International Journal of Operations & Production Management

Emerald Article: Workload control: Successful implementation taking a contingency-based view of production planning and control

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Workload control

Successful implementation taking a contingency-based view of production planning and control

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Received 5 November 2010
Revised 10 August 2011
11 January 2012
26 March 2012
Accepted 5 May 2012

Abstract

Purpose – The purpose of this paper is to present a successful implementation of a comprehensive workload control (WLC) concept; and to describe the associated implementation process.

Design/methodology/approach – Longitudinal action research using a contingency-based approach to ensure alignment between the case company and the characteristics of the WLC approach; and the resulting expected improvements in performance. A set of 17 issues and responses from the literature is used as a checklist for implementing WLC.

Findings – Performance improvements include: reduced lead times; significant improvement in lateness and tardiness; reduced costs; improved internal and external co-ordination; and higher quality. The relevance of 15 of the 17 implementation issues is confirmed along with the same response as in previous research for ten issues and an improved response for five issues. In addition, three new issues are identified and addressed.

Research limitations/implications – Dependability was a more important competitive priority in this company than speed; and, therefore, the ability of WLC to reduce lead times was not fully assessed.

Practical implications – The importance of a contingency-based approach to production planning and control is confirmed. Comprehensive WLC approaches are closely aligned with the high-variety/low-volume context of make-to-order (MTO) companies.

Originality/value – This is the first paper that empirically demonstrates performance improvements resulting from WLC alongside a detailed discussion of the implementation process. Few examples of successful implementations have been published previously, and these tend to treat the implementation process as a "black box". Where more detail on the implementation process has been given in previous studies, evidence of effectiveness in practice was not provided.

Keywords Workload control, Implementation strategy, Make-to-order, Production planning and control, Action research, Performance management

Paper type Research paper

International Journal of Operations & Production Management
Vol. 33 No. 1, 2013
pp. 69-103

0144-3577
DOI 10.1108/01443571311288057

1. Introduction

Although production planning and control (PPC) is a seemingly mature topic, authors such as Tenhiälä (2011) have called for further research so more successful implementations of appropriate PPC methods can be achieved. Tenhiälä (2011) suggested many implementations fail because a contingency-based view is not taken when selecting a PPC approach, thus firms attempt to implement systems that are inapplicable. It follows that there is a need to develop approaches that are contingent on key company characteristics, including production strategy and process type. Workload control (WLC) is one such approach, primarily designed for the make-to-order (MTO) sector where job shop configurations are common. Land and Gaalman (2009) indicated that such companies continue to have inadequate planning information for sales decisions but that WLC is uniquely placed to meet their PPC requirements, particularly among small and medium sized enterprises (SMEs).

A particular focus of this paper is on the process required to successfully implement WLC. First, there are issues that may exist for any concept, such as those related to resistance to change. Authors such as Hendry *et al.* (2008) indicated that resistance can be particularly strong when a concept is not well-known amongst practitioners, as is the case for WLC. Second, many practical issues arise for which theoretical research has made simplifying assumptions; as a result, refinements to PPC theory may be identified to enable a better fit with the production environment in practice. For this reason, implementations of new research ideas are often followed by a return to the "drawing board" to refine the underlying concept. For example, Thürer *et al.* (2010) described their simulation study as a return from case study research to theory development in which they consider how WLC theory can be refined to handle the varying job sizes and rush orders observed in practice. In addition, Perona *et al.* (2009) encouraged greater interaction between research and practice when PPC approaches are developed, so that incremental improvements that bridge the gaps between theoretical methods and everyday production can be found. It is therefore argued that there is a need for more participation with companies through action research to develop and refine PPC approaches such as WLC, whilst also exploring how to implement them successfully.

Many WLC methodologies, varying in sophistication, are described in the literature (Land and Gaalman, 1996). The common denominator is the use of a pre-shop pool and job release mechanism (Wisner, 1995). First, jobs are held back in a pre-shop pool to regulate congestion on the shop floor. While in the pool, unexpected changes to quantity and design specifications can be accommodated. Second, jobs are released in time to meet Due Dates (DDs) whilst ensuring workloads do not exceed certain limits or norms. Limits are typically set on the released workload length (RWL), which refers to the time required (e.g. days or weeks) to process the current workload based on planned capacity. RWL limits are defined for each work centre and RWLs are monitored to ensure the limits are not exceeded as each job is released. Thus, WLC partially embodies lean manufacturing principles in a MTO context where a full implementation of lean, e.g. using kanban signals, is not feasible (Stevenson *et al.*, 2005). As is argued by Fredendall *et al.* (2010), WLC sets an upper limit on work-in-process (WIP) through the use of RWL limits, creating a pull system which is an essential element of lean production (Hopp and Spearman, 2004). As a result, the shop floor consists of a series of short queues making it independent of variations in the incoming order stream (Bertrand and Van Ooijen, 2002), reducing WIP and lead times (Hendry *et al.*, 1998). It may be possible to reduce the current workload length and increase the input rate of orders if the output rate can be increased (e.g. through over time or by reallocating operators from an under-loaded to an overloaded work centre) – this is known as input/output (I/O) control (Wight, 1970).

While all WLC approaches have a pre-shop pool and job release mechanism – meaning the shop floor is less congested and only a simple dispatching rule is needed (Kingsman, 2000) – the most comprehensive cover four PPC stages: customer enquiry planning, when bids are made; job entry planning, when jobs are confirmed; job release; and (simplified) priority dispatching (Thürer *et al.*, 2011a). In comprehensive WLC concepts, a hierarchy of workloads and workload lengths are controlled whereby planned workload lengths (PWLs) are controlled at the job entry stage and total workload lengths (TWLs) are controlled at the customer enquiry stage in addition to RWLs at the job release stage. PWLs are based on the workload of all accepted orders and TWLs on the workload of all accepted orders plus a proportion of unconfirmed orders according to order winning probability, known as the strike rate percentage (Kingsman *et al.*, 1996; Kingsman and Mercer, 1997). I/O control can be exercised throughout the hierarchy of workloads, simultaneously planning capacity (output) at the same time as making decisions regarding the jobs (input). The evidence presented by Land and Gaalman (2009) suggests a need for more successful implementations of comprehensive WLC approaches; and, more research evidence to determine the effect such approaches have on key performance measures.

To date, most WLC research attention has focused on theoretical development of the concept. Relatively little WLC research has focused on implementing the concept in practice (Stevenson *et al.*, 2011). Where successful implementations have been reported (Bechte, 1994; Park *et al.*, 1999), the implementation process itself has been treated as a "black box", thus detailed information on how success was achieved is limited. Thus, there is a significant gap in the literature to describe a successful implementation along with an understanding of the implementation process itself. There is also insufficient empirical evidence on the impact of WLC on key performance indicators for MTO companies. Such research may facilitate more widespread adoption of WLC in practice. This paper seeks to contribute by describing a longitudinal action research project conducted over more than three years with a subcontract precision engineering company in which a comprehensive WLC approach was successfully implemented.

The remainder of the paper is structured as follows. Section 2 reviews WLC literature, focusing on empirical evidence on the implementation process. Section 3 outlines the research method and specifies the research question before Section 4 justifies the choice of performance measures used to determine whether a WLC implementation has been effective. The findings are then discussed in Sections 5 and 6, with conclusions drawn in Section 7.

2. Literature review

WLC research can be categorised into three broad types: simulation studies; other theoretical papers and empirical papers. Simulation has been the predominant WLC research method and continues to be so. While many studies have focused on the job release stage, recent contributions have tended to focus on ways in which the method itself can be developed or to look at more complex practical environments. For example, Weng (2008) proposed a new multi-agent approach and assessed its effectiveness using simulation; Lu *et al.* (2011) considered the use of order release in a complex assembly job shop; whilst Thürer *et al.* (2011b) used simulation to compare two alternative WLC approaches to determine which would be simplest to implement in practice in terms of the ease of establishing the required parameters. In addition, Fredendall *et al.* (2010) used simulation to compare 25 WLC rules and develop WLC associated theory through a set of hypotheses. The latter authors use the term "WLC" in a broad sense to include CONWIP (i.e. CONstant work-in-progress, introduced by Spearman *et al.*, 1989) and the Drum-Buffer-Rope (DBR) concept (Goldratt and Cox, 1992).

In addition to simulations, there have also been a number of other theoretical papers which focus on using conceptual arguments or mathematical analysis to advance the field. For example, Kingsman (2000) developed a mathematical programming model of the WLC concept; Henrich *et al.* (2004) developed a contingency-based framework for assessing the applicability of WLC; and Fowler *et al.* (2002) investigated the applicability of WLC to the semi-conductor industry. Such papers play important roles in developing the theory behind WLC and many also aid in understanding what is relevant to WLC implementation in practice. However, it is argued by authors such as MacCarthy (2006) that too much research using either simulation or other theoretical methods simply widens the gap between theory and practice, if the implementation literature does not keep up with these developments.

