Computers & Industrial Engineering 87 (2015) 465–480

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Evaluation of multi-product lean manufacturing systems with setup and erratic demand ☆

Chukwunonyelum Emmanuel Onyeocha [a], Joseph Khoury [b], John Geraghty [a,*]

[a] Enterprise Process Research Centre, School of Mechanical & Manufacturing Engineering, Dublin City University, Dublin 9, Ireland
[b] Methode Electronics International, Germany

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 6 March 2015
Accepted 24 May 2015
Available online 4 June 2015

Keywords:
Multi-product systems
Production control strategies
Production authorisation cards
Erratic demand

ABSTRACT

The consideration of demand variability in Multi-Product Lean Manufacturing Environment (MPLME) is an innovation in production system engineering. Manufacturing systems that fail to recognise demand variability generate high Work-In-Process (WIP) and low throughput in MPLME. In response to demand variability, organisations allocate large quantities of Production Authorisation Cards (PAC). A large proportion of PAC results in a high WIP level. However, the Shared Kanban Allocation Policy (S-KAP) allows the distribution of PAC among part-types, which minimises WIP in MPLME. Nevertheless, some existing lean manufacturing control strategies referred as Pull Production Control Strategies (PPCS) that have shown improved performance in single-product systems failed to operate S-KAP. The recently developed Basestock–Kanban-CONWIP (BK-CONWIP) strategy has the capability of minimising WIP while maintaining low backlog and volume flexibility. This paper investigates the effects of erratic demand on the performance of PPCS in MPLME. It is shown that S-KAP BK-CONWIP outperforms other PPCS. Finally, it is feasible to design quick-response PPCS for MPLME under erratic demand.

1. Introduction

In recent decades, trends in the literature showed that lean manufacturing has become a fundamental model for manufacturing industries, especially in the United States (Shah & Ward, 2007). The competitiveness and superior performance of lean manufacturing has been acknowledged by academicians and practitioners (see, Krafcik, 1988; MacDuffie, 1995; Pedrielli, Alfieri, & Matta, 2015; Pil & MacDuffie, 1996; Prakash & Chin, 2014; Shah & Ward, 2007). Critics of lean manufacturing agree that alternatives have not been widely accepted (Dankbaar, 1997; Shah & Ward, 2007). Therefore, lean manufacturing remains the basic manufacturing method of the 21st century (Shah & Ward, 2007). The success of the Toyota Production System (TPS) has caused many organisations to adopt lean manufacturing strategies, resulting in a rich literature with case studies on organisational challenges, ranging from selection to implementation (Grewal, 2008; Seth & Gupta, 2005). However, the findings of Bamber and Dale (2000) showed that implementing lean manufacturing strategies in a traditional aircraft industry failed, owing to an inappropriate lean control strategy. As a lean manufacturing tool, the pull production control strategy is widely used in manufacturing environments to respond to the actual demands and to control the WIP inventory of a system. The performance improvement of Toyota's pull control strategy, known as the Kanban Control Strategy (KCS), resulted in a widespread study on the design, operation and optimisation of the pull production control strategy. These studies produced other pull production control strategies (variants of KCS) that are referred as Kanban-Like PCS.

Many organisations that have reported difficulties in adopting pull production control strategies are complex and multi-product manufacturing organisations with customised products and/or unstable demand profiles (Bamber & Dale, 2000). Both Onyeocha and Geraghty (2012) and Olaitan and Geraghty (2013) have reported that the attention of academic research on the development and comparison of pull production control strategies has focused on single-product environments. Recently, researches on the selection and implementation of pull production control strategies in multi-product environments have gained momentum. Olaitan and Geraghty (2013) investigated the performance of various PPCS combined with Kanban Allocation Policies (KAP) in a two-product, three-stage manufacturing system with negligible setups and linear demand. The study concluded that different pull production control strategies and Kanban allocation policies may

☆ This manuscript was processed by Area Editor Manoj Tiwari.
* Corresponding author.
E-mail address: john.geraghty@dcu.ie (J. Geraghty).

http://dx.doi.org/10.1016/j.cie.2015.05.029
0360-8352/

be preferred if the settings of the performance metrics to small changes in the assumptions made for optimisation are considered.

This paper will investigate the impact of erratic demand in MPLME to understand how this governs the selection and optimisation of a pull production control strategy and Kanban allocation policy. This investigation is conducted through the lens of a case study from an automotive electronics components manufacturing plant. Simulation models of the real system were developed for three pull production control strategies and two Kanban allocation policies. The system is a five-stage serial assembly line, with setups, producing products classified into two distinct product families. Planning in the line is complex owing to significant variability arising from machine unreliability, besides unstable/erratic demand profiles for the four products.

Each pull production control strategy examined is optimised in terms of its control parameters for a demand profile for the product range. The performances of each of the pull production control strategies are compared in terms of backlogs and the inventory positions of the line and of the supermarket area under changing demand profiles typical of the experiences of the case study organisation. To determine the factor influencing the performance of the pull production control strategies operating a specified Kanban allocation policy, the product volume and mix are examined.

The rest of this paper is organised as follows: Section 2 presents a brief literature review of MPLME. Section 3 describes the case study and the experimental conditions. The experimental results are provided in Section 4. The findings of the study are described in Section 5. Finally, Section 6 provides a managerial insight, a conclusion of the study and further research areas.

