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Pull-logic and ERP within Engineering-to-Order (ETO): the case of a British Manufacturer

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Summary Abstract

Lean production and ERP systems are two of the most desirable manufacturing best practices (Bamford *et al.*, 2015); the link between them has been widely studied and discussed within the academic literature. However, the focus to-date has mainly been on low and medium variety production. In Engineering-to-Order (ETO), the high variety nature of the business and the use of ERP systems impact the ability to implement pull, a term widely misinterpreted. Using the case of a British Engineering-to-Order company, this paper analyses and determines the extent to which an ERP can support an ETO to tend towards a “pure” pull system.

Keywords: Engineering-to-Order, Pull production, ERP

Introduction

The concept of ‘pull’, while often applied to Make-to-Order (MTO), is rarely studied against Engineering-to-Order (ETO) companies (Kjersem *et al.*, 2015). Furthermore, a common inaccuracy is to define pull as Make-to-Order (Hopp and Spearman, 2004). A pull system is not only producing to an order; it also has an information flow opposite to the material flow and it maintains a constant level of Work-in-Progress (WIP) within the system (Hopp and Spearman, 2004, Powell and Arica, 2015). Because most well-known pull mechanisms are adapted to low variation production, ETO companies do not seem at first sight to be adapted to exploit the benefits of pull systems. Another misconception is that ERPs are predominantly facilitating push production, as they work and calculate a schedule based on a demand forecast. This paper will challenge

both misconceptions by investigating the following research question: how can ERP support an ETO process in moving towards a pure pull system? It will aim to analyse the characteristics of pull systems, ERPs and ETOs and determine to what extent they are compatible.

Literature review

Engineer-to-Order

The term Engineering-to-Order (ETO) has many different interpretations, as shown by Gosling and Naim (2009), but a commonly agreed feature is the uniqueness of each order. The main interpretation focuses on the location of the decoupling point. The “customer order decoupling point (CODP) is a stock holding point that separates the part of the supply chain that responds directly to the customer from the part of the supply chain that uses forecast planning. [...] Upstream from the CODP all products are produced to forecast; downstream from the CODP all products are pulled by the end-user” (Gosling and Naim, 2009, p.743).

The definition used for this paper is that a company is an ETO when the decoupling point is located at the design phase of the product (Gosling and Naim, 2009). In other words, anything produced during and after the design phase answers a unique customer demand.

Push vs Pull

When the concept of pull was developed in the 1960's, it was applied through the use of Kanban (Hopp and Spearman, 2004, Papalexli *et al.*, 2016). The Pull concept was then broadened, which led not only to a wider use of the terminology but also to the misinterpretation of its meaning (Hopp and Spearman, 2004). The most common inaccuracy is to simply equate pull with a Make-to-Order strategy and push with a Make-to-Stock one (Powell and Arika, 2015). The original meaning was defined by Hopp and Spearman (2004, p. 142) as a system that “explicitly limits the amount of work in process that can be in the system. By default, this implies that a push production system is one that has no explicit limit on the amount of work in process that can be in the system”. Powell and Arika (2015) on the other hand considered the evolution of the interpretation of pull by establishing three context-dependant definitions of pull systems: i) Demand-pull: “in Demand-pull, value-adding activities only take place in response of real customer demand. However, production can still be either pull-based or push-based” (Powell and Arika, 2015, pp. 67); ii) Plan-pull: “in the case of high variety, low volume (project-based) production, Plan-pull is the appropriate pull mechanism. The focus here is on the finished items and respective due dates, and value-adding activities take place based on a priority rule such as earliest due date (EDD) and constraint management” (Powell and Arika, 2015, pp. 70); and iii) Production-pull: “in Production-pull, value-adding activities take place in response of a specific withdrawal from an explicitly limited inventory buffer, or supermarket. The direction of information flow is the reverse direction of material flow, and production

takes place in order to replenish an exact amount of consumed products and / or components” (Powell and Arika, 2015, pp. 69).

