---|
| A. Market/ customer | A1 | Characteristics of order quotations | n | No issue for MTS manufacturer |
| | A2 | Uncertainty at the customer enquiry stage | n | |
| | A3 | Rush orders | n | Only 5% of all orders are rush orders |
| | A4 | Seasonality and volume growth | y | Case company also faces seasonal demand |
| | A5 | Hybrid production | y | Only a small number of orders are MTO |
| B. Primary process | B1 | Assembly requirements | n | No assembly structures |
| | B2 | Sequence dependent set-up times | n | No sequence dependent set-up times |
| | B3 | Alternative shop floor routings | y | Some machines are inter-changeable |
| | B4 | Industry-specific process | y | Batching at grinding machines |
| | B5 | Uncertainty after the order release stage (e.g. changing customer priorities) | n | No issue for MTS manufacturer |
| C. WLC system | C1 | WLC-related start-up issues (e.g. change of WLC parameters) | n | Minor issue since 'only' order release was implemented |
| | C2 | Incomplete routing data at customer enquiry | n | No issue for MTS manufacturer. Routing is known beforehand |
| | C3 | Time-span-dependent critical resources (e.g. changing bottlenecks from mid- to short-term) | n | No major difference was noted between mid- and short term identification of bottlenecks |
| D. Organi-zational embedding | D1 | Awareness of the concept of WLC | y | Only managers knew the concept (not the implemented LUMS approach) |
| | D2 | User visibility | y | End-users had problems with calculations of norms (see Section 5.1) |
| | D3 | Support of task structures | y | Nearly no coordination between managers and production planners |
| | D4 | End-user choice and involvement | y | Resistance of employees (see Section 4.3) |
| | D5 | Accommodating functionality requests | y | Functionality requests led to the design of the workload control cockpit (see Section 5.1) |
| E. Infor-mation flow | E1 | System-related start-up issues | n | Very minor issue for large company/IT-department |
| | E2 | Integration with other systems | n | |

Huang 2013) that training of end users is one of the key aspects to a successful implementation of a WLC concept (see also Section 4.3).

The major implementation issues (A4, D2-D5) were encountered as follows: With respect to issue A4 (Seasonality), we followed the suggestion by Hendry et al. (2008) to use flexible workload limits. With regard to the four issues listed in category D (organisational embedding) we addressed them by paying special attention to the pre-implementation phase as described in the next subsection.

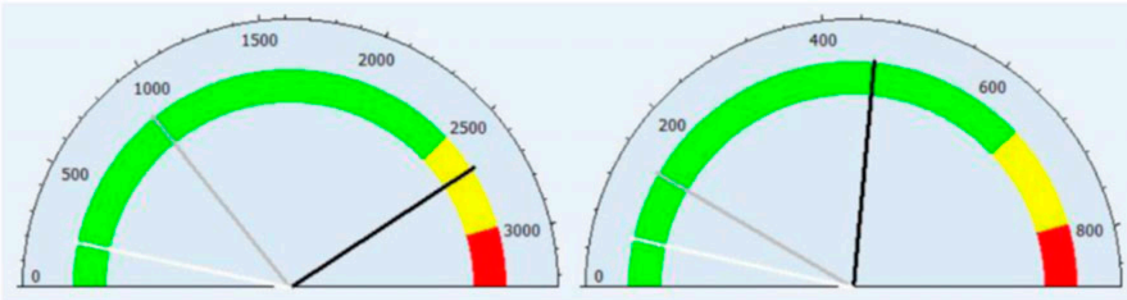


Figure 2. Workload control cockpit – a visual decision support tool.

### 4.3 *Overcoming managerial and social implementation barriers*

The main cause of resistance was due to the so-called 'status quo bias', meaning that resistance can be due to the bias or preference to stay with the current situation (Samuelson and Zeckhauser 1988). At the beginning of the implementation project, supervisors and workers on the shop floor were also sceptical, but they soon appreciated the benefits of the WLC concept. An additional challenge was a change in the management team where we had to ensure that the project momentum was retained. With regard to these social and managerial implementation barriers, we followed the literature and took measures to ensure a successful implementation (as described in Hendry, Stevenson, and Huang 2013):

- We regularly held shop floor meetings with all affected workers to explain what will change in their daily routines and what role they could play.

