COMPARISON OF PARALLEL KANBAN-BASE STOCK SYSTEM TO CONTROL MULTI-PRODUCT MULTI-STAGE PRODUCTION WITH REWORK THROUGH SIMULATION

by

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AvHR	Average flow time of HR
Avk_s	Average flow time for standard kanban
AvLR	Average flow time of LR
AvThr	Average throughput
AvUtil	Average utilization of machine
AvWIP	Average WIP level
BSS	Base stock System
CR	Critical ratio
DBD	Dynamic bottleneck dispatching
DES	Discrete-Event Simulation
DP	Depaneling machine
DR	Defect rate
EDD	Earliest due date
EKCS	Extended Kanban Control System
FBN	First bottleneck strategy
FIFO	First-in-first-out
GKCS	Generalized Kanban Control System
GRPD	Greedy rework probability with a due date
HIHSs	Horizontally Integrated Hybrid Systems
HL	High runner-Low runner
HPCS	Hybrid production control system

HR	High-runner
JIT	Just-In-Time
k_o	Order kanban
KS	Kanban System
k_s	Standard kanban
LH	Low runner-High runner
LM	Lean Manufacturing
LR	Low-runner
LRB	Low runner buffer
LRR	Low runner ratio
LS	Lot size
MPS	Master production schedule
MR	Merge reworking policy
MRP	Material Requirement Planning
MRPD	Minimum rework probabilities with due dates
MRPII	Manufacturing Resource Planning
ODD	Operational due date
OPT	Optimized Production Technology
OR	Original reworking policy
OV	Overall flow time
P	Push system
PAC	Production Authorization Card
PCB	Printed circuit board
PCS	Production controlsystem

PD	Probability defect
PIHSs	Parallel Integrated Hybrid Systems
PKB	Parallel Kanban-Base stock
PKB-HL	Parallel Kanban- Base stock system with HL dispatch rule
PKB-HL-MR	Parallel Kanban- Base stock system with HL dispatch rule and MR rework entrance policy
PKB-HL-OR	Parallel Kanban- Base stock system with HL dispatch rule and OR rework entrance policy
PKB-LH	Parallel Kanban- Base stock system with LH dispatch rule
PKB-LH-MR	Parallel Kanban- Base stock system with LH dispatch rule and MR rework entrance policy
PKB-LH-OR	Parallel Kanban- Base stock system with LH dispatch rule and OR rework entrance policy
PM	Probability of merging
P-MR	Push system with MR rework entrance policy
P-OR	Push system with OR rework entrance policy
PPCS	Production planning and control system
PPS	Production planningsystem
PSBS	Problem space based research
REP	Rework entrance policy
RR	Rework runner
RSM	Response Surface Methodology
RV	Rendezvous strategy
RWK	Rework priority

SA	Starvation avoidance
SIC	Statistical Inventory Control
SME	Surface mount equipment machine
SP	Split strategy
SP	Split strategy
SPT	Shortest processing time
SST	Shortest setup time
TO	Total output
UCELL	U-shaped cell
VIHSs	Vertically Integrated Hybrid Systems
WAIT	Wait strategy
WIP	Work-in-process
WIP_{max}	Maximum WIP level
WR	Workload regulating

LIST OF SYMBOLS

P_c	collective probability
n	number of RR orders waiting to be merged
t_1	production control system
t_2	dispatch rule
t_3	rework entrance policy
R^2	coefficient of determination

PERBANDINGAN SISTEM STOK ASAS-KANBAN SELARI UNTUK MENGAWAL PENGELUARAN PELBAGAI PRODUK DI PELBAGAI PERINGKAT DENGAN MENGAMBILKIRA AKTIVITI KERJA SEMULA MELALUI SIMULASI

ABSTRAK

Cabaranglobalisasi kinimemaksaindustri pembuatanuntuk menawarkanpelbagai produk dengan keperluan yang berbeza-bezauntuk memenuhi keperluan pelanggan mereka. Walau bagaimanapun,senario kompleks ini telah menyebabkan kerja dalam proses (WIP) dan kecacatan yang tinggi, dengan itu memberi inspirasi kepada penyelidik untuk menyelidik cara-cara yang optimum untuk menguruskansistem pembuatanyang kompleks ini dalam skop sistemkawalan pengeluaran(PCS). Kebanyakan penyelidikan dalamPCSsebelum inimemberi tumpuan kepadasistem pengeluaranyang idealdankerja semulajarangdipertimbangkan.Kajian inibertujuan untuk membangunkandan menilaiprestasi suatuPCShibridyang baru yang dikenali sebagaisistem Stok asas-Kanban Selari(PKB) untuk mengawal seliapelbagai produk pengeluaran pelbagai peringkatdenganpintu masukkerja semula. Berbeza dengansistem hibridstok asas-kanban asal,sistemPKBmengambil kiratiga varian.Varianpertamaadalah duakelasprodukkeluarga dikenali sebagai pelari tinggi(HR)dan pelari rendah (LR) berdasarkan permintaancampuranproduk.Variankedua ialahvariasikaedah untuk mengawal seliapenghantaranproduk keluargadikategori sebagaipelaritinggi-pelari rendah (HL) dan pelari rendah-pelari tinggi (LH). Varianketigamempertimbangkan duapolisipintu masukkerja semuladiklasifikasikan sebagaicantum(MR) dan asli(OR).