Finally, there have been a number of empirical research papers that investigated the use of WLC in practice. The few contributions reporting successful cases of WLC implementation include those by Bechte (1988, 1994), Wiendahl (1995) and Park *et al.* (1999). Whilst these illustrate that WLC can be used successfully in practice, a number of authors have commented that the performance observed in reality often differs from that seen in simulations, a phenomenon called the "WLC paradox" (Stevenson *et al.*, 2005). For example, Bertrand and Van Ooijen (2002) remarked that empirical research reports reductions in total work order throughput time of 40-50 per cent, whilst theoretical research reports reductions of only a few percent or even an increase in total order throughput time. Thus, more research is needed to determine the effect of WLC on key performance measures in a practical MTO environment. However, to investigate this issue, it is also necessary to develop research into the process of implementing WLC so that more successful implementations can be achieved. Thus, this topic is discussed in more detail below.

2.1 Implementation process in WLC research

In a case presented by Hendry *et al.* (1993), full implementation of WLC was obstructed by: the selection of an inappropriate end-user for WLC software, who was unfamiliar with computer systems and delegated the decision support task to a secretary with no planning experience, leading to its misuse; a lack of awareness in practice regarding WLC and the parameters that need to be set in order to use the concept (e.g. workload length limits); and, a reluctance or inability to meet the information requirements of the software, leading to neglect of the system. Among other insights, this work highlighted a need for the end-user to be trained in an attempt to ensure that WLC and associated software is used appropriately.

Contributions by Fry and Smith (1987) and Wiendahl (1995) are rare in that they are empirical studies which proposed and applied strategies for implementing WLC in practice. The former presented a six-stage implementation procedure which applies to the job release stage of the WLC concept; it does not encompass the customer enquiry stage (important in customised production contexts). Wiendahl (1995) considered the implementation of a more complex WLC approach – the probabilistic load-oriented manufacturing control method – and outlined an implementation process covering six-stages. This includes the need to analyse current manufacturing performance, it explores how to change company attitudes and concludes with a full implementation of the proposed WLC system. While valuable, this did not generate a comprehensive list of the detailed implementation process that needs to be undertaken, including all the issues that can arise and how they should be overcome. Furthermore, strategy was developed in the context of a particularly complex variant of WLC. There is a need to consider how simpler variants that may be more readily adopted by practitioners can be implemented.

More recently, comparative case study analysis has provided a deeper insight into factors that influence WLC implementation (Hendry *et al.*, 2008; Stevenson and Silva, 2008). Stevenson and Silva (2008) focused primarily on theoretical refinements made to the WLC concept during two independent longitudinal WLC case study projects. The authors also highlighted a number of implementation challenges, including:

- Meeting the data requirements of the concept.
- The need to develop further strategies for implementing WLC.
- The need to increase awareness of the concept in practice.

Hendry *et al.* (2008) investigated issues arising from implementing WLC through comparative case study analysis of two MTO companies: a capital goods manufacturer and a precision engineering subcontractor. The authors asked: how should implementation issues that arise in the context of WLC be addressed to enable improved implementation in practice? The study identified 17 implementation issues based on evidence from the two cases. For some issues, appropriate responses were identified (e.g. refinements to WLC theory or the development of strategies to overcome the issue); for others, outstanding research questions were posed. Other notable contributions to furthering WLC use in practice include those by Soepenberg *et al.* (2006, 2008). For example, through the use of order progress diagrams and WLC principles, the authors sought to diagnose and resolve logistic performance problems in SMEs.

Therefore, there is a limited yet growing body of evidence on the use of WLC in practice, but more evidence is needed to further develop understanding of the implementation process and add to the debate on the WLC paradox. In particular, more evidence is needed on the performance and implementation process of a comprehensive WLC concept including the customer enquiry and job entry stages, given that the majority of previous simulation and empirical studies focus on the job release stage.

In response, this paper takes the recent work of Hendry *et al.* (2008) and Stevenson and Silva (2008) as a starting point and uses the set of implementation issues detailed in Hendry *et al.* (2008) as a checklist for implementing WLC through action research. Action research is a participative approach originating in the work of Lewin (1946, 1947) and associated with authors like Argyris (1970, 1994) and Checkland (1991). It has been described as a special type of case study (Coughlan and Coghlan, 2009) where the researcher is immersed in a problem setting yet must remain objective; and, in which the outcome is co-produced by the researcher(s) and subject(s). The WLC method adopted in this action research project can be described as a hierarchical approach which incorporates control at the key planning and control stages of relevance to MTO companies. For a detailed description of this approach to WLC, referred to as the "LUMS approach", see Hendry and Kingsman (1991) and Stevenson and Hendry (2006). This is argued to be the most comprehensive WLC method in the literature; it provides an end-to-end solution from the moment a customer enquiry is received. Thus, the research presented here is a further step towards the development of theory surrounding comprehensive WLC concepts; the required implementation process and associated improvements in key performance indicators in a MTO context.

3. Methodology

The main research question considered in this paper is:

RQ1. How can a WLC system be effectively implemented in practice to achieve performance improvements?

To unpack this question, it is essential to:

- determine whether an implementation has been "successful" by looking for improvements in key performance indicators; and, if so, to ask; and
- how was "success" achieved, i.e. what key steps were undertaken during the implementation process?

An action research project was undertaken in "Company Y" to answer this question between 2007 and 2009, with the effect of implementation beginning to occur in 2008; more limited contact continued into 2010. A longitudinal project was considered essential to track the implementation process in detail and determine whether use of the WLC system was sustained. Action research was appropriate given the need for the research team to engage with the practitioners, to participate in the implementation process and observe its outcomes (Westbrook, 1995; Eden and Huxham, 1996; Gummesson, 2000; Coughlan and Coghlan, 2002, 2009). For example, there was a need to train users of the system and educate key personnel in the need for a new PPC concept. The researchers were also involved in initially populating the system's database; giving advice on how to group machines into work centres; determining capacity availability, etc. An element of observation was also maintained as the day-to-day use of the system was undertaken by company personnel responsible for the decisions that WLC supports. As the project progressed, the level of participation lessened and the level of observation increased. For further details on the WLC software system implemented in this study, the reader is referred to Stevenson (2006) and Huang (2011).

Action research is characterised by conscious cycles of intervention and reflection (Lewin, 1946; Checkland, 1991), with specific stages specified by authors such as Coughlan and Coghlan (2002, 2009) as: diagnosis, planning, action and evaluation. In this project, there was one "macro" and several "micro" cycles. At the macro level, the cycle involved the diagnosis of PPC-related problems at the outset of the project, including an inability to provide a key customer with realistic DD quotations, and subsequent missing of promised DDs; the planning of the WLC implementation process; the action of implementation and the subsequent evaluation of the project outcomes as reported in this paper. Numerous micro level cycles took place as specific parts of the implementation process were undertaken, typically during regular monthly management meetings arranged to maintain project momentum.

Figure 1 provides an example of a micro level cycle related to "rush" (i.e. urgent or short-notice) orders. The findings related to this issue are later discussed in Section 6.

Much has been written about avoiding the pitfalls associated with action research and ensuring rigorous, high quality outcomes (Eden and Huxham, 1996; Gummesson, 2000; Levin, 2003; Coughlan and Coghlan, 2002, 2009). Two key themes are:

(1) Effective roles and relationships.

(2) Appropriate data collection methods.

Regarding the former, it is important to ensure good working relationships throughout the project, ensuring a common purpose despite the potentially conflicting objectives of research and business (Baskerville and Wood-Harper, 1996; Eden and Huxham, 1996). This is a complex issue, but was greatly facilitated in Company Y by pressure to improve DD adherence from a key customer and the potential of the WLC system to address this. A second key contributor to effective roles and relationships was the identification of an appropriate project champion from within the organisation with enthusiasm to learn and power to promote organisational change

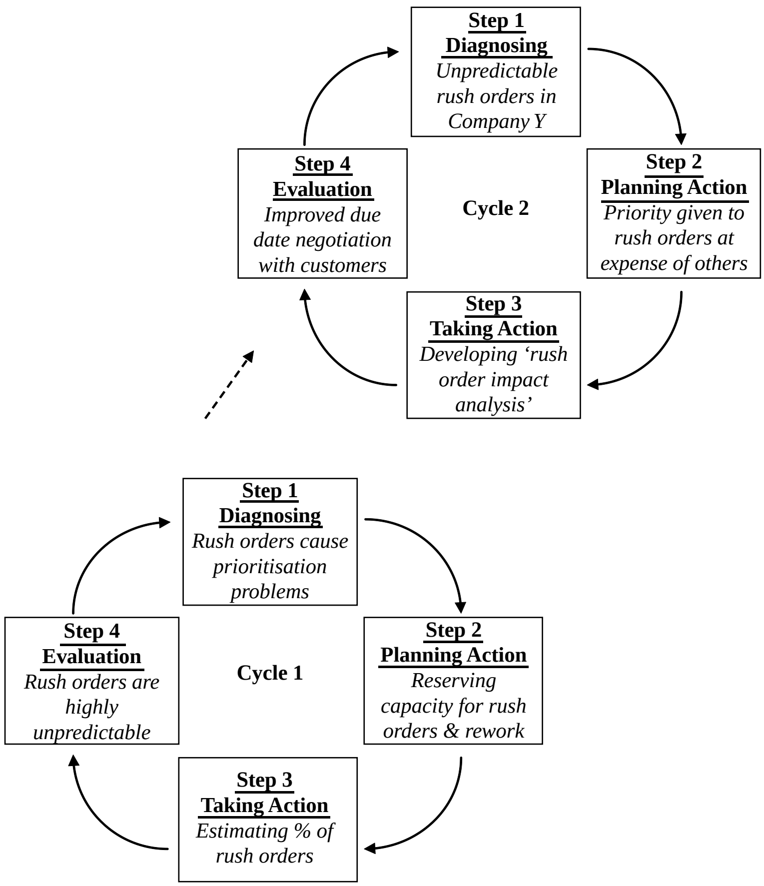

Figure 1. Action research cycle for rush order "impact analysis"

(Coghlan and Coughlan, 2006). Company Y's Operations Director played this role at the strategic level, whilst the Production Controller kept the project on track at the tactical level. The former role was the most pertinent given that fire-fighting would tend to periodically side-track the tactical champion. In addition, it is important that some experienced action researchers are involved: here, two experienced researchers worked with one new researcher thereby employing the "apprenticeship" model (Eden and Huxham, 1996).