2. Background

A manufacturing system refers to a set of interlinked entities (e.g. Workstations) that interacts to accomplish defined tasks, objectives or goals. A multi-product lean manufacturing system relates to a manufacturing system capable of producing over one product-type while operating under the concept of continuous improvement. The process of reducing the sum of the idle times of all the workstations in a manufacturing or assembly line to the barest minimum is known as assembly line balancing. However, perfect balancing is complex and rare in practice (Baybars, 1986; Soroush, Sajjadi, & Arabzad, 2014).

Furthermore, scheduling and sequencing in an assembly line poses a difficult challenge because of the setup times, the load on workstations and the use of parts in the assembly line (Esmaeilian, Sulaiman, Ismail, Hamedi, & Ahmad, 2011; Monden, 1983; Soroush et al., 2014). Setup refers to adjusting a machine/workstation or a set of machines to switch from producing a product-type to a different product-type. The frequency of setups affects the performance of a manufacturing system. Setup times have attracted a lot of attentions owing to the effective performance of a system when setup times are considered (Allahverdi & Soroush, 2008). Setups are sequence-independent or sequence-dependent.

In this paper, pull production control strategies are examined owing to their documented performance and effectiveness in manufacturing systems with stochastic demand and make-to-order policies (Krafcik, 1988; MacDuffie, 1995; Pedrielli et al., 2015; Pil & MacDuffie, 1996; Prakash & Chin, 2014; Shah & Ward, 2007). Pull production control strategy uses actual customer demands in planning, scheduling and control of production in a system. In academic research works, demands are often represented as a single demand profile or linear whereas in the manufacturing industry practitioners report that actual customer demands are erratic (Geng, Jiang, & Chen, 2009).

Erratic demand refers to demand profile characterised by irregular demand sizes with high variations (Onyeocha, Khoury, & Harik, 2014; Syntetos & Boylan, 2005). The probability of measuring the uncertainty of the erratic demand variability is critical and affects the performance of the manufacturing system (Feng, Gowrisankar, Smith, & Yu, 2006). Managing such erratic demands is challenging and requires a proper selection and implementation of pull production control strategies with volume flexibility. Volume flexibility is referred as the ability of pull production control strategy to respond to demand variations without reconfiguration of the production control parameters at any production period. However, in lean manufacturing, pull production control strategies have shown poor responses to large varying product volume or mix in a system (Marek, Elkins, & Smith, 2001). This issue of product volume variations often results in flow line congestion, long lead times and low throughput rate in MPLME, such that the performance goals and the principle of lean manufacturing is undermined.

A majority of the studies on pull production control strategies considered single-product production lines (e.g. Ang, 2015; Deleersnyder, Hodgson, King, O'Grady, & Savva, 1992; Geraghty & Heavey, 2005; Kleijnen & Gaury, 2003; Koh & Bulfin, 2004; Krejewski, King, Ritzman, & Wong, 1987; Lee, 1989; Sharma & Agrawal, 2009; Spearman, Woodruff, & Hopp, 1990; Weitzman & Rabinowitz, 2003; Özbayrak, Papadopoulou, & Samaras, 2006). These studies assumed that research results on single-product lean manufacturing environments are scalable to multi-product lean manufacturing environments. This assumption is not reliable because a pure implementation of a PPCS in a multi-product environment requires maintaining semi-finished parts of each of the products distributed throughout the system, which proliferates WIP inventory (Olaitan & Geraghty, 2013; Onyeocha, 2012, 2014; Onyeocha, Khoury, & Geraghty, 2013, 2015; Satyam & Krishnamurthy, 2008).

A review of studies on a multi-product lean manufacturing environment shows that the majority of those studies focused on an analysis, planning and scheduling problems (Akturk & Erhun, 1999; Gurgur & Altiok, 2008; Hum & Lee, 1998; Krieg & Kuhn, 2008), production configuration settings and optimisation of production control parameter cards (Bard & Golany, 1991; Soroush et al., 2014), or understanding the control mechanisms of specific pull production control strategies (e.g. Duenyas, 1994; El-Khouly, El-Kilany, & El-Sayed, 2009; Prakash & Chin, 2014; Ryan, Baynat, & Choobineh, 2000; Ryan & Vorasayan, 2005; Satyam & Krishnamurthy, 2008; investigated the behaviour and the effect of the work-in-process inventory limit of CONWIP). The assumptions that production authorisation cards are the same in single and multi-product lean manufacturing environments were prevalent in these studies, resulting in the dedication of production authorisation cards to a part-type in these studies. However, the findings of Baynat, Buzacott, and Dallery (2002) showed that production authorisation cards could be rigid (dedicated to a part-type in a stage or system) or be flexible (shared among part-types) in multi-product lean manufacturing environment.

Therefore, these two production authorisation card allocation policies are referred as Dedicated Kanban Allocation Policy (D-KAP) and Shared Kanban-Allocation Policy (S-KAP). Baynat et al. (2002) showed that shared Kanban allocation policy maintained lower work-in-process inventory in a multi-product lean manufacturing environment than dedicated Kanban allocation policy when implemented with the same pull production control strategies. However, not all pull control strategies can operate in S-KAP mode. Onyeocha and Geraghty (2012) proposed a technique for modification of pull control strategies to operate in S-KAP mode and they developed a new pull production control strategy called the Basestock Kanban-CONWIP (BK-CONWIP) with high demand