The above are the definitions used to conceptually frame the paper and address the research question.

Enterprise Resource Planning (ERP)

In parallel to the increase in popularity of pull and lean production, ERP systems have been developed in order to optimise scheduling. ERP systems schedule production according to the demand forecast and therefore have a reputation of being incompatible with a pull system (Bertrand and Muntslag, 1993). However, even though modern standard ERPs are still not fully adapted to the implementation of pull systems, bolt-on solutions can allow both systems to cooperate (Powell *et al.*, 2013).

Pull mechanisms

Several mechanisms can be used to transform a production into a pull system. We will focus on three of them specifically: i) kanban, ii) CONWIP and iii) POLCA.

Kanban is a Production-pull method (Powell and Arika, 2015) where the signal to start producing is given through a card (Shahabudeen and Sivakumar 2008). Using Kanban cards implies keeping an intermediate stock between each work station and a stock of finished products in a supermarket at the end (Germs and Riezebos, 2010). When a finished item is taken off the shelf, a signal (often materialised by a card) is sent to the last work station to replenish the stock. The consumption of the intermediate stock then sends a card to the previous work station to replenish the intermediate stock. The process continues down to the raw material stock (Aqlan *et al.*, 2011). In order for a kanban system to be effective, it is preferable to apply it in a high-volume, low-variety environment (Germs and Riezebos, 2010).

CONWIP (Constant Work-in-Progress) is an adaptation of the kanban system to high-variety environments (Aqlan *et al.*, 2011). It consists in keeping a supermarket of finished goods but no intermediate stock (Aqlan *et al.*, 2011). When a finished item is taken off the shelf, a card is sent to the first work station to replenish the finished goods’ stock. While CONWIP caters for a higher variety of products than kanban, it still requires the existence of a supermarket of finished goods.

POLCA is a system that was created in 1998 to adapt kanban to low-volume high-variety environments; it is an acronym for Paired-cell Overlapping Loops of Cards with Authorisation (Fernandes and Carmo-Silva, 2006). Like kanban, it operates with cards, but unlike it, it does not require a supermarket of finished goods. The aim of POLCA is to maintain a level of control on the Work-in-Progress (WIP) inventories, by only authorising production upstream when the queue of the machines downstream is lower than the authorised maximum (Kabadurmus, 2009).

ERP and Pull in ETO

Pull production, as well as most lean concepts, has been developed by organisations with a limited portfolio of products and a relatively low range variety. These production

concepts might therefore be, in the first instance, considered ill-suited for Engineering-to-Order companies (Powell and Arika, 2015). Existing literature suggests that solutions, such as POLCA, exist to implement a pull structure to Engineering-to-Order companies; however these systems work with cards, and are not paired with an ERP system. This led us to investigate the following research question: how can ERP support an ETO process in moving towards a pure pull system?

Methodology

In order to answer the research question, this paper uses a British ETO company as a case study (Yin, 2013). By collecting and analysing qualitative and quantitative data from the ERP and the production results, the affiliation of the case company to the different pull definitions was assessed. The research question was then answered by discussing how existing techniques could be used to close the existing gaps with a “pure” pull system.

Qualitative data

In order to set up a baseline for the research and have an overview of the ERP system’s capabilities, interviews were conducted. This enabled the capture of the perceptions of the company on their own scheduling system. Company ERP users were asked to explain their definition of “pull” during a semi-structured interview, and to define whether in their eyes the company operates on a pull system. Their opinion on how well the current ERP system operates was also captured. Through the diversity of job roles selected, both a strategic and operational understanding of the ERP system was acquired.

Four people were interviewed: i) a Team Leader, as a primary user of the scheduling system ii) an administrator, who is part of the manufacturing support team iii) the Operations Manager, who has an oversight of the schedule and is accountable for On-Time-In Full (OTIF) delivery iv) the Financial Director, who defined the ERP system requirements.