  In order to gauge commitment and readiness for a full implementation of the order release mechanism, we decided to initially start a 'test run' with the chosen WLC approach for some representative product groups. For the 'test run', we selected product groups that make up the major share of the volume at the company and reserved capacity at the work centres for the 'test run', respectively.

  This enabled us to embed the WLC concept in the organisation and to accommodate functionality requests made by the end users (as also described in Hendry, Stevenson, and Huang 2013). For example, a user interface (the 'WLC cockpit'; see Figure 2 below) was designed within this test phase which created a sense of ownership of the resulting system. Furthermore, we used some scenarios from this 'test run' for training of end users from other production lines and we could adapt the prevalent planning procedure and modify the ERP system to fit the WLC concept.
- Finally, we held regular planning meetings to ensure understanding and to retain project momentum (Lock 2007).

## 5. Order release mechanisms based on WLC

Over time several order release mechanisms were developed (see, e.g. Thuerer, Stevenson, and Silva 2011 for a comprehensive review). The aim of this study was to implement a WLC order release mechanism that lowers WIP levels and thus reduces flow times at the case company. Throughout the discussion with the company representatives, the following three criteria seemed to dominate the debate on the suitability of different order release mechanisms:

(1) Simplicity of the mechanism since all end users should understand the concept.
(2) Robustness of the approach since repetitively recalculating and updating of parameters is not desirable.
(3) Knowledge/awareness of the concept. Managers quickly excluded order release mechanisms they did not know beforehand.

We used the reference framework presented by Bergamaschi et al. (1997) (see Table 3) to design the WLC order release mechanism.

Regarding the *order release mechanism* (Bergamaschi et al. 1997) we chose the *load limited* approach where the order release decision is based on the workload which is contrary to a time-phased order release mechanism which bases the order release decision on a computed release date which normally neglects the shop load at that time. We adopted a *discrete timing convention* meaning that orders are released at every discrete time interval, since the decision of order release is made once a day in the case company. Furthermore, we chose to use the *work quantity* (e.g. in hours of work) rather than the number of jobs as the *workload measure*, since measuring the workload in number of jobs would be too

Table 3. Design options for order release mechanisms based on WLC (Bergamaschi et al. 1997).

| Dimensions | Options | |
|---|---|---|
| Order release mechanism | Load limited | Time phased |
| Timing convention | Continuous | Discrete |
| Workload measure | Number of jobs | Work quantity |
| Aggregation of workload | Total shop load | Bottleneck load |
| Measure | Load by each work centre | |
| Workload accounting | Time bucketing | Probabilistic |
| Over time | Atemporal | |
| Workload control | Upper bound only | Upper and lower bounds |
| | Lower bound only | Workload balancing |
| Capacity planning | Active | Passive |
| Schedule visibility | Limited | Extended |

unprecise (Bergamaschi et al. 1997, 408). We chose the *load by each work centre* for the *aggregation of workload measure* since this workload measure is the most precise and earlier studies emphasise its use in practice (see e.g. Bergamaschi et al. 1997, 409). The *workload accounting over time* strategy was subject to several discussions and will be discussed later in a more detailed way. With regard to *WLC* we decided to use an *upper bound only*. Earlier studies report a decrease in performance by adding a lower bound (Cigolini and Portioli-Staudacher 2002) and furthermore Stevenson and Hendry (2006) suggest using an upper bound only in order to limit initial errors and the start-up time. We adopted an *active capacity planning* approach (rather than passive capacity planning) which means that the mechanism can adjust the machine capacity during the system's operation. This can be done by either assigning overtime or by reallocating workers to work centres. Note that the possibility of combining capacity adjustments (output control) with order release mechanisms (input control) was emphasised in early WLC research (e.g. input/output control by Wight [1970]) as well as in very recent studies that show a positive impact of combining input and output control on the performance of WLC mechanisms (Thuerer et al. 2016).The last criterion by Bergamaschi et al. (1997) is the length of its planning horizon, thus, the amount of information on future planned orders which is called *schedule visibility*. Due to the lack of implementation studies of order release mechanisms with an extended schedule visibility (e.g. BaLanced Release (BLR) by Portioli-Staudacher and Tantardini [2012] or optimisation-based order release models of Asmundsson et al. [2009]) we chose to use a *limited schedule visibility*. Note that during the implementation project we added a feature in our visual decision support tool (WLC cockpit) that addresses this issue (see Section 5.1).