Regarding the second key issue for ensuring high quality outcomes, effective documentation is needed through appropriate choice of data collection techniques that can be used by other researchers (Westbrook, 1995). The approaches used included:

- Semi-structured pre-implementation interviews of four key members of staff and one key customer (providing more than 80 per cent of the orders).
- Maintenance of a research diary.
- Minutes of the monthly planning meetings, including key evaluations of previous actions along with diagnosis and planning of actions for the next month.
- Screenshots to illustrate use of the system for decision making.
- Quantitative data on key performance measures, as justified in Section 4.
- Post-implementation interviews of the same four key members of staff and key customer.

The questions asked at the pre- and post-implementation interviews enabled a comparison of the PPC methods before and after WLC was implemented; and, analysis of perceptions of the implementation process. Triangulation of the evidence was key, particularly where it was subjective. For example, evidence from the interviews was stronger when the same information was collected from several of the staff interviewed.

Data was recorded in a suitable manner for the setting, and included: audio-recording of formal conversations, note taking, and writing down both key quotations and reflections at intervals during the day. Tables were also used extensively to document the whole implementation process, including the key implementation issues encountered and the responses to the issues. Where conversations were audio-recorded and transcribed, interview transcripts were returned to the interviewees for validation. Before presenting these findings, the choice of case company is justified.

3.1 Selection of Company Y

The case company was selected as *typical* of the type of company expected to benefit from WLC implementation (Yin, 2009). It employed 32 people (25 on the shop floor) and had a turnover of approximately £1.5m per year at the start of the project, and can hence be classified as an SME. The dominant manufacturing strategy of the company is MTO, with some work produced on a repeat and some on a one-off (or order-by-order) basis. Company Y provides subcontracting for a variety of customers, including in the aerospace, commercial, textile and food industries and also undertakes work for "challenger projects", e.g. land speed record attempts (partly for the publicity; this is not very profitable). MTO SMEs have also been the subject of other case studies (Hendry *et al.*, 2008), thus replication logic is being used in building up the case study evidence available (Yin, 2009).

In addition to looking at company size and process type to determine applicability, Henrich *et al.* (2004) proposed the use of 12 product and production process-related characteristics to determine the fit between a company and WLC. Table I uses an adapted set of these contextual factors to show the expected fit between Company Y and the LUMS approach to WLC. This analysis hence looks at the more detailed company context typical of a MTO environment, thereby taking a detailed contingency-based approach to the choice of PPC concept (Sousa and Voss, 2008). For example, high routing sequence variability and high processing time variability are expected in a company manufacturing a high variety of items; and low levels of processing time "lumpiness" are due to low volumes for most products. This analysis shows a high level of fit for WLC overall. A key exception is the ratio between set-up and processing times which should be low enough that sequences on the shop floor are not dictated by set-up requirements. It was agreed that ways to address this issue through the implementation process may be needed. Thus, it can be argued that there is a reasonable alignment between the PPC approach and company characteristics. To determine whether this alignment is in fact appropriate, it is important to assess the performance impacts that would be expected to result from WLC implementation, as discussed in the next section, before determining whether those effects were realised in Company Y.

4. Determining performance measures for WLC

All simulation studies referred to at the beginning of Section 2 used a set of performance measures argued to be pertinent in the industrial context in which WLC can be applied. It is important to ask whether the same set of measures should be used to assess WLC implementation in practice in order to determine appropriate measures for this project. This section addresses this by summarising and then analysing the performance measures used to date in key simulation studies; and also by discussing measures used in prior implementation studies. The performance measures used previously can be categorised into six groups: time-related; dependability; cost-related; shop load-related; market-related and internal co-ordination. Table II gives examples of authors that have used measures in each category since 1999.

Time-related factors include the total manufacturing lead time (MLT), which consists of the "pool delay" and the shop floor throughput time (SFTT). It is claimed that WLC can reduce lead times in job shops (Land and Gaalman, 1996; Hendry *et al.*, 1998); however, some studies have shown an increase in the MLT, with the explanation being that whilst the SFTT decreases, the extra time spent in the pool may be greater than this reduction (Fowler *et al.*, 2002). Thus, a number of simulations have also considered the pool delay and SFTT to explain variation in the MLT. For example, Kingsman and Hendry (2002) broke the SFTT down further, including queuing time as a separate measure but found that it is not a significant performance measure in its own right. It is therefore concluded that some measure of lead time is important. The most important is the MLT; breaking this down into more detailed components is only important to understand how the MLT has changed.

The dependability measures of lateness and/or tardiness are also included by many authors (Cigolini and Portioli-Staudacher, 2002; Fredendall *et al.*, 2010). For WLC

Table I.
Assessing the fit of Company Y to WLC

Contextual factors	LUMS WLC "best fit"	Evidence in Company Y	Assessing the applicability				
			Poor fit				Best fit
Order arrival intensity	A high arrival rate of many relatively small jobs allows greater flexibility at job release and for workload balancing	Approximately five jobs/day on average; a high arrival rate of rush orders	Poor fit			•	Best fit
Inter-arrival time variability	WLC pre-shop pool typically absorbs high inter-arrival time variability	Although there are five jobs per day on average, this varied between zero and 34 jobs, implying that the inter-arrival times vary significantly from a few minutes to several days	Poor fit			•	Best fit
Due date tightness	Low tightness (adequate slack) provides flexibility at the job release stage	Low tightness as large difference between SFTTs and delivery lead times	Poor fit			•	Best fit
Variability of DD allowances	Shop floor buffering using the pre-shop pool suits high variability of DD allowance	A diverse mix of urgent jobs (rush orders) and non-urgent jobs (e.g. repeat orders, i.e. kanban)	Poor fit			•	Best fit
Processing time lumpiness	Short processing times on average allow greater workload balancing and the use of aggregate workload measures	An average job processing time of six hours, which is considered relatively short, and few large jobs leading to low lumpiness	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	High unit processing time variation (e.g. 30 seconds-six hours)	Poor fit			•	Best fit
Set-up/processing time ratio[a]	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	Typical set-up time is two to three hours; average machine processing time is six hours per job, thus a relatively high set-up time compared with the 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	Usual sequence of operations in sections but routings within sections can be random. Overall, a general job 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	Jobs have three or four operations in their routing, on average	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 14 or 15 operations	Poor fit			•	Best fit
Routing flexibility	High flexibility is good for balancing workloads across work centres	Some inter-changeable machines, but grouped in the same work centres. However, semi-skilled people can move to different sections providing reasonably high flexibility	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	Few sub-assembly/assembly structures for the products	Poor fit		•		Best fit

Note: [a]Needs to be addressed the implementation process
Source: Adapted from the framework by Henrich *et al.* (2004)

Category	Measures	Examples of authors including this measure
Time-related	Manufacturing lead time	Henrich *et al.* (2004), Land (2006), Moreira and Alves (2009), Sabuncuoglu and Karapinar (2000), Thürer *et al.* (2010)
	Shop floor throughput time	Bertrand and Van Ooijen (2002), Henrich *et al.* (2006, 2007), Oosterman *et al.* (2000), Thürer *et al.* (2010), Weng (2008)
	Pool delay	Bertrand and Van Ooijen (2002), Moreira and Alves (2009)
	Shop floor queuing time	Enns and Prongue Costa (2002), Kingsman and Hendry (2002)
	Time to process customer orders	Park *et al.* (1999)
Dependability	Lateness	Land (2006), Missbauer (2002), Sabuncuoglu and Karapinar (2000), Weng *et al.* (2008)
	Tardiness	Cigolini and Portioli-Staudacher (2002), Fredendall *et al.* (2010), Missbauer (2002), Weng (2008), Ebadian *et al.* (2009)
Cost-related	Work-in-progress	Cigolini and Portioli-Staudacher (2002), Kingsman and Hendry (2002), Missbauer (2002)
	Overtime	Kingsman and Hendry (2002)
Shop load-related	No. of jobs on the shop floor	Enns and Prongue Costa (2002), Fredendall *et al.* (2010), Land (2006)
	Shop utilization over time	Cigolini and Portioli-Staudacher (2002), Kingsman and Hendry (2002)
	Bottleneck shiftiness	Fredendall *et al.* (2010)
	Reallocation of operators	Kingsman and Hendry (2002)
Market-related	Proportion of rejected orders	Moreira and Alves (2009)
Internal co-ordination	Co-ordination between production and marketing	Park *et al.* (1999)

Table II. Performance measures used in previous studies

approaches that include a customer enquiry stage, this is key because it assesses whether the approach is able to better manage the DD setting process, ensuring that DDs are both realistic and competitive. Therefore, it is argued that lateness and/or tardiness also need to be measured when an implementation includes the customer enquiry stage. Mean lateness, for example, indicates the average time between order completion and the DD. First, the difference between the order completion date and the DD is calculated for all orders; then, the differences are summed and the average is taken. Meanwhile, mean tardiness indicates the extent to which delayed orders are late. First, the difference between the order completion date and the DD is calculated for late orders only; then, the differences are summed and the average is taken. Thus, the mean lateness could be negative (i.e. early completion on average, or negative lateness) or positive (i.e. late completion on average, or positive lateness) while the mean tardiness is always positive.