Sistem yang dikajitelah dimodelkan menggunakan simulasiperistiwa diskret. Keputusan simulasi dianalisisberdasarkankaedah statistiktermasuk analisisvarians, regresi danmetodologi permukaan sambutan. Pemilihanparameter,pembolehubahdanprestasi yang diukuradalah berdasarkan kajianilmiah danamalansemasa syarikatkajian kes.Kajian ini telah dibahagikan kepada tiga kes. Bagi Kes 1, di antara polisi masuk kerja semula, MR polisi masuk kerja semula memberi hasil yang lebih wajar seperti yang dikaji bagi pengukuran prestasi berbanding OR polisi masuk kerja semula. Bagi Kes 2, keputusan menunjukkan bahawa sistem PKB dengan permintaan pelanggan yang berbeza menunjukkan peraturan penghantaran HL adalah lebih baik berbanding peraturan penghantaran LH. Bagi Kes 3, *PKB-HL-MR* memberikan hasil optimum berbanding model lain.Secara keseluruhan keputusan menunjukkan, sistem PKB mempunyai kelebihan sistem stok asas (untuk LR) dengan menghasilkan hampir 1.3% jumlah keluaran lebih tinggi dan kelebihan sistem kanban (untuk HR) dengan mempunyai WIP terkawal. Lebih penting lagi, kajian ini menyumbangkepada pengetahuandalam bidangPCSdalam persekitaran pelbagai produk pelbagaiperingkat dengan mengambilkira proseskerja semula.Bagi penyelidikanmasa depan, kajian iniboleh dilanjutkankepada analisiskonfigurasisistem yang lebihrumitsepertikerosakanmesindan menjalankanmodelsimulasiuntuk pelbagaijenis industri.

COMPARISON OF PARALLEL KANBAN-BASE STOCK SYSTEM TO CONTROL MULTI-PRODUCT MULTI-STAGE PRODUCTION WITH REWORK THROUGH SIMULATION

ABSTRACT

A recent globalization challenge compels manufacturing industries to offer a large variety of products with varied demands to suit their customers' needs. However, these complex scenarios have led to high work-in-process (WIP) and defects, thus inspires many researches to investigate the optimum ways to manage this complex manufacturing system within the scope of production control system (PCS). Most research in PCS has previously focused on the ideal production system and rework is seldom being considered.This study aims to develop and to evaluate the performance of a new hybrid PCS known as Parallel Kanban-Base stock (PKB) system to regulate a multi-product multi-stage production with the entrance of rework. In contrast to the original hybrid kanban-base stock system, PKB system takes into account of three variants. First variant are two classes of the product families known as high-runner (HR) and low-runner (LR) based on the demand of the product mix. The second variant is the variations of dispatch rules to regulate product families categorized as high runner-low runner (HL) and low runner-high runner (LH). Third variant considered was two rework entrance policies classified as merge (MR) and original (OR). The studied systemshave been modeled using discrete-event simulation. The simulation results are analyzed based on statistical methods including analysis of variance, regression and response surface methodology. The selection of related parameters, variables and performance measures is relatively based on literature study and current practice of a case study company. This study has been divided into three cases. For Case 1, among rework entrance policies, predominantly MR rework entrance policy yields more desirable results as observed within the performance measures, compared to OR rework entrance policy. For Case 2, the results revealed that PKB system with different customer demands shows HL dispatch rule is superior to LH dispatch rule. For Case 3, *PKB-HL-MR* gives the optimum results compared to other models. Overall findings show that PKB system possesses the advantage of a Base stock System (for LR) by causing an approximately 1.3% higher total output and the advantage of a Kanban System (for HR) by having controllable WIP levels. Significantly, this research contributes to the knowledge in the area of PCS in multi-product multi-stage environment considering reworking process.For future research, this work can be extended to the analysis of more complicated system configurations such as a machine breakdownand run the simulation model for various types of industries.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter intends to help reader to gain initial understanding about the research. It covers the underlying background and manufacturing concerns leading to this research. It also presents the research objectives, limitations and significance of this research. Finally, the structure of the thesis is specified.

1.2 Background

The nature of competition in manufacturing has shifted since the debut of the lean manufacturing. Customers have changed and their necessities have shifted. Customers demand more and more variety in their products and request for their products be delivered punctually.In the manufacturing sector, production consists of multiple processes to convert raw materials into completed products and throughout the processes; values are added into the products. Consequently, there is a need to control over the processes to signal abnormalities from plans and trigger corrective measure (Kanawaty, 1992; Panhalkar et al., 2014). However, the decisions to choose the suitability of the production planning and control system (PPCS) are determined by various elements such as load factor, number of products, the nature of production, management style and level of instability of system, for example, variability in demand, processing time, setup time and/or breakdown and repair time(Olaitan and Geraghty, 2013). Significantly, the PPCS in which a company chooses will have an impact on its flexibility, productivity, cost and quality.

A PPCS covers the planning and controlling aspects of manufacturing, including materials, scheduling machines and people and coordinating suppliers and customers. A right and efficient application of PPCS reduces manufacturing cost and meeting customer demands on time is crucial to the success of any company (Sule, 2008; Mehrjoo and Bashiri, 2013). A PPCS's design is not a one-off task; it should be adjusted to respond to alterations in the competitive manufacturing, customer requirements, strategy, supply chain and other possible problems (Vollmann et al., 2005).

PPCS can be divided into two elements: production planning system (PPS) and production control system (PCS). PPS determines what, when and how much to produce to meet the customer's needs, without excessive inventory or back order costs (Sule, 2008). The PCS can be depicted as a set of activities which regulates and controls the flowof information and the logic behind it that controls the movement of materials during manufacturing while consideringseveral requirements such as the cost, labor, demand, resource availabilityand capacity restrictions (Hopp and Spearman, 2008). This study focuses more on PCS and attempts to develop a model system to regulate and control the flow of materials with additional element that will be explained further in the following chapters.