With regard to workload accounting over time, three options have been presented in the WLC literature: The time bucketing approach (see e.g. Bobrowski 1989), the probabilistic approach (see e.g. Bechte 1994) and the atemporal approach (see e.g. Bertrand and Wortmann 1981).

- *Time bucketing approach*: The time bucketing approach was introduced by Bobrowski (1989) and divides the planning horizon into load periods (‘time buckets’). By the use of forward or backward scheduling or with the help of a flow time estimator (e.g. Total Work Content; see Melnyk and Ragatz 1989), the approach assigns each operation to the appropriate time bucket. We did not choose this approach since firstly (1) in comparison to the atemporal approach (see below) the time bucketing approach is more complex and secondly (2) the simulation study by Cigolini, Perona, and Portioli (1998) shows that – in comparison to the other two workload accounting strategies – time bucketing is the least robust approach.
- *Probabilistic approach (LOMC):* Several studies describe this approach theoretically and also report successful implementations (Bechte 1988, 1994; Wiendahl 1995; Riezebos, Korte, and Land 2003). As described above, this method divides the workload into direct and indirect load. Thus, the probabilistic WLC approach estimates (based on historical data) the input to the direct load of each work centre over time and converts the direct load contributed at release using a depreciation factor (see Bechte 1994, 298). In the beginning of the implementation project, management preferred this approach since some of the managers were aware of LOMC which is quite popular in German speaking countries. However, two arguments led to an refusal of the approach: Firstly, the study by Oosterman, Land, and Gaalman (2000) shows that in the case of directed material flow the probabilistic approach is outperformed by the atemporal approach and secondly in comparison to the atemporal approach the probabilistic approach was too complex (especially the load conversion procedure).

- *Atemporal approach (LUMS):* The classical aggregate load approach by Bertrand and Wortmann (1981) and Hendry and Kingsman (1989) simply adds direct and indirect load (so-called aggregate load) but does not consider the position of a work centre in the routing of an order. Therefore, Oosterman, Land, and Gaalman (2000) proposed an order release mechanism that corrects the load calculation by dividing the contributed load by the position of a work centre in the routing which leads to more robust workload norms by levelling short-term load fluctuations. Thus, the two main reasons for choosing this approach was firstly that the atemporal approach was shown to be superior to the probabilistic approach (e.g. Oosterman, Land, and Gaalman 2000; Henrich 2005) and secondly because of its simple workload accounting over time.

The next subsection describes the implemented order release mechanism in detail.

### 5.1 *Implemented order release mechanism*

The implemented order release mechanism subdivides the workload into the direct load ($WL_n^{direct}$) at the work centre and the upstream load. Both parts together are the so-called aggregate load. For each work centre $n$ a workload norm ($WN_{n,t}$) is defined for each period $t$ as follows (see Lödding [2008, 370] or Oosterman, Land, and Gaalman [2000] for similar expressions):

$$WN_{n,t} = E[WL_n^{direct}] \cdot \frac{\sum_{j=1}^{J} (p_{j,n} \cdot T_{j,n}^{aggregate})}{\sum_{j=1}^{J} (p_{j,n} \cdot T_{j,n}^{direct})} + \bar{O}_n, \tag{1}$$

