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CARD-BASED SYSTEMS: SYSTEMATIC LITERATURE REVIEW OF NEW SYSTEMS AND PROPOSAL OF A LIST OF SOFT FACTORS FOR SYSTEMS IMPLEMENTATION

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CARD-BASED SYSTEMS: SYSTEMATIC LITERATURE REVIEW OF NEW SYSTEMS AND PROPOSAL OF A LIST OF SOFT FACTORS FOR SYSTEMS IMPLEMENTATION

Dissertation presented to the Graduate Program in Production Engineering of the Federal University of São Carlos, to obtain the title of Master in Production Engineering.

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Prof. Dr. Moacir Godinho Filho

DEDICATION

To my beloved parents, Claudinéia and Orlando, and brother, Guilherme, who gave me strength and continually provided their support along this journey.

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To my parents, Orlando and Claudinéia, who supported me unconditionally in this challenge as in many others, providing all the support I needed.

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RESUMO

Embora os Sistemas de Coordenação de Ordens sejam considerado um tópico maduro na literatura, o foco da literatura até o momento recaiu especialmente sobre a otimização dos parâmetros de funcionamento de cada sistema, atribuindo pouca importância aos fatores relacionados a influência humana (*soft factors*). A implementação, contudo, continua a ser um problema complexo. Esse trabalho visa reduzir essa lacuna, propondo, através de uma combinação de métodos de pesquisa, uma lista de fatores soft críticos para o sucesso na implementação de sistemas baseado em cartão, os quais são os mais estudados e implementados e que compartilham como característica uma forte influência humana em seu funcionamento. Contudo, para realização desse objetivo, inicialmente foi necessário identificar quais são os sistemas baseados em cartão. Embora para sistemas como o Kanban e o CONWIP exista uma grande literatura disponível, sistemas desenvolvidos após a proposta do POLCA em 1998 foram pouco explorados. Assim, essa dissertação inicialmente realiza uma revisão sistemática de literatura identificando 13 sistemas desenvolvidos entre 1999 e 2018, tais como COBACABANA, DDMRP, Redutex, B-CONWIP, BK-CONWIP, dentre outros. Brevemente, é apresentado o funcionamento, características, estágio atual de pesquisa e ambientes propícios para cada sistema, visando aumentar as pesquisas sobre eles. Os sistemas são também comparados em relação a seis variáveis, identificando-se que muitos dos novos sistemas são baseados em cartão. Os fatores soft propostos para a implementação de sistemas baseado em cartão se baseiam na análise de problemas citados na literatura bem como de dificuldades identificadas através de um estudo de caso longitudinal. Essa lista foi validada por especialistas assim como por um grupo de colaboradores da empresa foco que participou da implementação do kanban. Nessa dissertação é proposta também uma casa de fatores soft para a implementação de sistemas baseados em cartão, nas quais os fatores são classificados como exclusivos dessa temática ou fatores clássicos de administração, bem como em relação ao nível organizacional em que atua. (organização, grupo de implementação ou indivíduo). Essa casa tem como objetivo auxiliar os gerentes na implementação de sistemas baseados em cartão, aumentando as taxas de sucesso nesse processo. Além disso, através da revisão de sistemas de coordenação de ordens recentes, essa dissertação visa aumentar o repertório dos gerentes sobre os sistemas existentes, possibilitando a implementação de opções mais adequadas para o ambiente produtivo em que se encontram.

Palavras-chave: Sistemas de coordenação de ordens. Sistemas baseado em cartão. Fatores soft. Kanban. COBACABANA. POLCA. DDMRP.

ABSTRACT

Although Production Control Systems are considered a mature topic in literature, up to now, the focus of literature has been on optimizing the operating parameters of each system, assigning little importance to factors related to human influence (soft factors). Implementation, however, remains a complex problem. This paper aims to reduce this gap by proposing, through a combination of research methods, a list of soft factors critical to success in implementing card-based systems, which which are the most studied and implemented and which share as a characteristic a strong human influence on their functioning. However, to achieve this goal, it was initially necessary to identify which systems are based on cards. Although for systems such as Kanban and CONWIP there is a large literature available, systems developed after POLCA proposal in 1998 were little explored. Therefore, this dissertation initially performs a systematic literature review identifying 13 systems developed between 1999 and 2018, such as COBACABANA, DDMRP, Redutex, B-CONWIP, BK-CONWIP, among others. Briefly, it presents how each system works, its characteristics, current research stage and environments in which it has been proved to be useful, aiming to increase researches about them. The systems are also compared in relation to six variables defined in the literature, identifying that many of the new systems are card-based. The soft factors proposed for the implementation of card-based systems are based on the analysis of problems cited in the literature as well as difficulties identified through a longitudinal case study. This list was validated by experts as well as a group of employees from the focus company that participated in the implementation of kanban. This dissertation also proposes a soft factor house for the implementation of card-based systems, in which the factors are classified as exclusive to this theme or classic management factors, as well as in relation to the organizational level in which it operates (organization, implementation group, or individual). This house aims to assist managers in implementing card-based systems, increasing success rates in this process. In addition, by reviewing recent production control systems, this dissertation aims to increase the repertoire of managers on existing systems, enabling the implementation of more appropriate options for the productive environment in which they are located.