PCS can be divided into two mechanisms, namely push system and pull system. In a push system, production is initiated when demand is scheduled to individual stage and parts are available for processing. In a pull system, production is initiated when finished goods or work-in-process (WIP) inventory are withdrawn and parts are available for replenishment.

While emerged long before pull system, push system is more common in manufacturing industries. Many organizations of the production have also been designed to suit push system. This includes departmentalization of production stages, centralized PPCS, local order sequencing at loading as well as large batch production. Although push system has shown to be a relative success in industries, erroneous demand forecasting may cause excess or deficient finished goods or WIP inventory, and overutilization/underutilization of capacity in meeting the actual demand. Push system tends to accumulate high WIP to buffer against shop floor uncertainties. This leads to long lead times.Therefore, production costs will be increased. Several PPCS tools associated with the push system are Material Requirement Planning (MRP) and Manufacturing Resource Planning (MRP II).

On the other hand, a pull system prompts the release of work into the system and pulling work through the system to fulfill customer demand. The pull system is capable to react to changing customer demands. Ultimately, it aims to support producing the right products at the exact times and the right quantity.

Nevertheless, due to rapid technological innovation, globalization of markets, the rising sophistication of client preferences and changes in commerce structure, lots of manufacturing industries provide a large variety of products to their customers (Groote and Yücesan, 2011). In multi-product production system, different products are manufactured through the same or similar sequence of operations by sharing available pieces of equipment, intermediate materials and other production resources (Lin et al., 2002). Moreover, multi-stage production systemis defined as a production system composed of a sequence of stages, in which one or more machines perform production operations and are decoupled by intermediate buffers (Colledani et al., 2008). The term ‘multi-product multi-stage,’is a formal term frequently used in the operational management field to address the various architectures of the production process consisting of more than a single product type and more than one processing stage (Amin and Altiok, 1997).

According to Fisher and Ittner (1999), one of the significant adverse impacts of multi-product is major rework. Most existing PCS models assume all items produced are of perfect quality, however, in real world production systems, due to several grounds such as process deterioration, human errors and other factors, generation of defective parts are expected. Recovering defective parts through rework inevitably adds another level of complexity to any PCS. To manage, operate, and improve the performance of such systems, modeling and analysis of production systems with rework are necessary and important. Such undertakings are backed with practical reasons, as many shop floor needs to regulate different product families with reworking process and a single PCS is found largely inadequate. Also, while various studies relate to dispatching rule and rework strategy on the rework process, study on rework entrance policy is considered scarce.

Lately, the research and development of PPCS have evolved into hybridization by integrating a number of established systems. It is becoming more apparent that in many cases, a hybrid production control system (HPCS) is more efficient than either a pure push or pure pull PCS alone in multi-product multi-stage environment. Thus, as the research objective, HPCS were to be designed to meet the requirements of manufacturing environment and the complexity of the manufacturing system activities. Most studies assume a simple factory setup of the few machines in series with only one type of product (Liberopoulos and Dallery, 2000;Geraghty and Heavey, 2005). The HPCS in this study is suggested because of the nature of the production and this research differs from the previous efforts in two aspects. Firstly, although some researchers considered complex systems with multi-product and multiple stages, unfortunately, they did not consider the variability of customer demand with shared machines. Secondly, one aspect of the system to be evaluated is the rework entrance policy.

This study develops model inDiscrete-Event Simulation (DES). Response Surface Methodology (RSM) was used to analyze the results of the developed simulation models. Integrating DES with RSM yielded critical insights into the investigated PPCS problem. Furthermore, this method shortens the time consumed, ease of use and ability to apply in wide area of application (Muhammad and Chin, 2014).

1.3 Problem statement

Most existing PCS models assume that all items produced are in good quality and the existence of defective parts is unimportant (Chong et al., 2013). However, in reality, defective parts are present in many production environments due to various reasons including process deterioration, human errors and other factors (Aghajani et al., 2012). For example, defects report for up to 10% of production in electronics manufacturing industry (Shina, 2002) and the costs may amount to 10-25% reduction of total sales due to such defects (Agnihothri and Kenett, 1995). One of the highest sources of defect is on stencil printing in the printed circuit board(PCB) assembly. It caused averagely 60% of all such defects (He et al., 1998; Pan, 2000). These defects generate waste in the form of production loss, extra material handling costs, excessive production delays and etc. (Hadjinicola, 2010). Consequently, in these circumstances, a procedure to recoverthe defective parts would be beneficial to the company and many industries having no recycling or reworking facility lose a heavy portion of profit margin (Aghajani et al., 2012). In that respect, various treatments for defective components can be implemented such as scraps, reworks or sold them at cut prices. Yet, for expensive products, processes or assemblies, such as plastic, metal, book shelves, injection molding, PCB assembly, semiconductor, glass, steel, pharmaceutical, chemical and advanced composites manufacture, rework is usually performed to transform them into serviceable ones rather than scrap or sold at cut prices due to economic and safety reason (Jamal et al., 2004; Chiu et al., 2007; Sarker et al., 2008; Liu et al., 2009; Chiu et al., 2011; Chiu et al., 2012).