Cost-related measures include WIP and overtime levels. Reducing capital tied up by restricting WIP is part of many concepts, including the lean paradigm. Equally well-established is the effect that lower levels of WIP have on reducing lead times.

Thus, the level of WIP is affiliated with time-related measures; it can be argued that this is not important as long as the MLT is known. Overtime has only been studied by Kingsman and Hendry (2002), but it is argued that this is a key measure given that WLC should reduce the need for overtime through better planning and less "fire-fighting". This is more likely to be achieved if there is effective use of output control, i.e. of capacity control at all planning stages. Thus, this is a key performance measure affecting the profitability of a company.

Shop load-related measures are of interest to many studies as explanatory variables rather than performance measures. For example, Fredendall *et al.* (2010) treated work centre utilisation as a controllable variable and explored the effect of different utilisation levels on other important measures such as the MLT. A similar argument can be applied to the number of jobs on the shop floor, as this is inherently controllable in a WLC system with a job release stage. In some studies, the number of jobs on the shop floor is a proxy measure for WIP, in which case the arguments used above for WIP would apply. "Bottleneck shiftiness" is only studied by Fredendall *et al.* (2010); the importance of this factor is contingent on whether bottlenecks are problematic in a company. The reallocation of operators is only included by Kingsman and Hendry (2002) and is not important in its own right. It is studied alongside overtime as a no-cost alternative to show the importance of first considering reallocation to complete work on time before assigning overtime.

The only study identified since 2000 that included a market-related measure was by Moreira and Alves (2009), which included the proportion of rejected orders. Whilst this is also a controllable variable, it is an important performance measure. WLC argues for the rejection of some orders if they cannot be completed within a competitive lead time to avoid the lead time syndrome (Land and Gaalman, 1996). Thus, authors such as Kingsman *et al.* (1996) argued that the order book should be moulded so that a set of orders is accepted that can be profitably produced. It is important to understand how many orders are rejected in order to fully understand the success of a WLC strategy.

In studies of successful WLC implementations, similar performance measures to those used in simulation have been used. For example, Bechte (1988, 1994) reported reduced lead times and inventories; the ability to maintain lead times at a planned level; to meet planned DDs and to maintain an appropriate work centre utilisation. Similarly, Park *et al.* (1999) reported an increased ability to meet DDs and a reduction in manufacturing costs. Interestingly, Park *et al.* (1999) also reported on two issues not commonly studied in simulations: a reduction in the time taken to process customer enquiries and in the discord between marketing and production departments. The former is important in an increasingly speed-conscious society; the latter is difficult to measure but is clearly important for maintaining an efficient and effective operating environment. Thus, these two measures are also argued to be important. No other additional measures have been identified from the WLC implementation literature.

The above discussion focused on quantitative data but it is argued here that reporting on quantitative data alone is insufficient to indicate a successful implementation. It is important to supplement this with qualitative evidence that improvements can be attributed to WLC rather than other environmental factors. Thus, qualitative evidence should also be collected through interviews with key company personnel.

In conclusion, where feasible, the following performance measures should be included in WLC implementation studies, and hence these are the key measures for this study:

- Time-related measures: the MLT (with component measures, such as pool delay and SFTT, only needed if the MLT increases); time to process customer enquiries.
- Dependability measures: including lateness and tardiness, if the study includes the customer enquiry stage, as is the case for the LUMS approach used here.
- Cost-related measures: including overtime level to indicate effectiveness of output control.
- Market-related measures: including the proportion of rejected orders.
- Internal co-ordination measures: including between marketing and production.
- Qualitative evidence to support the claim that improvements are linked to the use of WLC.

Measures of shop load are not important as performance measures but, given that this is the WLC concept, it is expected that shop load would explain variability in other measures that do assess performance. Hence, such measures should also be collected if they are important explanatory variables. This study therefore sought to gather data under each heading.

5. Impact of WLC implementation on key performance measures in Company Y

To determine whether WLC implementation has been successful in Company Y, a comparison of pre-, mid- and post-implementation performance is given in Table III. The world economic recession meant that quantitative data for 2009 is not comparable with pre-implementation data; and hence mid implementation data for 2008 and post-implementation quantitative data for 2010 is compared with the same period, April-September, in 2007. Using data for 2010, after a year in which contact with the research team was much reduced, provides evidence of sustained changes in performance that cannot be attributed to the Hawthorne effect (Chakravorty and Hales, 2008). In addition, some data in Table III is qualitative, and this evidence needs further justification, which is given below after first discussing an overview of the evidence in Table III.

This evidence indicates that MLTs and delivery lead times (DLTs) have been reduced. The MLT values are estimates as data was not available, thus a range is given for the post-implementation stage to represent the range of views of those interviewed, whilst one value is given for pre-implementation indicating that all interviewees were in agreement. As only estimates were available for the MLT, the DLT is also included. This shows only a small reduction; however, the DLT includes time awaiting materials from suppliers and so is not wholly controlled by the company. The evidence also indicates a particularly significant improvement in dependability measures, including lateness and tardiness, and reduced costs due to less overtime. Shop load-related measures have been included to indicate that improvements in time-related and dependability measures have been achieved in parallel to growth in the number of orders and average order quantity. Thus, improvement cannot be attributed to a reduced workload. The strike rate, or proportion of bids that result in confirmed orders, is reported as an additional market-related measure, given that the proportion of rejected orders is thought to have

Category	Measures	Case study evidence: Pre-implementation 2007	Mid-implementation 2008	Post-implementation 2009-2010[a]	Link to use of WLC decision level
Time-related	Mean MLT (estimate)	3 weeks	1-2 weeks	1-2 weeks	All
	Mean quoted DLT	57 days	41 days	40 days	CE
	Mean actual DLT	45 days	38 days	40 days	All
	Time to process customer enquiries	Not known	Faster as information more readily available		CE
Dependability	Proportion early	55%	33%	22%	
	Proportion on-time	26%	52%	61%	
	Proportion tardy	19%	15%	17%	All
	Mean lateness	− 12.13 days	− 2.69 days	0.35 days	
	Mean tardiness	12.81 days	9.29 days	9.4 days	
Cost-related	Overtime	Less overtime post-implementation, as more intelligent reallocation of operators and better pre-planning before problems arise			I/O – all levels
Shop load-related	Number of orders	500	581	519	N/A
	Average quantity per order	26	40	38	N/A
Market-related	Proportion of rejected orders	Negligible	Negligible	Negligible	CE
	Strike rate (estimate 2007, actual in 2008 and 2010)	20% aerospace; 50% textiles	25% all	41% all	All
Internal co-ordination	Co-ordination between production and marketing	Improved communication between the planning staff and the engineering staff post-implementation, with both groups working on quotations			CE
External co-ordination	Co-ordination with customers	Improved information flow down to the key customer, in terms of capacity availability and order progress visibility			All
Quality-related	Quality improvements;	Less quality problems, as less rushing			JR
	Auditing process support	Greater professionalism, recognised at customer audits			All

Notes: [a]Quantitative data is from 2010; qualitative evidence from interviews in 2009; MLT – manufacturing lead time; DLT – delivery lead time; CE – customer enquiry; JR – job release; I/O – input/output control; "All" includes CE, JR, job entry and improved priority dispatching with I/O control at each stage

Table III. Evidence of effective implementation of a WLC concept

been negligible throughout the project. Thus, as a market-related factor, strike rate data was analysed more consistently as the project progressed and is concluded to now be higher than before implementation. Hence, the project has also had an impact on market-related factors. In addition, evidence on improved internal co-ordination was identified along with two additional areas: external co-ordination and quality-related issues. These additional areas had not been identified as associated with WLC implementation in Section 4. Overall, Table III suggests that WLC has had a significant positive impact on the performance of Company Y.