Quantitative data

While the interviews helped create a baseline, the research question also required quantitative data. One of the beneficial characteristics of the custom-made ERP system is the large amount of raw data captured and stored, and therefore available for collation and analysis. As the key quantitative features that determine the affiliation to a pull system are WIP quantities, and the nature of the rule behind the priorities of the scheduling system, relevant data had to be collected to assess these features. The data collected included historical production data on machine loading and on the starting and finishing time of jobs. The code behind the scheduling priority rule of the ERP system was also acquired.

Findings

The case company

Reliance Precision Ltd, which we will refer to as “the organisation” is a family-owned British Engineering-to-order SME. They design, produce and assemble very tight tolerance components. Their capability to machine to sub-micron level allows the organisation to serve the market of Space, Aerospace, Defence, Medical and Scientific Instrumentations.

Due to the nature of the business, over 2000 new part numbers are created per year. Because of the high variability of the work, the organisation could not risk producing a part that is not required, as there is no guarantee that orders will repeat. If the orders do repeat there is a high probability for the design to have changed, making any stock obsolete.

The organisation is proud to deliver quality products on time. While quality is their primary concern, delivering On-Time-In-Full (OTIF) is a key value of the business. Apart from an increased customer satisfaction, maintaining an OTIF of over 95% allowed them to obtain and sustain the SC21 silver award, an important award in UK Defence and Aerospace supply chains.

The biggest challenge faced by the organisation is that customers often move their deadlines forward. While they are not contractually required to comply with the changes, the organisation aims to always satisfy customer requirements. They therefore need to be able to modify a job priority at any time.

Qualitative findings

The expected outcome of the interviews was a general understanding of organisation’s perception of pull and of the ERP system. Out of the four interviewees, three had an understanding of the “pull” concept. The results are shown in table 1.

Table 1-Definition of pull collected through interviews

Role	Definition of Pull
Team Leader	<i>“A pull system is when there is a delivery date to the customer that is broken down to take into account all the current lead times of each individual component and the supply chain.”</i>
Operations Manager	<i>“A Pull system is when the priority is not driven by a plan date but by the ship date.”</i>
Financial Director	<i>“A pull system is pulling from demand. It is working off the customer demand, rather than being pushed though from some kind of planned date.”</i>

It appears that the commonly agreed definition of a pull system in the organisation is similar to Powell and Arica’s (2015) definition of Plan-pull.

The organisation previously used third-party software for scheduling. Data from the ERP system was fed weekly into the scheduling software and its output fed back into the ERP system. Given the changing demands on the business it was felt that the system

was not flexible enough and too much manual intervention was required to meet changing priorities. As a result the decision was made to integrate a custom made scheduling system directly into the ERP. The scheduling was therefore tailored to meet the needs of the company, and both shop-floor and management were consulted.

During the interviews everyone reported that they were happy with the custom-made ERP. All four people interviewed described the ERP as very flexible and user friendly, and as responding efficiently to changes in customer demand. While the amount of manual management was greatly reduced, it was reported to still be required. In addition to the ERP’s flexibility, the capacity flexibility was also addressed. The Operations Manager stated that the organisation “*has enough flexibility to influence its capacity if required. Machine capacity can be changed by allowing overtime or adding a nightshift. When it comes to manpower, our flexible workforce can be reassigned to the bottleneck areas*”.

Quantitative findings

By analysing the code used to define the priority of jobs, the key factors of the priority were determined. Each machine is given a prioritised list of job. The prioritisation is done through a priority figure calculated as the sum of four main figures explained in table 2.