With

| | |
|---|---|
| $E[WL_n^{direct}]$ | Expected direct workload at work centre $n$, measured in time units, |
| $p_{j,n}$ | Operation time of order $j$ at work centre |
| $\bar{O}_n$ | Average output at work centre $n$ (measured in time units) |
| $T_{j,n}^{aggregate}$ | Time from release of order $j$ until its completion at work centre $n$ |
| $T_{j,n}^{direct}$ | Flow time of order $j$ at work centre $n$ (time between entry to the queue and completion at work centre $n$) |

The reasoning behind using Equation (1) is the following: The expected direct workload $E[WL_n^{direct}]$ at work centre $n$ is estimated based on the planned flow time (which is set by production management) and the planned throughput using Little's Law (Little 1961). Since planned flow times are defined for all work centres $n$ and the routing of each order is known, the planned flow time at each work centre ($T_{j,n}^{direct}$) and the planned time from release until completion at each work centre $n$ ($T_{j,n}^{aggregate}$) are known for each order. The contribution of order $j$ to the direct load at work centre $n$ (load, measured in hours of work, at the work centre multiplied by the time the work spends at the work centre) is $p_{j,n} \cdot T_{j,n}^{direct}$. Likewise, $p_{j,n} \cdot T_{j,n}^{aggregate}$ is its contribution to the aggregate load of work centre $n$. Thus, the fraction in Equation (1) is the estimated steady-state ratio between average aggregate load and average direct load of work centre $n$ for given planned flow times, and the planned expected direct workload $E[WL_n^{direct}]$ at work centre $n$ is scaled up by this ratio (see the reasoning in Lödding [2008, 369]). The average output at the work centre ($\bar{O}_n$) is added to the workload norm since order release decisions are made periodically and the norm should also include a provision for the capacity during the period (see Bertrand and Wortmann 1981, 338).

Note that the calculation of the workload norms (Equation (1)) is made by the management and the user never sees this formula, but only the value of the limit on the aggregate load per work centre.

For the order release decision, we check whether the operation time of order $j$ together with the current aggregate workload of each work centre fits within the calculated workload norm calculated in equation (1). This is contrary to other atemporal approaches (e.g. LUMS – Corrected Order Release mechanism; see e.g. Thuerer et al., 2016) which compare the current direct load to the workload norms of the work centres. The order release mechanism works as follows:

(1) Select all orders from the pre-shop pool with a planned release date within a specified time limit (normally four days). These pre-shop pool orders are automatically sorted by given priorities (e.g. due dates) which can be altered by the production planner (which is done occasionally). Note that the due dates of the orders are set for each order individually by adding the average total throughput time of the order to the date the order was generated.
(2) Select the order with the highest priority (e.g. earliest due date).

(3) Check whether the order quantity is greater than the required minimum lot size at the required grinding machine.
   (a) If yes, go to step 4.
   (b) If no: Search within the pre-shop pool for orders of the same setup family (orders that require the same grinding machine).
      (i) If there is another order of the same setup family: add it to the current order and go back to step 3.
      (ii) If there is no eligible order, increase the quantity of the order to the minimum lot size and go to step 4.
(4) Does the order fit the workload norm as calculated in equation (1)?
   (a) If yes, release the order(s).
   (b) If not, then delete the order from the order list and go to step 2 (Note that the first order that exceeds a norm is released (Bechte 1988; Thuerer, Silva, and Stevenson 2010).

The production planner has the authority to change the automatically generated order release list within the bounds provided by the WLC system. Therefore, we designed the WLC cockpit (provided for each work centre) which is a visual tool to support the altering process (see Figure 2).

The WLC cockpit is structured into three areas (from left to right: green, yellow, and red; here dark grey, light grey and black, respectively). The upper bound of the 'green' (dark grey) area is the workload norm as calculated in equation (1) and the 'yellow' (light grey) area marks the (predefined) allowed overload. Furthermore, the WLC cockpit shows three different pointers (black, grey and white).