The main thrust of the qualitative evidence is to assess whether performance improvements can be attributed to WLC implementation. This was particularly pertinent given the timing of the project, as this evidence provided insights into how the system can help a company survive a recession. The pre- and post-implementation interviews investigated perceptions of the use of the WLC system and how it had affected planning and control processes. These interviews provided key evidence that use of WLC was gradually being improved. The discussion below is initially structured around the key decision points at which WLC is being used rather than around each performance improvement. The right-hand column of Table III indicates the aspect of the WLC approach that is argued to be responsible for each improvement. Links between the improvements and WLC are also indicated below:

- At the customer enquiry stage, the Operations Director stated: "We are actually attempting to manage the [customer enquiry] process now, whereas before we were just drifting through". This includes the monitoring of strike rates which was introduced as a result of the project, and consequently improved understanding of why orders are won or lost. Better information on capacity is particularly key here:

  > In the past, we were guessing how much work we could take on, but now the system tells us how much of a "hole" [spare capacity] we have [. . .] So we can quote for work that fills that hole.

  This was particularly important when the recession hit, as the company wanted to impress any new customers, meaning dependability was more vital than ever and had to be achieved without expensive overtime. They were also able to respond more quickly to enquiries as: "everything [order information] is there [in the system]". Thus, this stage contributed to improvements in time-related, dependability, cost and market-related measures.

- At the job entry stage, the Operations Director stated:

  > When we get an order, we will review it to make sure the lead time we quoted is achievable. Whereas before, we just got the orders and got on with them. If we achieved it, we achieved it; if we didn't, we didn't.

  The use of input/output control at this stage, as discussed further below means that Company Y is better able to manage confirmed orders, solving problems before they arise and, where necessary, discussing potential delays with customers at an early stage. Thus, key measures of time, cost and dependability are further managed at this stage.

- At the job release stage, the Production Controller stated that:

  > I've got the order book and I know what we need to get out [dispatch] in a month. I can make sure they [shop floor operators] are not running "stuff" I don't want [. . .] I can prioritise what I'm releasing.

  The Operations Director confirmed this, stating that they can also use:

  > [. . .] the system to "juggle" things around so that we are achieving what the customer requires [. . .] he [the Production Controller] was able to move work to get the best benefit for the customer.

The effect of this in terms of reduced WIP was confirmed by the Chief Engineer for Milling: “We used to have to wait while work piled up around the machines. That was basically because we were releasing them [orders] too early”. He also stated that in the past: “a job that might only take five days to manufacture could take a lot longer because it was “sat” on the shop floor waiting for key operations”. In contrast, he indicated that this is no longer the case and jobs are being held back in a pre-shop pool. The main contribution of this stage is hence in achieving improved dependability, with associated reductions in MLTs, DLTs and costs.

- Input/output (I/O) control is being used at all stages. For example, the Operations Director discussed the quotation stage:

  > Sometimes you say: “yes”, I can do it in three weeks; but you are not really thinking about all the other jobs you’ve also got to do in three weeks, whereas the system is a lot more objective.

  and once a job is in the system, the Production Controller indicated that the WLC system:

  > [. . .] highlighted the fact that we would never get this job finished in “a month of Sundays” if we just ran it on one machine, consequently we ran it on two machines.

  He went on to say that, in general, the system will “highlight manpower shortages” enabling decisions to be made on whether to reallocate operators or whether overtime is needed. Consequently, Company Y is now reallocating operators in a more intelligent way and seeing a reduced need for overtime. The Operations Director stated that: “we thought we were reallocating operators fairly well anyway, but I don’t think we were really”, and also explained that:

  > [. . .] in the past, with a job that we couldn’t do on time, we would have been “crashing on” unaware that we couldn’t make the delivery date. Now we know where and when to add in capacity to make sure we deliver on time.

  The potential to use the system for planning during a recession was also confirmed: “We can even use it [the system] to decide whether we need to make layoffs if it gets that bad”. Thus, I/O control, as a key part of each decision level, can also be linked to improvements in dependability and cost, and associated time-related measures.

- Throughout the PPC stages, there is improved internal co-ordination between those responsible for sales/marketing roles, including making quotations and liaising with customers, and production/engineering personnel. External co-ordination, including smoother information flow, has also been confirmed by Company Y’s key customer:

  > They’ve got much more control of the information flow going into the business [. . .] they can now do the “number crunching” and look at the loading against the capacity. They couldn’t do that before [. . .] This is something that all companies should do, but most don’t.

  The importance of visibility down through the supply chain, which has been improved by using the system, was also highlighted by the customer:

  > If you can see where the job is in the process, it gives you good visibility of whether it is nearly finished [. . .]. it gives you an extra level of confidence that they [the supplier] are on course [...] The system has made them [Company Y] more fit for purpose to supply the leading aerospace companies.

- The additional area of quality-related measures in Table III has been split into: quality improvements; and, auditing process support. Although initially unexpected benefits of WLC implementation, they can be intuitively explained given that a reduction in WIP is often thought to lead to improved quality (e.g. by reducing defects) in other approaches such as the lean paradigm (Womack and Jones, 2003; Rother and Shook, 2003; Sullivan *et al.*, 2002). For example, the customer stated that:

  > [. . .] in the past, they [Company Y] weren't able to control the influx of orders and did not have the capability to accurately reschedule [. . .] when you are fire-fighting, you're not as focused on quality.

  while the Operations Director of Company Y explained that:

  > [. . .] the system and its output look very professional, and it provides traceability. It is easy to follow and an auditor can quickly look at it and evaluate the business [. . .] they are more confident we are doing the right things.

  This is supported by studies on the importance of traceability to quality control (Kim *et al.*, 1995), and consequently improving customer trust and confidence (Rijswijk *et al.*, 2008).

Overall, it can be concluded that the reported performance improvements can be attributed to WLC. It is also anticipated that further improvements could be achieved as users continue to gain confidence in the system and use it more "aggressively". For example, it can be seen in Table III that the quoted DLTs have not been reduced as much as the actual values. This is because there is still a tendency to quote conservatively when the DD is not thought to be an order winner (e.g. for repeat work). Having established that this action research project has led to successful WLC implementation, it is also important to understand the process used to achieve this success, as discussed in the next section. At the end of the next section (Section 6.4), we will briefly return to the data discussed above when reflecting on the project and drawing parallels between the improvements made in Company Y and both lean and total quality management (TQM).

6. Developing a successful implementation process for WLC

The 17 implementation issues identified in Hendry *et al.* (2008), together with proposed responses, were used as a framework for determining how to implement WLC in Company Y. Hendry *et al.* (2008) categorised these 17 issues into five categories as follows:

(1) Market/customer-related issues.

(2) Primary process-related issues.

(3) WLC system-related issues.

(4) Organisational embedding-related issues.

(5) Information flow-related issues.

We use these same categories here. The project confirmed the importance of 15 of the 17 issues, and identified a further three issues; all 20 are summarised in Table IV. Issues encountered in this project are marked with a "✔". Newly identified issues are

Category	Key implementation issues			Description of implementation issue
A. Market/customer	✓	A1	Characteristics of order quotations	Unspecified or unrealistic DDs
	✓	A2	Uncertainty at the customer enquiry stage	Effect of long delays between a customer enquiry and order confirmation on workload calculations
	✓	A3	Rush orders	Orders sometimes have greater urgency, e.g. replacement parts during a harvest season
	✓	A4	Seasonality and volume growth	Seasonal demand and/or step changes in demand
	✓	A5	Hybrid production	Mainly MTO, but some stock items also
B. Primary process	✓	B1	Assembly requirements	Release decisions for separate parts which converge for assembly processes
	✓	B2	Sequence dependent set-up times	Workload calculations when there are sequence dependent set-ups
	✓	B3	Alternative shop floor routings	Grouping machines to allow flexibility of capacities
	✓	B4	Industry-specific process	E.g. oven processes that require batching
	✓	B5*	Uncertainty after the order release stage	Changing customer priorities that require some orders to be delayed in favour of new orders
C. WLC system	✓	C1	WLC-related start-up issues	Making an effective transition from current practices including long lead times to new ways of working, by changing the WLC parameters over time
	✓	C2	Incomplete routing data at customer enquiry	Making appropriate DD assignment decisions when the routing information available is incomplete
		C3	Time-span-dependent critical resources	Bottlenecks that can change between the customer enquiry stage and the job release stage
D. Organizational embedding	✓	D1	Awareness of the concept of WLC	Education needed for the workforce in the WLC concept as initial awareness low
	✓	D2	User visibility	Balance between providing easily understandable information and sufficient of the underlying WLC logic to ensure WLC is appropriately used
	✓	D3	Support of task structures	Integrating the WLC concept with current tasks, such as providing support for decisions involving both planning and sales

(*continued*)

Table IV.
Summary of key issues related to WLC implementation

Category	Key implementation issues			Description of implementation issue
	✓	D4*	End-user choice and involvement	Appropriate selection of the end-user for each stage of the WLC process
	✓	D5*	Accommodating functionality requests	Ensuring that additional functionality requested does not conflict with the WLC concept
E. Information flow	✓	E1	System-related start-up issues	Finding effective ways to fill the database at the onset of the project
		E2	Integration with other systems	Integration of the WLC system with existing ERP or other database systems

Notes: A1-A5, B1-B4, C1-C3, D1-D3 and E1-E2 taken from Hendry *et al.* (2008); "✓" – issues encountered in this research (other issues not considered significant in this case); "*" – new issues identified in this research (not identified as significant in Hendry *et al.* (2008))

Table IV.

marked with an asterisk (*) and appended to the appropriate category (A-E). The two issues from Hendry *et al.* (2008) not relevant to Company Y are time-span-dependent critical resources (C3) and integration with other systems (E2). In this case, bottlenecks did not move significantly between the customer enquiry stage and the job release stage for an order; and no existing information system needed to be integrated with the WLC system. Instead, all existing systems were replaced. Such issues may be relevant in other settings and should therefore remain part of the set of WLC implementation issues. It is noted that each of the 20 issues in Table IV and/or the response is considered specific to WLC implementation given the characteristics of this approach.