Table 2- Components of priority rule

Name	Description
Hot list	Boolean taking the value of 0 or 1000. The value 1000 appears only when a job is manually hot listed by the operations manager. This figure only equates 1000 when unexpected events require the priority to jump up. It is mainly used when a customer pulls their deadline forward.
Disruption risk	Twice the number of operations left to complete the product. This figure includes internal operations and sub-contractor operations.
Time pressure	Difference between number of days left to manufacture the job and the numbers of days required to manufacture it. It is calculated based on a deadline set three weeks before the ship date.
Scope to influence	This figure has the biggest impact on the priority list. It is based on the agreed delivery date, and is increased inversely proportionally to the number of days left until the acknowledged delivery date. While it is given an arbitrary high value to ensure that jobs close to customer deadlines are prioritised, the time pressure and disruption risk values usually achieve schedule adherence before the scope to influence is required.

The orders of magnitude of the different variables used show that the customer delivery date becomes the prevailing priority as this date approaches.

By collecting historical production data on machine loading and on the starting and finishing time of jobs, the quantity of Work-in-Progress in the system could be assessed. The results are showed in figure 1.

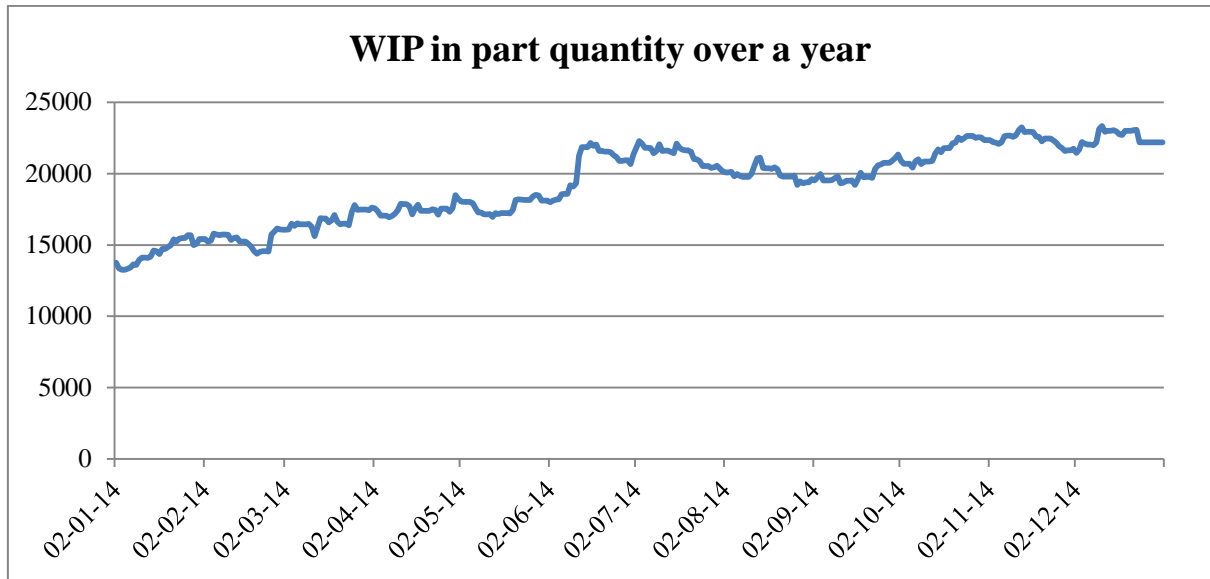


Figure 1-WIP quantities over a year

The graph clearly shows that there is no defined limit to the amount of WIP, as we can see the quantities varying throughout the year. However, it is important to consider that WIP is entirely dependent on the customer mix, product type and sourcing decisions, as, for example, 100 small parts can require the same effort as a single complex item, for a similar value.

Discussion

In this section we will address the research question, by analysing to what extent the ERP system of the organisation allows it to fit with each of Powell and Arica's (2015) definition of pull.

Demand-pull — from the interviews, all four people agreed that no production was started without a real customer demand. The analysis of the scheduling rule confirmed that jobs are scheduled to work towards a defined acknowledged delivery date, therefore implying an order placed. Through the custom-made ERP, “value-adding activities only take place in response of real customer demand” (Powell and Arica 2015, p.67) validating the Demand-pull definition.