- The black pointer indicates the aggregate workload at the respective work centre which is calculated as the direct workload (sum of all operation times of orders waiting in front of a capacity group and the remaining processing time of orders in process) plus the indirect workload (sum of operation times of orders upstream that need to be processed by this capacity group).
- The grey pointer shows the direct workload of the work centre.
- The white pointer shows the workload waiting for release in the pre-shop pool. We added this information in order to address the limited schedule visibility of this order release mechanism. Information on the workload in the pre-shop pool enables the production planner to anticipate the consequences of today's decisions on the workload of tomorrow.

If the aggregate workload of the work centre (black pointer) is on the left-hand side/below the 'red' (black) area order release is permitted (with restriction in the 'yellow' (light grey) region) and is blocked if it is in the 'red' (black) zone. The WLC cockpit is provided to all involved employees (managers, production planners, supervisors and shop floor workers) and also indicates a need for capacity adjustments. When a work centre enters the 'yellow' (light grey) area, a standardised problem solution process is triggered. For example, this process includes a discussion with management on possible short-term capacity adjustments. These can be made via short-term overtime or by reallocating operators from an under-loaded to an overloaded work centre. Finally, the parameter setting is revisited regularly in accordance with the main users of the WLC mechanism. Note that at the beginning of the project, the authors suggested to include a pull release option in order to avoid premature idleness (as described in Stevenson 2006), but until now it has not been included in the implemented WLC mechanism.

### 5.2 *Impact on performance measures*

In order to assess whether the implementation of the WLC mechanism is successful we measure the average lead times, lead-time variation and we conducted some interviews with key company personnel. We define lead time as the time duration from an order's release date to its completion time. The implementation project was initiated in 2012 and since the implementation in 2014 the performance increased substantially. Figure 3 exhibits the average lead times and lead-time variation the year before and one year after the implementation project was finished, respectively.

The average lead time and the lead times before the implementation project (dashed lines) represent the reference values and are compared to the same measures and the same time span after the implementation project was completed. One can see that the average lead time was reduced by approximately 40% and that lead-time variation could be reduced significantly. The positive effect of the implemented WLC mechanism on the lead-time variation is most obvious in June where the lead time normally reaches a peak due to seasonal effects which is amplified by business holidays in May. Of course the reduction in average lead times and lead-time variation cannot solely be attributed to the implemented WLC mechanism since other measures were introduced in the company as well. In particular the following two initiatives should be mentioned: First, the technical improvement that this company is undergoing constantly which

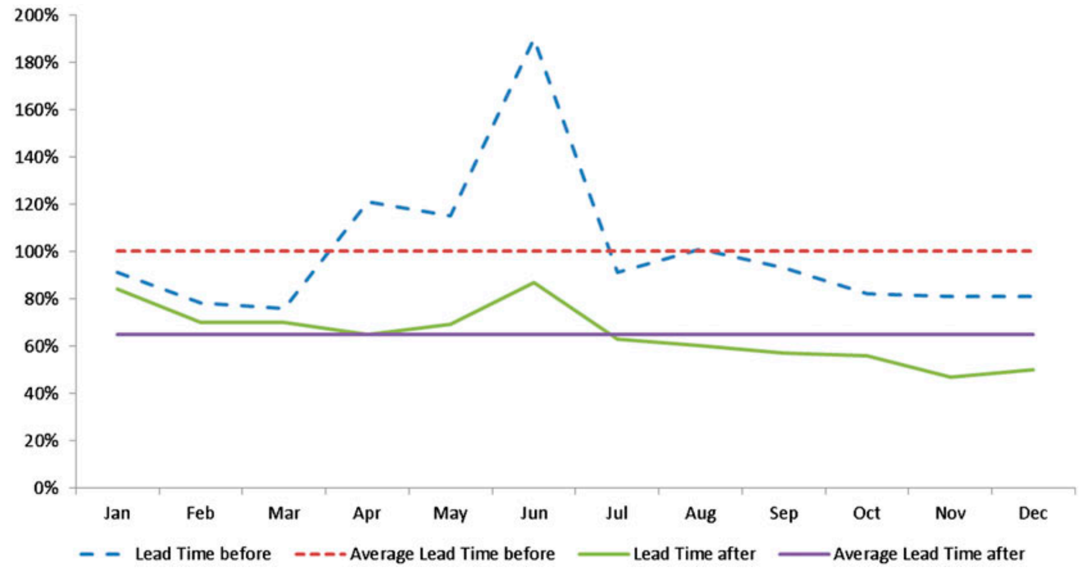


Figure 3. Development of average lead times before and after the implementation project.