Table V lists the 18 key implementation issues relevant to Company Y in the left-hand column. In the second column, the specific implementation issues that arose in Company Y are briefly described. The third column then explains how those issues were addressed to ensure a successful implementation. Finally, in the right-hand column, the researchers have identified the contribution to the literature. This column thus indicates whether the response to an issue is consistent with that proposed in prior research or whether a new contribution is made (to the implementation strategy and/or WLC theory). For ten of the original 17 issues, this research provides support for the previously proposed aspects of WLC theory or WLC implementation strategy. This is significant in that the support is given in the context of evidence of a successful implementation, which was not true of the cases in Hendry *et al.* (2008). For example, characteristics of order quotations (A1) is typical of MTO companies where unrealistic promises may be made at the customer enquiry stage in order to win a tender. Such short term benefits can have adverse knock-on effects in the long run as the company develops a reputation for not delivering on time, thereby reducing their social capital (Moses *et al.*, 2004). The customer enquiry stage in WLC offers a means to set DDs that are both realistic and competitive by managing the length of time needed to process the current workload (Kingsman *et al.*, 1996). However, a careful implementation strategy has been previously proposed to gradually change company practices as confidence in the WLC system is gained. This project provides support for this strategy as the employees gradually began to rely on the WLC system to determine the DDs to quote;

Table V. Summary of WLC implementation issues and responses in Company Y

Key	implementation issues	Company Y implementation issues	Responses: addressing implementation issues	Contribution
A1	Characteristics of order quotations	DDs initially determined using experience/"best guess" and stated as "x weeks from date of confirmation". Main aim to tell the customer what they wanted to hear rather than giving realistic quotes	Personnel trained in importance of setting realistic DDs Gradual change towards realistic quotations Increase communication with customers	Supports implementation strategy previously proposed for subcontractors
A2	Uncertainty at the customer enquiry stage	Customer confirmation lead times (CCTs) often unpredictable (varying from the same day to several weeks or longer). The strike rate can vary by customer or specific order; however, the current unconfirmed load that is likely to be won by the company is large enough to have a significant effect	Determine individual CCTs for repeat customers Liaise with customers between enquiry and order acceptance decision, removing order from TWL when appropriate Apply different strike rate values for different customers and update the strike rate over time	Implementation strategy refinement to vary CCTs. Strike rate inclusion supports WLC theory previously proposed
A3	Rush orders	Sometimes short lead times are "imposed" on the company by influential customers. Some of the DDs imposed have already passed when Company Y receive confirmation	Customer involvement to encourage understanding of capacity constraints and "impose" more realistic DDs Conduct rush order "impact analysis" at the job entry stage	Refinement to WLC implementation strategy and WLC theory
A4	Seasonality and volume growth	No seasonality, but at the start of the project, the company was in a period of steady growth and the shop was heavily loaded but visibility of future orders was low. However, the recession slowed growth in 2009	Step changes in capacity made as volume required this, including working shorter hours during the recession WLC system tracked overtime used to assist in making decisions on strategic level changes to capacity	Supports WLC theory previously proposed
A5	Hybrid production	Not a major issue; some items produced on a repeat replenishment order basis – referred to as "kanban jobs" Separate area of the factory used for the kanban jobs	Bespoke and repetitive manufacturing decoupled; the WLC system focuses on bespoke production. The capacity made available in the WLC system is reduced according to the proportion of the workload made up of kanban jobs	Refinement to WLC implementation strategy

(*continued*)

Table V.

Key implementation issues		Company Y implementation issues	Responses: addressing implementation issues	Contribution
B1	Assembly requirements	Few sub-assembly/assembly structures; most jobs involve sequential operations on a single component	Release of parts co-ordinated. Calculations for determining operation completion and latest release dates adapted to cater for the few assembly operations based on the critical path method	Supports strategy as previously proposed for capital goods manufacturer
B2	Sequence dependent set-up times	Planners try to group similar jobs together where possible to reduce the set-up times, whilst also considering other factors including the urgency of the order, value of raw materials, machine loadings, etc	The WLC system supports interactive decision making at the job release stage with a comprehensive consideration of all these factors Processing time norms used at customer enquiry stage replaced with more specific values from job entry stage onwards	Supports WLC theory previously proposed for subcontractors
B3	Alternative shop floor routings	Some machines are inter-changeable, i.e. certain operations can be performed on several machines	Machines grouped into 12 work centres based on inter-changeability. Grouping machines reduces the number of workload lengths to be controlled and means jobs do not have to be assigned to a particular machine until the dispatching stage	Supports implementation strategy previously proposed
B4	Industry-specific processes	Some inspection operations only apply to part of the job (i.e. not to the full quantity). Some jobs include operations performed externally by the customer and have long and unpredictable lead times, making it difficult to plan the job	A "participation percentage" can be defined for partial operations (e.g. a 10 per cent inspection quantity) Jobs with long (external) lead-time operations are decoupled and treated as separate jobs when they return	WLC theory/implementation strategy refinement
B5*	Uncertainty after the order release stage	Scrap, reducing the size of a job at subsequent operations, is common. In addition, sometimes jobs have to be suspended on the shop floor or return to the pool part-finished (defined as freezing or suspending a job), such as when a customer requests that a more urgent order must take precedence	The RWLs of downstream shop floor resources are reduced in the event of scrap or if a job is suspended indefinitely	New WLC theory refinement

(*continued*)

Table V.

Key implementation issues		Company Y implementation issues	Responses: addressing implementation issues	Contribution
C1	WLC-related start-up issues	Current lead times are long. However, dependability more important than speed	Planned a gradual reduction of workload limits to gain control of lead times, but not implemented as speed was not a crucial competitive priority	Same strategy as previously, but not fully implemented
C2	Incomplete routing data at customer enquiry	Detailed routing data not available until after an order is confirmed. Engineers not initially involved in the early stages of planning	Data entry requirements in the WLC system reduced to encourage use at each planning stage, including the customer enquiry stage (e.g. throughput norms used when detailed data not available) Also possible to search, retrieve and alter previous similar jobs held in an archive to reduce duplication and ease the process of gathering routing data for similar jobs Engineers gradually became more involved from an earlier stage of the planning process	Supports WLC theory refinement previously proposed
D1	Awareness of the concept of WLC	Operations Director aware of the WLC concept from a part-time postgraduate course. Other employees have no prior knowledge. Planners unaware of WLC principles, e.g. have a tendency to release jobs as soon as materials are available	Training via workshops and a hands-on simulation/gaming using an interactive WLC training tool Operations Director acted as a project champion and was key to the system gaining credibility on the shop floor in the early stages	Supports WLC implementation strategy previously proposed
D2	User visibility	Planners keen to only learn on a "need to know basis"	Decision support provided without showing the user detailed calculations Comment boxes within the software available to help users Graphical support emphasized in system development	Supports WLC implementation strategy previously proposed
D3	Support of task structures	Customer enquiries, material planning and release performed by different individuals. Hence current task structures not sufficiently integrated	Greater cooperation between sales, planning and production departments encouraged and achieved	Supports WLC implementation strategy previously proposed

(*continued*)

Key implementation issues		Company Y implementation issues	Responses: addressing implementation issues	Contribution
D4*	End-user choice and involvement	Those responsible for the decisions that WLC supports were not all willing to be trained as end-users of the system. In particular some of the engineers preferred to be advised through interaction with trained staff	One main end-user who received most training and became a second project champion at the tactical level Effective involvement of other staff through interactive use of the system, e.g. at planning meetings System access via the intranet, allowing multiple users, thought to be worth exploring in the future	New Implementation strategy refinement
D5*	Accommodating functionality requests	Functionality requests included the provision of key company documents including route cards and dispatch notes	Functionality requests that do not conflict with the WLC concept are accommodated, and tied to aspects of WLC to encourage appropriate use of the WLC concept	New implementation strategy refinement
E1	System-related start-up issues	Limited data available at the start of the project, with no IT support for planning	Populate the system manually with initial orders and shop floor workloads Release current jobs on the shop floor manually to create initial values of workloads and workload lengths	Supports WLC implementation strategy previously proposed

Table V.

and as DD dependability increased, user confidence in the system increased likewise. For other issues where the response is the same as that previously proposed, the response is only summarised in Table V, and not explained further in the discussion.