Plan-pull — in the case of this organisation, the ERP system drives a Plan-pull environment. The analysis of the way the schedule is organised shows that the focus “is on the finished items and respective due dates” (Powell and Arica 2015, p.70). By adding several criteria with different levels of impact, the ERP system ensures that “value-adding activities take place based on a priority rule such as earliest due date” (Powell and Arica 2015, p.70). While the ERP rules do not consider constraint management, the interviews showed that the structure of the organisation did not require it. As the ERP system has access to information on machine and men constraints, the choice of not integrating these data sets to the scheduling was deliberate. However, as the ERP was made in-house, this feature could be added if deemed necessary. In this

case, the ERP system is an enabler to the implementation of a Plan-pull system, rather than an obstacle.

Production-pull — In order to correspond to Powell and Arika's (2015, p.69) definition of Production-pull, three conditions need to be met: i) "The direction of information flow is the reverse direction of material flow"; ii) "Value-adding activities take place in response of a specific withdrawal from an explicitly limited inventory buffer, or supermarket"; and iii) "Production takes place in order to replenish an exact amount of consumed products and / or components". While the use of a scheduling system seems to indicate that the information flows in the same direction as the material, it is not always the case. While the value of the scope to influence is 0, operations upstream takes place without being influenced by operations downstream. However, the increase of the scope to influence value is triggered by operations downstream, as it illustrates the need for the following operations to start. It can therefore be argued that when the scope to influence starts increasing, the information flow is opposite to the material flow. The ERP system therefore allows the organisation to have a breakeven point after which the first criterion is met. However, the ERP system does not allow the other two criteria to be met. A consequence of meeting the last two criteria would be uniform Work-in-Progress through time, which the analysis of the organisation's WIP data demonstrates is not happening. The organisation's ERP therefore does not currently allow them to be a Production-pull.

In this particular case study, the ERP system has enabled an ETO to become a Demand-pull and a Plan-pull organisation, but it has not supported them in becoming a Production-pull environment. However, by pairing the ERP with a known Production-pull technique, the organisation could become a "pure" pull. In this situation, kanban and CONWIP techniques are not adapted, as the creation of internal supermarkets is not desirable for an Engineering-to-Order company. The POLCA method, on the other hand, could be put in place. This method does not determine priorities, but only acts as traffic light, with machines downstream sending an authorisation to produce upstream. By pairing the scheduling system with POLCA, the organisation would still benefit from the ERP systems capabilities, and comply with the Demand-pull and Plan-pull definitions. It would also comply with the Production-pull definition, as the WIP would stabilise, and information would flow in an opposite direction to material.

The answer to our research question therefore is that while the ERP system currently makes this ETO into a hybrid pull-push organisation, it could become a "pure" pull organisation by combining the current ERP system with a POLCA method. However, when asked about it in the interview, the Operations Manager stated that POLCA might not be compatible with the challenges of the business; in this case allowing high WIP quantities is a calculated risk, as it allows the organisation to face sudden changes in customer deadlines.

Conclusion

Through the analysis of a case study, this paper has analysed how an ERP could support an ETO to tend towards a "pure" pull system. Evaluating the case company's affiliation

to Powell and Arika's (2015) three definitions of pull has led to the following conclusion: the functionalities of the organisation's custom-made ERP system fits with the Demand pull and Plan-pull definitions, however not with the Production-pull one. This paper has also shown that by pairing the ERP system with a POLCA method, a "pure" pull organisation can be attained. A limitation of this study was that the supply-chain could not be analysed, and the reasons behind customer changes in deadlines could not be addressed. While this paper addresses the current situation, a change upstream could provide a better integration of pull throughout the supply chain. This provides some relevant directions for future research.

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