A recent globalization challenge compels manufacturing industries to provide a large variation of products with varied demands to fit their customer's need. Duri et al., (1995) and Kenne et al. (2003) expose the importance of addressing the influence of multi-product in production; failure to do so may accrue problem such as unnecessary costs (Gharbi and Kenne, 2003). According toSmalley (2009), a PCS in a multi-product multi-stageenvironment encounters two challenges; firstly, is to satisfy the demand of product variety and secondly, is to maintain the low inventory level. Additionally, the difficulties presented in multi-product and demand variability production environment significantly distract the synchronization of materials movement between stages, resulting in underutilization of manufacturing resources, long lead times and poor delivery reliability (Khalil and Stockton, 2010). Moreover, the existence of a single PCS might not be favorable in multi-product multi-stage environment with different order priorities, process constraints and control policy requirement set by customers and the industry (Prakash et al. 2011). A possible solution is a HPCS.

Recovering defective parts through rework inevitably adds another level of complexity to any PCS especially to companies that have to confront the problem of high variety of products in dynamically changing demand and in particular ones aim to control discrete WIPs. Release of parts successfully reworked to production will temporarily disrupt the control of WIP level and production flow, thus, study on rework entrance policy should be studied. To understand the relevant complexities, it is important that a case study with multi-product multi-stage environment is conducted.

1.4 Research objectives

The main objective of this research is to investigate various production performances of a new hybrid PCS called Parallel Kanban-Base stock (PKB) system. The PKB system considers different customer demands and rework entrance policy in multi-product multi-stage environment. This is achieved through the following objectives:

1. To develop a PKB system with several variants based on a literature review of existing PCS in multi-product multi-stage manufacturing environments by using simulation.
2. To evaluate the production performances of push system and PKB system with several variants in the multi-product multi-stage environments.
3. To define the simulation variables influencing system models and determine their significant relationships to the performance measures.
4. To validate and verify the system models through a real industrial case study.

1.5 Limitations of the research

The limitations of this research are:

1. The accuracy of the information and data used in this research highly dependent on the records provided by the case study company.

2. The reliability of collecting data and collection procedures from a statistical point of view is not the main concerned with this research.

3. Only a portion of the production characteristics are extracted into the research. Assumptions are made accordingly in the subsequent chapter.

4. The study of the supply chain is excluded because it is dictated by the market position of the suppliers, wherethere is restricted control (Mares, 2010). However, the research necessitates that raw materials of products under investigation are consistently available.

5. WITNESS 2008 is the only manufacturing simulation software used in this study and it is applied in numerous researches (see; Lu, 2009 and Prakash and Chin, 2014). Thus, the results gained from this software were not verified using other softwares.

1.6 Significance of the research

This research holds significance for organizations that are constantly striving for their customers and at the same time competing with other manufacturers. This research should also be important to organizations that seek to minimize waste by recovering defective parts through rework process. Furthermore, the significance of performing the present study also rests on the grounds that such a situation is shared by many industries. The outcomes obtained from this study shows that, the PKB system is potentially forthcoming to a management that is presently adopting a pull production system, in view that the changes required are less drastic compared with a push system. Above all,the data gathered from this study will contribute to the knowledge in the area of PCS in multi-product multi-stage environment considering reworking process.

1.7 Thesis structure

The organization of this thesis is as follows. The Chapter 1 begins with a description of the research background, problem statement, research objectives, limitation and the significance of the research. Chapter 2 provides a review of the literatures as the fundamental motivation of this research. It provides complete explanations tovarious PCS (push system, Kanban System, Base stock System, Generalized Kanban Control System, Extended Kanban Control System and mixed pull system). The chapter also introduces the rework processes in manufacturing and clarifies the terminologies used in this research.Chapter 3 introduces the steps involved in a simulation study. The research methodology used in this study can be divided into three main phases. Phase 1 explains the structuring of the conceptual model. This is followed by Phase 2 that is the development of DES models and the software used in this research. The final phase is Phase 3, where it concerns the performance of simulation model analysis through RSM.Chapter 4 introduces a detail development of the simulation model. This chapter also contains an explanation of the experimental designs and analysis pertinent to this research in a case study with multi-product multi-stage manufacturing environment. The model translation is divided into three cases and followed by verification and validation of the model. The results obtained from the statistical analysis are discussed in Chapter 5. Chapter 5 explains the overview of the simulation model results followed of analysis of variance (ANOVA) results and regression equations by respective cases. The underlying cause and the significance of these trends based on the results are discussed and the performances of simulation models are compared. Chapter 6 brings together the conclusion and findings of this research. The chapter also highlights the significance of this research and potential areas for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims to describe and discuss the existing theories and practices that can be found within the research topic to place the research in the manufacturing research context. Reviews of literature, primarily of books and journals commonly applied to gain scientific information and new findings (Ngai et al., 2008).

The first section outlines the production control system (PCS) in manufacturing on multi-product multi-stage environment. The second section shows the characteristics of push systems and the third section presents the characteristics of pull systems including [1]Kanban System (KS) and Base stock System (BSS). Hybrid production control systems (HPCS) such asthe Generalized Kanban Control System (GKCS), Extended Kanban Control System (EKCS) and mixed pull system are outlined in the fourth section. A literature review of the rework processes in manufacturing is highlighted in the fifth section. The final section is a discussion and summary of the findings from the literature survey.

In the following sections, the diagrams of all PCS are illustrated based on the examples obtained from Krieg (2005). The ease-to-understand representation is standard to depict production flow that and has been used by many researchers. A list of the corresponding symbols is described in Figure 2.1.