The remainder of this section focuses on responses which led to modifications to the previously proposed WLC implementation strategy and/or concept before looking at how to address the three new implementation issues. The section then summarises factors considered critical to the success of the project but which are not considered specific to WLC implementation. These are included because a combination of generic and specific WLC issues needs to be addressed for a successful implementation. Finally, the section closes with reflections on the overall project outcomes and the links with lean and TQM.

6.1 Modified responses to Hendry et al. *(2008) implementation issues*

New or modified responses are described below for five of the original implementation issues.

Uncertainty at the customer enquiry stage (A2). There is a great deal of uncertainty surrounding the outcome of quotations in Company Y. The customer confirmation time (CCT) varies and can depend on tendering decisions at other supply chain points. The length and accuracy of the anticipated CCT impacts the effectiveness of DD calculations in the WLC system. Given high CCT variability, a CCT estimate for each customer (also changeable for each individual order) was introduced instead of an average value for the whole business. In addition, to avoid an unconfirmed job contributing to the TWL for too long, the system prompts users to contact the customer when the anticipated confirmation date has passed; chasing-up quotations may also increase order acceptance probability. Company Y's strike rate also varies between customers (e.g. in different industry sectors). An average strike rate percentage can be incorporated in the TWL calculations at the customer enquiry stage; however, the initial strike rate was approximately 20 per cent for aerospace work, 50 per cent for commercial work and for some particular orders, almost 100 per cent. Hence, an average value was considered unsuitable. Therefore, different values were applied for different customers. In doing so, jobs with an anticipated strike rate of 100 per cent make a full contribution to the TWL calculation when the quotation is made. As indicated in Table III, the strike rate changed as the project progressed, but the ability to vary it by customer or specific order was retained.

Rush orders (A3). Company Y receives some rush orders from important customers, causing prioritisation problems. Rework also increases the workload when quality problems occur. Reserving capacity for rush orders and rework, as described in Hendry *et al.* (2008), is impractical in this case since both rush orders and rework are highly unpredictable. "Impact analysis" functionality was developed to solve the problem of accommodating unexpected extra jobs with tight DDs. Under this method, if the unexpected job cannot be included in the workload by the required DD, the user can change the DD (e.g. by delaying it) or determine the impact that expediting the job will have on other orders (e.g. potential length of delay).

Hybrid production (A5). Hendry *et al.* (2008) suggested that replenishment production was unlikely to be an issue in a subcontracting company, but a similar issue arose due to the manufacture of bespoke parts on a repeat basis – known as "kanban jobs" in Company Y. As a particular part of the factory was devoted to these products, the two types of production were decoupled so that kanban jobs (and the capacity used to produce them) were not included in the WLC calculations. It was previously proposed that replenishment parts should be included in the system but only produced when the load is low; that solution would only be appropriate when there is seasonal demand, which is not the case in Company Y.

Industry-specific processes (B4). Some "special" operations which require particular attention when applying WLC were identified. For example, there are several different inspection operations, some of which do not apply to the full order quantity. The WLC method was designed without considering such "part operations". To reflect part-processes in workload contribution calculations, the "participation percentage" was defined as an operation characteristic and incorporated in the WLC system. In addition, some jobs include operations performed externally by the customer (e.g. particular operations where the customer has expert process knowledge that is not shared with Company Y). Such operations could be treated as subcontracting but often have long and unpredictable lead times, making it difficult to plan the job. It is impractical under the LUMS approach to account for the workload of operations that only commence after the job is returned to Company Y from the customer at order release, so the job is decoupled into two. This is because the LUMS approach incorporates an aggregate-load-oriented method for workload accounting over time (Stevenson and Hendry, 2006); usually, under this method, the entire job's workload for a work centre is placed in that work centre's workload at order release. However, in the situation where a job must exit the shop for an external operation and re-enter at an undetermined time, it is not appropriate to place the workload of a work centre visited after re-entry into the work centre's workload at order release. Accounting for this workload at release could delay the release of other jobs which would arrive sooner, potentially leading to work centre idleness or starvation. Therefore, the workload of operations undertaken prior to the external operation is accounted for when the job is released from the pool and the remaining workload is only accounted for when the job returns. The workload of the external operation is not controlled directly by the WLC system but it is important to have a good estimate of its lead time and hence the expected date on which the order will return to Company Y so the final operations can take place in time to meet the DD.

WLC-related start up issues (C1). For this issue, the same strategy was planned as previously proposed, i.e. the gradual reduction of workload length limits (or norms) so promised lead times gradually became more competitive. Hence, workload length limits were to be initially set quite loose and then gradually tightened. This was proposed in preference to immediately setting tight limits and using overtime while the initial order book was brought under control. However, dependability proved to be more important than speed for the duration of the project, and so the planned reduction in workload length limits was not fully implemented. This explains why DLTs were not significantly reduced. Further research is needed to provide evidence on whether this implementation strategy could fully realise its potential in an environment where speed is a more crucial competitive priority.

6.2 New Implementation Issues Encountered in Company Y

*Uncertainty after the order release stage (B5 *).* Change and uncertainty on the shop floor, after a job has been released, impacts the released workload of shop floor resources. According to the LUMS approach, the workload contribution of a job is added to the RWL of corresponding work centres at the moment of order release and deducted from the RWL of a work centre when the operation has been completed. Any changes during the primary production process (e.g. scrap/quantity reductions) are not considered in the loading calculations of downstream work centres. Similarly, if a job is stopped indefinitely (e.g. at the customer's request), the job continues to contribute to the RWL of downstream work centres. However, scrap was identified as a significant issue leading to a reduction in job size at subsequent operations (and, perhaps to the release of a "replenishment order"). In addition, jobs are sometimes suspended on the shop floor or returned to the pool part-finished (defined as "freezing" or suspending a job), such as when a customer requests that a more urgent order take precedence. The Production Controller insisted that the WLC concept be flexible enough to cope with such uncertainties after jobs have been released. The WLC system has therefore been refined so that the RWLs of downstream shop floor resources are decreased when scrap occurs or jobs are "frozen". This is based on the primary manufacturing process of Company Y but is considered a relatively generic issue.

*End-user choice and involvement (D4 *).* Previous attempts to implement WLC have suffered due to the choice of an ill-informed end-user (Hendry *et al.*, 1993). In Company Y, there were multiple end-users. The Production Controller end-user was in charge of planning, scheduling and order progress control. He received the most training and became a second project champion at the tactical level thus proving to be an effective end-user choice. However, other members of staff were responsible for new enquiries, engineering and low-level production control. Some of these staff were also trained to use the system, but others were unwilling or unable to do so. This problem of ineffective end-users was addressed by making the WLC system a central part of Company Y's planning system so that it was used in all decisions. This was done through informal communication and more formal meetings. For example, the job release stage of the system was used at daily planning meetings so that release decisions had the support of all engineers enabling the consideration of issues such as batching jobs to reduce set-up times. This overcame the key set-up related issue highlighted in Section 3.1 when examining the alignment between WLC and Company Y, i.e. that set-ups were high relative to processing times. While sequences on the shop floor should not be dictated by set-up requirements only, some batching of orders may be employed where appropriate. Daily planning meetings were attended by the Production Controller and staff responsible for enquiries, engineering and heading up the milling and turning sections of the shop floor. Production priorities for the day were discussed with the support of the WLC system, which was checked to ensure the shop floor loads were up-to-date and orders were released from the pool whilst considering urgency and current RWLs (and limits). Hence, the WLC system became a central part of planning and was used every day within Company Y.

*Accommodating functionality requests (D5 *).* To embed WLC in an organisation, it was found to be important to accommodate functionality requests made by end-users. Several such company-specific functions were incorporated but to avoid these "bells and whistles" distracting attention away from the core WLC concept, new functions were tied to encouraging appropriate use of the system. For example, the Operations Director requested that the system produce dispatch notes, which must accompany each order delivered to a customer. This has been accommodated but each note could only be produced if information on order progress was fed-back into the system – information which was required by WLC for shop floor control and to release other jobs from the pool. Hence, unlike previous functionality requests (e.g. for discrete scheduling functionality as requested by Company X, see Stevenson (2006)), these requests helped, rather than hindered, the core WLC system. They not only generated a sense of ownership but also attempted to ensure the WLC system was used effectively.