increased the overall performance at certain machines. And second, several ‘lean management tools’ were implemented in some departments e.g. to improve the transparency of the situation on the shop floor. However, the WLC project was the only project to include the whole material flow of the company and thus had (and still has) the most influence on the total lead time, since the lean instruments were only implemented to particular departments. Note that due to confidentially reasons we are not able to include more performance indicators, but we substantiate the success of this implementation project without disclosing specific numbers:

- After the implementation of the WLC mechanism the total throughput times remained on the same level as in 2012 (before the WLC implementation). Additionally, we want to note that the economic valuation of orders waiting in the ‘order pool’ is different to orders that wait on the shop floor. A company will always prefer longer and more volatile pool waiting times then shop floor throughput times.
- The service level slightly increased and the output of the production system did not decrease after implementing the WLC mechanism.

Furthermore, we obtained qualitative insights into the effectiveness of the approach, with managers, production planners, supervisors and shop floor workers describing the WLC mechanism as being successful and extremely useful. They especially emphasised that the implemented WLC mechanism facilitates coordination between production planners and line managers and that the tool offers valuable support in the decision-making process. Supervisors and shop floor workers described the WLC mechanism as being very valuable and that its implementation led to more smooth workloads over time.

## 6. Conclusion

This study adds to the growing body of evidence that WLC can contribute positively to a company’s performance. This paper described a successful implementation of an order release mechanism based on WLC in a large almost pure make-to-stock (MTS) company. The paper describes the implementation process, how the order release mechanism was implemented and its impact on the company’s performance. The average lead time of the case company could be reduced by approximately 40% and the lead-time variation was reduced significantly. We showed that – if social and managerial implementation barriers are properly addressed – an order release mechanism based on WLC can be applied to large MTS manufacturers using a state-of-the-art ERP system. Additionally, it was shown that due to the company characteristics (large MTS company) less implementation issues arose and thus WLC can be implemented to a wider range of companies than suggested by recent empirical WLC literature.

The existing implementation frameworks from literature (especially the most recent form Stevenson et al. 2011) are very precise and almost complete. Although we do not think that important steps should be added, we want to highlight some important observations from this implementation study. Please note that, different to earlier implementation studies within the WLC literature (e.g. Hendry et al. 2008; Hendry, Stevenson, and Huang 2013), we 'only' implemented an order release mechanism and not a whole PPC system based on WLC: First, with regard to implementing WLC to MTS environments one has to put a strong emphasis on the suitability of the chosen WLC mechanism to the company under study. Second, throughout this implementation study we had an excellent IT-support which might be a general advantage of implementing WLC mechanisms to large companies. And finally, overcoming managerial and social implementation barriers was one of the key success factors to this project which might be true for implementation studies in general (as pointed out by Bhasin and Burcher [2006] as well).

We overcame these barriers by paying special attention to the pre-implementation phase in order to get 'quick wins', which was important for gaining appreciation and enthusiasm during the initial implementation stage (Maier and Remus 2003). This was done by holding several shop floor meetings with all affected workers and by implementing the chosen WLC approach for some representative product groups. This enabled us to embed the WLC concept in the organisation and to accommodate functionality requests made by the end users. Furthermore, within the pre-implementation phase we collaboratively designed a novel user interface called 'WLC cockpit' which increased the user acceptance and created a sense of ownership of the resulting system (as described in Hendry, Stevenson, and Huang 2013). We hope that this visual decision support tool may help to facilitate a more widespread use of WLC in practice and provide successful post-implementation results in future research. Future studies need to test and expand on our findings especially with regard to the application and implementation issues of WLC in make-to-stock environments and large enterprises.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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