[1] For clarity, the capitalized Kanban will refer to the control system while the lower case kanban will refer to the signal system (Nicholas, 1998)

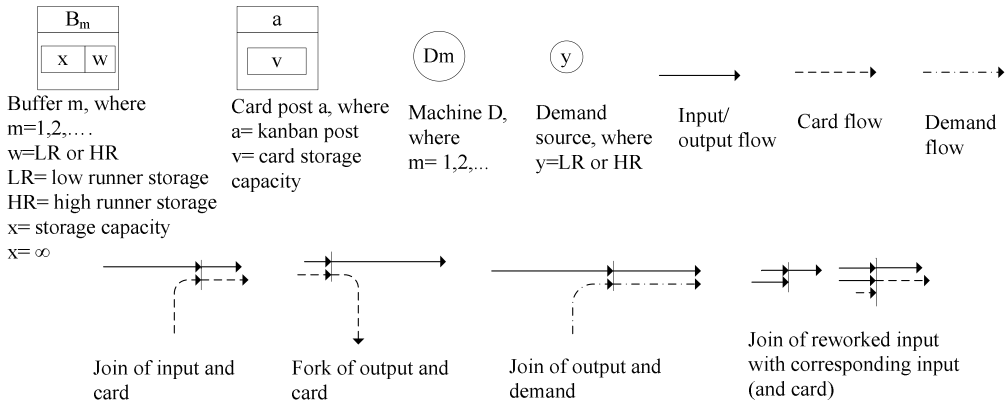

Figure 2.1: Symbols used in a diagram

2.2 Production control system

PCS is also known as ordering system (Burbidge, 1990), material planning and control strategy(Karmarkar, 1991; Krishnamurthy et al., 2004) material flow control mechanism (Graves et al., 1995), production planning and control system (MacCarthy and Fernandes, 2000), material planning method (Jonsson and Mattsson, 2002), production inventory control policy (Geraghty and Heavey, 2004), production and material flow control mechanism (Fernandes and Carno-Silva, 2006), logistics control system (Khojasteh-Ghamari, 2009), production control policies (Sharma and Agrawal, 2009) and system for coordination of orders (Fernandes and Filho, 2011).

Burbidge (1990) described PCS as the role of management to plan, direct, control and regulate the flow of information, materials and processing activities in the manufacturing.

According to Grünwald et al. (1989), there are four production control concepts: Statistical Inventory Control (SIC), Materials Requirement Planning (MRP), Just-in-Time (JIT) and Optimized Production Technology (OPT). The most common terms applied to depict the logic in PCS are push system (MRP) and pull system (JIT) (Cochran and Kaylani, 2008).

There are various definitions of push and pull that can be found in the literature, see; Pyke and Cohen (1990) and Bonney et al. (1999). Generally, there are several ways to define or distinguish the push and pull systems. The most usual mean is by characterizing the differences in term of the order release (Ding and Yuen, 1991). A push system schedules the release of works based on the future demand, while a pull system authorizes the release of works based on the system status (Hopp and Spearman, 2000). Another way is to study the structure of the information flow (Olhager and Östlund, 1990). According to Bonney et al. (1999), in push systems, the flows of information and materials follow the same direction, while in pull systems, the flow of information and materials follow the opposite directions respectively.PCS are described and reviewed specifically in multi-product multi-stage environments in the subsequent subsections.

2.2.1 Production control system in multi-product multi-stage environments

There have been numerous studies conducted on PCS in single product manufacturing environments, for example,Bonvik et al. (1997), Liberopoulos and Dallery (2000), Marek et al. (2001), Geraghty and Heavey (2004) and Alfieri and Matta (2012). On the other hand, there also has been growing interest in understanding PCS in multi-product multi-stage environments.

There are several challenges encountered on PCS in a multi-product multi-stage environment. First challenge is to satisfy the demand and customer service level for product variety in a multi-product multi-stage environment ranges from low to high demand (Smalley, 2009; Prakash and Chin, 2014). For high demand products, generally demand forecasts can be calculated from historical data. For this category, work-in-process (WIP) are maintained for frequent use and refilled to ensure that the demand is continually met. However, for low demand products, demand forecasts may not be useable. For this category, WIPs are usually not kept, as less frequent use and refill may result in their declines in quality over time. Second challenge is to maintain low inventory levels (Smalley, 2009; Prakash and Chin, 2014). Push systems, although simple, may result in a high WIP level and long flow time (Karmarkar, 1991). On the other hand, pull systems are important to maintain low inventory, particularly WIPs, as they regulate their movements. Various methods to limit the WIP level can be used, and the chosen method must facilitate the level of product variety offered by the manufacturing facility (Framinan et al., 2003). Third challenge is to estimate lead time of a newly arrived order with specific processing requirements (Ioannou and Dimitriou, 2012). Fourth challenge is to control the allocation of functions, resources and products to stages in the multi-stage manufacturing system environments(Dallery and Liberopoulos, 2000).

In Onyeocha et al. (2013), studies that considered multi-product multi-stage manufacturing environments concentrated on areas such as: planning and scheduling (Hum and Lee, 1998; Akturk and Erhun, 1999; Erhun et al. 2003), optimization of production control parameters (Bard and Golany, 1991;Krishnappa, 1999; Paris and Pierreval, 2001) and behavior investigation of a particular strategy (Ryan and Vorasayan, 2005; Satyam and Krishnamurthy, 2008; Aghajani et al., 2012). Besides, there also studies onkanban allocation policy known as the Dedicated Kanban Allocation Policy and Shared Kanban Allocation Policy (Baynat et al., 2002; Onyeocha and Geraghty, 2012; Onyeocha et al., 2013). Numerous studies compared the performances of traditional push to pull systems with the latter deemed superior (Khojasteh-Ghamari, 2009; Lavoie et al., 2010)or compared performances between pull systems (Putt, 1995; Onyeocha et al., 2013). Many pull systems are continuously developed or modified to cater more effectively to different environments. For instance, studies on product mix diversity (Krishnamurthy et al., 2004), varying levels of processing time variability (Li, 2003) and variable demand (Onyeocha et al., 2013).