6.3 Generic implementation issues

Having provided evidence for parts of the implementation process specific to WLC, a brief list of more generic implementation issues is given below. This describes ways in which the WLC implementation process is informed and/or complemented by other literature. A full discussion of such issues is beyond the scope of this paper, but as these issues were critical to the success of this project, the description of the WLC implementation process would not be complete without at least alluding to them briefly. Therefore, the following is a set of insights gained from the implementation of WLC in this company with a brief discussion of their relevance to the literature:

- First, the need for "quick wins", which is important for gaining appreciation and enthusiasm during the initial implementation stage before an initiative is incrementally rolled out (Coronado and Antony, 2002; Maier and Remus, 2003). This was achieved by tying the system to the company's existing processes as described under D5 above. In addition to dispatch notes, route cards are now also produced by the system even though this is not part of the WLC concept or essential to the research project per se.
- The training of users through a WLC simulation tool. Computer-based simulated learning tools can provide useful hands-on learning (Rauch-Geelhaar *et al.*, 2003; Olhager and Persson, 2006). This was particularly important for the main user as it enabled him to gain confidence in using the system without the danger of "messing up" the real data; see Stevenson *et al.* (2009) for further details on the simulation-based training tool.
- Training in "alien" aspects of WLC, such as the use of a pre-shop pool was also a key turning point. This was fully understood and enforced by the project champions, illustrating the importance of establishing roles and responsibilities both in action research projects and other change management programmes (Coghlan and Coughlan, 2006; Schroeder *et al.*, 2008).
- Holding a shop floor meeting to which all workers were invited to explain how they would be affected by the initiative and what role they could play, as workforce culture only changes when employees learn and understand new sets of behaviours (Huq *et al.*, 2006). Initially there was some resistance to change, but by listening to their views and making minor changes to the documentation that the shop floor workers received, buy-in was achieved.
- Involving a representative of a key customer who was responsible for supplier development and supported the need for better capacity planning, and consequently better information flow between supply chain partners. This is supported by research on the influence of customer involvement in organisational innovation processes (Lundkvist and Yakhlef, 2004; McAdam *et al.*, 2007).
- Effective project management through regular monthly planning meetings to enable the action research cycle and ensure project momentum was retained (Lock, 2007).

It is therefore concluded that key skills in project and change management are also essential in the implementation process for WLC. These need to be used alongside the enhanced version of the framework proposed in Hendry *et al.* (2008), as given in Table IV to guide the implementation process in practice.

6.4 Further reflections on WLC implementation: achieving lean and TQM in MTO companies

It was earlier suggested that WLC may provide benefits akin to lean in contexts where the generally accepted pull mechanisms for achieving lean, e.g. kanban signals, do not apply (such as due to high variety). Although in outlining their definition of lean production, Hopp and Spearman (2004) explained that pull mechanisms can be used to limit WIP, they also stated that lean is concerned with minimising the cost of buffering the shop against variability – not necessarily providing the smallest WIP or buffer, but the "best buffer" (Eroglu and Hofer, 2011). WLC is consistent with this definition: the concept's RWL limits are effective in restricting WIP to a suitable level, resulting in short and manageable queues or buffers on the shop floor; furthermore, the pre-shop pool provides a second buffer which, as highlighted by Bertrand and Van Ooijen (2002), protects the shop floor from variation in the incoming order stream. Revisiting Table III, and comparing the pre-implementation data from 2007 with the post-implementation data from 2010, demonstrates that restricting WIP contributed to shorter MLTs (three weeks vs one to two weeks); and it is argued that this improved flow was not simply the result of a displacement of lead time from the shop floor to the pre-shop pool. Moreover, the actual DLT also reduced (45 vs 40 days). Lower WIP and controlled order release also ensured operators worked on the "right" jobs and did not "cherry pick" (Philipoom and Fry, 1999). As a result, improved adherence to DDs can also be observed in the table: far fewer orders were completed early in 2010 compared with 2007 (55 per cent vs 22 per cent) and fewer orders were late (19 per cent vs 17 per cent); instead, far more orders were completed just-in-time (JIT) (26 per cent vs 61 per cent). Similarly, the mean quoted and actual DLTs converged (57 and 45 days vs 40 and 40 days). This was achieved whilst reducing waste in terms of operator time – for example, the improvements are made in parallel to a reduction in overtime, as suggested by Kingsman and Hendry (2002). The result is a more transparent, and less congested, shop floor with less time-wasted fire-fighting and expediting. Hence, it can be concluded that the implementation of WLC in Company Y has indeed been an effective means of achieving aspects of lean.

The above had a knock-on effect on quality – as explained, this is an effect not previously discussed in the WLC literature, perhaps because of the focus on using simulation (as quality effects cannot easily be modelled). Whilst reducing time pressures contributed to the quality improvements (i.e. less fire-fighting and expediting), it is also noted that the approach to implementing WLC described above has some similarities with that advised for TQM. For example, the TQM literature emphasises the importance of customer and employee involvement and of management commitment (Flynn *et al.*, 1994, 1995; Powell, 1995; Cua *et al.*, 2001). Thus, WLC implementation may also provide the catalyst for a second major influence on production systems: TQM. Research has investigated relationships between JIT/lean and TQM practices and firm performance (Flynn *et al.*, 1995; Sriparavastu and Gupta, 1997; Cua *et al.*, 2001) and, now, further research is required to study how well

WLC is truly aligned with both lean and TQM in the context of MTO companies. Firms often adopt integrated approaches whereby multiple improvement programs are embedded, e.g. JIT, TQM and Total Preventative Maintenance (Flynn *et al.*, 1995; Cua *et al.*, 2001). Equally, future research could investigate how MTO companies can use WLC as a springboard for adopting further organizational change and improvement programs.

While the discussion above on lean-oriented benefits that result from WLC implementation focused on the differences between 2007 and 2010, it must also be acknowledged that the differences between 2008 and 2010 are less striking, particularly for the time-related measures of performance. On the one hand, it could be argued that performance improvements were already evident by 2008 and that these were sustained through to 2010 but, on the other hand, it could be argued that performance has somewhat "plateaued". Thus, future research should also investigate how continuous improvements – a cornerstone of both lean and TQM (Cua *et al.*, 2001) – can be made through WLC implementations, exploring how smaller incremental benefits can be achieved once the initial "blitz" is over, e.g. by gradually tightening RWL limits and extending involvement to include suppliers. But this may have to be in another case study company, where speed is as important a competitive priority, if not more so, than dependability.

7. Conclusion

This action research project, spanning more than three years, asked: How can a WLC system be effectively implemented in practice to achieve performance improvements? This was answered in two parts: first by assessing the performance improvements that indicate implementation has been effective; and, second by looking at the implementation process used to achieve success. Contingency theory was also used to show how the characteristics of the WLC approach are aligned with the contextual environment of the MTO case company, as shown in Table I; and to illustrate that changes in performance are attributable to the use of WLC.

In terms of performance improvement, data confirmed that the comprehensive LUMS approach to WLC can lead to: reductions in time-related factors, including the MLT and the time to process customer enquiries; increased dependability, including mean lateness and tardiness; reduced overtime costs and improved internal co-ordination between sales and production. These improvements can be attained without increasing capacity or reducing the workload processed (in this case, the number and quantity of orders increased). In addition, evidence was found of improved external co-ordination; improved quality performance and an overall improved ability to pass customer audits, which are performance indicators not previously associated with WLC in the literature. Thus, the first contribution of this paper has been to provide a more in-depth understanding of the effect of a comprehensive WLC concept on business performance measures in a MTO SME; whilst also adding to previous evidence to confirm the effectiveness of the approach on key performance measures, such as reducing lead times, thereby enabling the lean paradigm to be adopted in a MTO context. This adds to the debate on the WLC paradox, as it provides evidence on a wider range of performance measures than is possible through simulation.

In terms of the implementation process, the evidence indicates that existing implementation strategies need to be further refined to successfully embed WLC within an organisation. This study used the issues presented by Hendry *et al.* (2008) as a checklist for embedding WLC in Company Y and confirmed the relevance of 15 of the 17 issues identified to an additional case setting; the response to the issues is the same as in the previous study for ten of the issues. This finding is significant as this is the first evidence that these responses are workable in the context of a successful implementation. Where the response differed, this was an improvement on the response previously presented (Table V). The two issues which have not been significant influences on WLC implementation in Company Y may still be important in other contexts. In addition, a further three issues have been identified. Appropriate responses for all 18 issues are described, which were either modifications to WLC theory or refinements to the implementation strategy. Examples of modifications to theory include: the need to add "impact analysis" and allow released jobs to be "frozen" and temporarily removed from the workloads. Examples of refinements to the implementation strategy include the need to tie the WLC system to existing practices and train users in "alien" aspects of the concept such as the use of a pre-shop pool. Hence, the second contribution of this paper has been to refine the theory surrounding WLC to make it more applicable to practical settings; to develop a deeper understanding of the available theory on the implementation process and provide evidence that this theory works in practice.

Managerial implications follow from these contributions. First, the importance of a contingency-based approach to PPC is supported. Comprehensive WLC approaches are closely aligned with the MTO environment in which competitive bidding takes place at the customer enquiry stage; and it is this alignment that leads to improved performance in this context. Second, for managers of MTO companies, the set of WLC implementation issues described in Table IV can be used to guide the process of implementation. Third, the importance of an appropriate PPC approach is argued to be even more essential in times of more extreme competition, such as a recession. The customer enquiry stage, in particular, became more widely used at this stage of the project as the need for dependability became a pertinent competitive priority.

Further research into the concept is still needed, given that some aspects of the system could be used more aggressively. For example, the workload length limits could be tightened to see whether lead times can be reduced further; and users could reduce their quoted DLTs so they are closer to the actual DLTs. This needs to be researched in a context in which speed is a key competitive priority. Future research should also explore further the potential link between WLC implementation and obtaining the benefits of lean and TQM in MTO companies. In time, and with more widespread industrial use of the concept, a survey of the effects of WLC on performance would also be worthwhile.

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