There are various types of PCS studies ranges from analytical studies (Duri et al., 2000; Erhun et al., 2003; Colledani et al., 2008; Krieg and Kuhn, 2008) and simulation methods (Paris and Pierreval, 2001; Krishnamurthy et al., 2004; MacDonald and Gunn, 2008;Onyeocha et al., 2013; Prakash and Chin, 2014) to implementation case studies (Naufal et al., 2012).

However, most of the research on PCS in multi-product multi-stage environment focuses on the ideal production system. From these reviews, the studies considered rework process on the PCS are still scarce. Their simulation models assumed no rework in their production processes. In reality of the production process in manufacturing environment, product defect is common and sometimes significant, especiallyif the raw material and process are high in costs.

Parveen and Rao (2010) developed an optimal multi-order policy of raw materials to meet the demands of a multi-stage production linked with the KS by considering reworking process. A single product was considered. They concluded that the total cost with rework policy tends to be higher than that without considering reworking. Meanwhile, Prakash et al. (2011) and Chong et al. (2013) consider rework in their study on hybrid parallel CONWIP and hybrid Kanban-CONWIP respectively.Aghajani et al. (2012) studied the cellular manufacturing system controlled by KS with rework policy through the development of mathematical modelsto determine the number of kanban and lot sizes between two stages to minimize the total relevant cost including material handling, holding and setup costs.

2.3 Push system

In PCS, push system is classified as a traditional tool and has been widely implemented. Push systems are supported by tools such as MRP and MRP II and have been illustrated in detail in many publications, for example, Vollmannet al. (1997) and Ioannou and Dimitriou (2012).

A push system is founded on the assumptions that production jobs are scheduled in advance in the master production schedule (MPS) either in the form of actual orders (Spearman et al., 1990) or demand forecasts (Amin and Altiok, 1997).Many parts are produced as forecasted and pushed from one stage to another based on that schedule (Lyons et al., 2012) as quickly as possible to avoid deprivation at the downstream stages. This system helps to reduce the process idling, however it causes a high volume of WIP and hence the corresponding holding cost. Besides, this leads to poor lead time performance if large forecast errors occur (Lee, 1989).

Figure 2.2 illustrates and summarizes the flow of material in a push system in multi-product multi-stage environment. In a push system, one batch of raw material from the input buffer enters into the system and is queued at the first required workstation process. Queue priority is determined according to the selected dispatching rule. On completion of a process, the batch proceeds to subsequent processes on the designated process route. If this workstation is being occupied, it waits until the workstation is vacant. When all processes are completed the batch exits from the system (Lee, 1989).

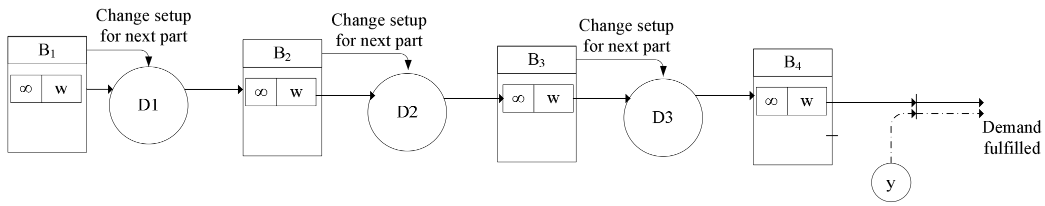

Figure 2.2: The flow of push system in multi-product multi-stage environment

There are numerous of literatures discussing push systems in multi-product multi-stage environments. They range from analytical studies (Nakagiri and Kuriyama, 1996; Lee et al., 2009; Mula and Poler, 2010;Ioannou and Dimitriou, 2012) and simulation studies (Koh and Saad, 2003; Aziz et al., 2013; Dongrecar and Singh, 2013).

Nakagiri and Kuriyama (1996) studied ona new dispatching rule based on the critical ratio rule in the MRP system with multi-product environment. The new dispatching rule considers backorders and stock-on-order rather than considering the due date. The results showed the proposed dispatching rule reduces due date delays and the timefor production re-planning on the MRP system and enabledmore effectively re-plan production based on the MRP system.

Lee et al. (2009) proposed finite capacitated MRP system using a computational grid. The aim is to resolve capacity constraint issues in multi-product environment by applying a simple heuristic model called the longest tail first rule. The outcome shows the duration of the production plan generation to production completion is reduced significantly.

Mula and Poler (2010) proposed new fuzzy mathematical programming models for production planning in MRP multi-product multi-stage environment using Fuzzy Sets Theory under uncertainty conditions. A fuzzy mathematical programming model is the basis in estimating the production lead time, inventory accumulated, delayed demand and total cost in a capacity constrained environment.

Ioannou and Dimitriou (2012)introduced a first endeavor towards conveniently incorporating updated lead time estimates in typical MRP calculations based on the system's current status via two alternative methods. The first method is the iterative decomposition algorithm and the second method is solvable in real time.The accuracy and reliability of these methods have been tested by comparing with the corresponding results from simulation runs on an industrial case in multi-product multi-stage environment.

Koh and Saad (2003) developed MRP system models to represent multi-level dependent demand system, with multi-product and controlled by a planned order release schedule based on planned lead time environment using ARENA simulation software. The outcomes prove the higher the level of the significant uncertainties, the higher the level of parts and finished products delivered late.

Aziz et al.(2013) conducted simulation based case studies to demonstrate the efficacy of a modified push system. They proposed a bottleneck oriented card based PCS for push system, where the material is expelled along the production based on the customer demand and material flow which are restricted by Production Authorization Cards (PAC). The design of the system includes; bottleneck identification, PAC number computation, computation of delay for time buffer and PAC design. The results of the case studies show the efficacy of the proposed system in reducing WIP build-up between the stages. The system is simple, easy to model, evaluate and implement, thus provides a cost efficient answer to the issue of WIP build-up in the push system using MRP/MRP II without the need of modifying the basic structure of operation in the existing system.

Dongrecar and Singh (2013) developed an algorithm and computer program for MRP. The developed system accepts inputs from MPS, bill of materials and considers factors like the first time through, delays in processes scrap rates, normal and crash lead times. The system had been applied and validated on the simulated data of a multi-product multi-stage environment of automobile components in small batches for its efficiency and applicability. The results show with the system, industry can achieve reduction in inventories, satisfy delivery commitments to the customers and reduce the possibility of supplier delivery delays.

Overall studies on push system in multi-product multi-stage environment do not consider defect product in their experiments or simulations. Even though there are studied on dispatching rules (Nakagiri and Kuriyama, 1996; Lee et al., 2009), however, there is still no studies on push system on rework dispatching rules in multi-product multi-stage environment.

2.4 Pull system

To regain the competitive edge, one of the most received considerable attentions on an improvement program from both industries and academics is Lean Manufacturing (LM) (Anand and Kodali, 2010). Succinctly, LM does more with less labor, less space, less inventory and delivery products in less time (Jacobsen, 2011). One important tool in LM is a pull system. Several pull systems found in multi-product multi-stage environments areKanban system(KS), Base Stock system (BSS), hybrid production control system (HPCS) and mixed pull system.

In a pull system, there are two fundamental pull based control systems known as a KS and BSS (Liberopoulos and Dallery, 2000). The KS is usually adopted when the system WIP has to be capped while the BSS is implemented when high production system reactiveness is requested. Generalized Kanban Control system (GKCS) (Buzacott and Shanthikumar, 1993) and Extended Kanban Control system

(EKCS) (Dallery and Liberopoulos, 2000) are two hybridpull based control systems that were produced in an effort to combine the merits of KS and BSS. These HPCS do generally well in most cases, especially in situations with customer demand variability (Alfieri and Matta, 2012). The working of each system is illustrated and explained as follows.

2.4.1 KanbanSystem

KS was originally used in Toyota production lines in the mid 70's and is often thought to be closely connected with the philosophy of the JIT (Groenvelt, 1993). In the KS, production authorization cards called kanban are used as a signal to control inventory levels and to limit the release of parts into each production stage (Lage Junior and Godinho Filho, 2010). KS is not zeroing inventory systems (Krieg and Kuhn, 2004). According to Kumar and Panneerselvam (2007), KS requires multi-product to be kept in a certain number of parts and finished goods because of the repetitive nature of production and to avoid long waiting times for internal and external customers. The planned inventory compensates for failures, machine breakdowns and uncertainty in demand.

The last two decades have seen a surge in the literature on the KS consisting studied on proposed KS which differ in type (e.g.: one card, dual card, signal, etc.) (Celano et al., 2004), management method (e.g.: instantaneous, periodic review, simultaneous, independent, etc.) (McMullen and Frazier, 2000; Jin and Wu, 2002) and variations on KS (Lage Junior and Godinho Filho, 2010). In addition, studies on dimensioning the number of kanban known as kanban allocation problem have efficiently proposed several methods in literature (McMullen, 2001; Khan and Sarker, 2002; Drexl and Matthieben, 2006).

Figure 2.3 shows the flow of material and information in a KS with multi-product multi-stage environment. In order for production to begin, there must be at least a kanban and a part present in the stage input buffer. Therefore, each of the stages is associated with a number of kanbans.

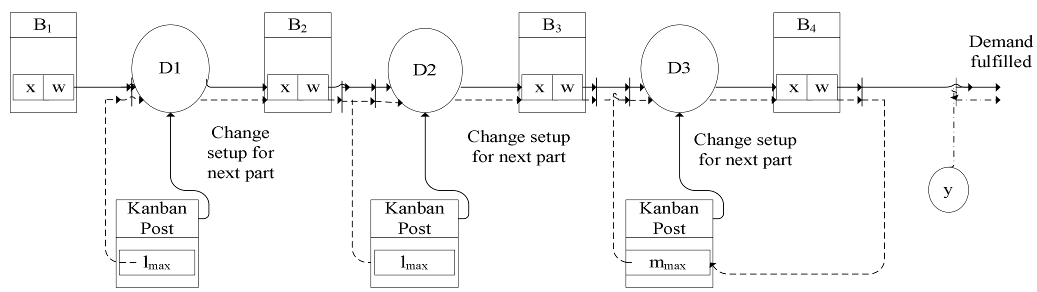

Figure 2.3: The flow of KS with multi-product multi-stage environment

Referring to Figure 2.3, when a customer demand arrives in the system, it joins kanban post, thereby requesting the release of a finished part from B_4 to the customer. If a part is available in B_4, it is released to the customer after liberating the kanban attached to it. This kanban is transferred upstream to kanban post carrying along with it a demand for the production of a new stage finished part and authorization for the release of a finished part from output buffer into input buffer. Production starts through the transfer of kanban to upstream stages and the circulation of kanban between two successive stages controls the WIP level between them (Wang, 2010).

Literature pertaining KS in multi-product multi-stage environments is usually analytically presented. Bard and Golany (1991) extended Bitran and Chang's model to determine the optimum number of kanbans in each stage. In order to minimize the total cost, including the setup cost, shortage cost and inventory holding costs, the model takes the form of a mixed integer linear program, and works with standard techniques. A number of alternative formulations are introduced. Askin et al. (1993) developed a continuous time Markov model to determine the optimal number of kanban with zero setup times. Duri et al. (1995) applied the queuing network model of the KS, which is a closed multiclass queuing network (each class represents one type of kanban) to estimate the performance measures considering setup times and processing orders. Gurgur and Altiok (2008) produced an approximation algorithm using a phase-type modeling to study interdependencies among the products in terms of the delay periods they experience. The study considered decentralization of two types of kanban with excess demand to be backordered. Askin and Krishnan (2009) have two objective studies: first to determine the number of kanban and container sizes in lead time variability conditions, second to determine placement of inventory buffers should locate in serial system. The KS was modeled using a decomposition algorithm. Widyadana et al. (2010) used optimal and metaheuristic methods to determine the kanban quantity and withdrawal lot sizes. They used a genetic algorithm and a hybrid of genetic algorithm and simulated annealing method and compared the performance of these methods with that of the optimal method using mixed-integer nonlinear programming.

On the other hand, simulation method used in multi-product multi-stage study shows growing attention. Hum and Lee (1998) compared the performance of KS using two scheduling rules: first-in-first-out (FIFO) and shortest processing time (SPT) under different scenarios. The scenarios are: the extent of setup time reduction, the amount of slack in the system, the extent to which uncertainty has been eliminated and the complexity of production requirements. Paris and Pierreval (2001) proposed to configure KS using distributed simulation optimization method based on evolutionary principles. Several parameters, such as the number of kanbans between machines, the transport lot sizes, the safety storage sizes and the sequencing rules are considered. Krishnamurthy et al. (2004) examined the performance of KS under different product mixes. They observed that a KS can lead to some inefficiency when the variability of demand is substantial or reliable information about future requirement is available.Deokar (2004) studied systems under varying levels of processing time variability and analyzed the comparison of KS with other PCSs based on the level of WIP to achieve different target service levels using two kanban allocation policies, dedicated and shared. The study noted that the shared policies always outperformed the dedicated types in the serial and assembly line configurations studied. Olaitan and Geraghty (2013) investigated simulation based optimization and stochastic dominance testing in employing KS. The simulationadopted dedicated and shared kanban allocation policies in multi-product multi-stage environments with negligible set up times and with consideration for robustness to uncertainty.

2.4.2 Base stock System

BSS is another pull based control system originated from the inventory control theory(Karaesmen and Dallery, 2000). The rule of the BSS attempts to keep a certain quantity of processed jobs in each output buffer, subtracting backlogged finished goods demand, if any. This amount is called the base stock level of each stage (Boonlertvanich, 2005). Therefore, it is a simple control mechanism that depends solely on one parameter per stage, namely, base stock level of parts in stock.

Figure 2.4 shows the flow of material and information in BSS. Every stage has a target inventory of finished parts called base stocks to control how many parts are held in the line when waiting for another demand. When a customer demand for an end item arrives, a signal is instantly transported to every stage to authorize the release of a new part (Dallery and Liberopoulos, 2000). For each stage, this signal allows the entry of a new job to immediately start working on a new part if the stock level is below the defined base stock at each stage.

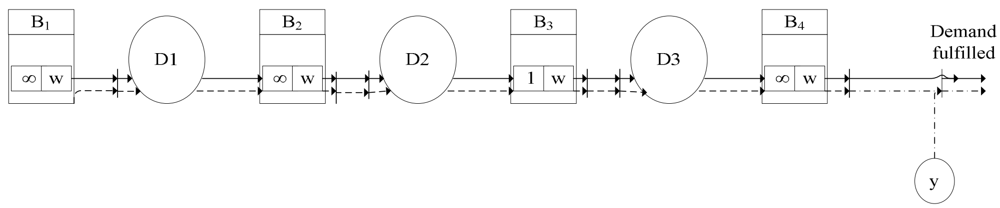

Figure 2.4: The flow of BSS with multi-product multi-stage environment

In the traditional BSS there is no production authorizations signal. All that is needed for a part to be released from the output buffer of a stage in the input buffer to the next stage is a demand for the release of such a part.

Thus, the BSS has evolved and nowadays it is common to find the implementation of BSS that use cards (Bonvik et al., 1997 and Gaury, 2000). The card-based system allows the WIP of each downstream in each station to be limited, which removes the problem of the infinite capacity of the original BSS (Graves et al., 1995). Afterward, Karl and Stefan (1998) studied to obtain the optimal base stock levels at each stage in multi-stage inventory systems with normally distributed demands. Warsing et al. (2013) offered analytical study for computing the optimal base stock level that accounts the uncertainty in demand and imperfect supply.

Numerous studies in BSS consider review policy known as continuous review policy (Larsen and Thorstenson, 2006) and periodic review policy (Dong, 2009; Silver and Bischak, 2011; Warsing et al., 2013). The continuous review policy