Keywords: Production Control System. Card-based system. Soft factors. Kanban. COBACABANA, POLCA. DDMRP

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LIST OF ABBREVIATIONS

BBC	Behaviour Based Control
B-CONWIP	Basestock-Constant Work-in-Process
BK-CONWIP	Basestock Kanban-Constant Work-in- Process
COBACABANA	Control of Balance by Card Based Navigation
CONLOAD	CONstant LOAD
CONWIP	Constant Work-In-Process
CSF	Critical Success Factors
CTBS	Customize Token-based system
DBR	Drum-Buffer-Rope
DDMRP	Demand Driven Materials Requirement Planning
DEWIP	Decentralized Work in Process
D-KDP	Dedicated Kanban Distribution Policy
DSSPL	Double Speed Single Production Line
G-MaxWIP	Gated MaxWIP
HK-CONWIP	Hybrid Kanban-CONWIP
IBS	Inverse Base Stock
LCS	Longitudinal Case Study
MRP	Master Requirements Planning
PBC	Periodic Batch Control
PCS	Production Control Systems
POLCA	Paired Cell Overlapping Loops of Cards
PPC	Production Planning and Control
PPF	Parallel Pull Flow
RRC	Restrictive Resource Capacity
S-KDP	Shared Kanban Distribution Policy
SLR	Systematic Literature Review
SME	Small and Medium Enterprises

SWIP	Self-regulated Work-In-Process
WIP	Work in Process
WLC	Workload Control

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1 INTRODUCTION

1.1 Contextualization

As a significant part of the capital of industrial organizations is in manufacturing, managing these resources efficiently is essential for building or maintaining competitive positions. Therefore, Production Planning and Control (PPC) plays a fundamental role in deploying organization's strategic plans in manufacturing tactical and operational plans, as well as in connecting production and purchase of materials to customer needs. In the heart of PPC, there are the Production Control Systems (PCS's), which regulate information and materials flows through the factory (KARRER; ALICKE; GÜNTHER, 2012).

The literature about PCS's has focus mainly on mathematical approaches to optimize the parameters of each system (PONS; 2010; HENDRY; HANGANG, STEVENSON, 2013). Implementation, however, remains a complex problem (RAZMI; AHMED, 2003). Most implementation studies only describe the system logic inside a business environment, but do not systemically address the difficulties during the implementing phase. For systems based on cards (card-based system), which are the most studied and implanted PCS's, those difficulties are even more significant as a characteristic shared by those systems is the strong human influence on its operation (SALEM et al., 2006; LIU; HUANG; 2009).

Those difficulties can be related to factors critical to card-based systems implementation. Those factors are referred in literature by different denominations, such as implementation factors (PARZINGER; NATH, 1998; CHOU; CHANG, 2008), project success factors (DVIR et al., 1998), critical success factors (ROCKART, 1979; HOWELL, 2009; NETLAND; 2016), among others. In this dissertation, as the emphasis is on the human influence on card-based systems implementation, these factors will be called soft factors (ABDULLAH; ULI; TARÍ, 2008). Examples of soft factors are workers motivation, support from top management and communication. Therefore, hard factors, such as availability of financial resources, adequacy of equipment, technology, among others, are out of the scope of this study.

Apart from Pons (2010), soft factors have been rarely studied in the specific context of card-based systems (MARODIN; SAURIN, 2013). Therefore, understanding which soft factors are critical to card-based system implementation are key to increase the success on implementing those systems. Moreover, there is no list of soft factors which managers should focus their attention on while implementing a card-based system (ROCKART, 1979; HOWELL, 2009). Therefore, the following research questions arises: Which are the soft factors critical to card-based systems implementation?

Aiming to reduce this gap, this dissertation provides a list of soft-factors for card-based systems implementation, based on empirical papers and on a longitudinal case study. The final list contains factors as diverse as management support, implementation during low demand period and card's material quality. In the list, we tried to maintain the factors as generic as possible, not including specific factors suitable for particular environments. Therefore, additional factors can be included for each individual implementation.

Therefore, in terms of research, we seek to highlight the importance of human factors on card-based system implementation, asking for more studies in this field. In terms of practice, we hope that the list helps companies to increase the success in implementing card-based systems and that managers know in advance which soft factors they should concentrated their attention during the implementation process.

However, while doing this research, we identified that it was not clear in literature which are the PCS' based on cards. Classical systems, such as kanban and CONWIP, were certainly part of this PCS's group, but what about more recently systems, proposed after 1998, the year that POLCA emerged? Therefore, aiming to identified card-based systems proposed in the last 20 years (from 1999 and 2018), we decided to perform first a SLR in which 13 PCS's were identified (based on cards or not) (Chapter 2). We briefly present how each system works, its characteristics and environments it is suitable for. To the best of our knowledge, there is no study that summarizes the main advances concerning PCS between 1999 and 2018.

All new PCS's identified in the SLR were included, although there is a great difference among them regarding evolutionary stage and number of articles published. However, they all can provide interesting insights to the proposal of new PCS's as well as they can provided elements to understand why some PCS's have more success than others do. Therefore, this dissertation also contributes to research, outlining new search directions for future research on PCS's and contributing to disclosure PCS's proposed recently, and for practice, helping managers to find new solution to their day-to-day problems.

1.2 Research Question and Objectives

From this research question, the following objectives were defined:

1. To identify the Production Control Systems developed over the last 20 years (from 1999 to 2018), their characteristics and environments in which they have been proved to be useful;
2. To identify which one of those systems are based on cards (card-based systems);

3. To identify difficulties in empirical card-based systems implementation related to human aspects;
4. Based on those difficulties, to propose a list of soft factors critical to card-based systems;
5. To refine this list by means of expert panel.

1.3 Overview of Research Method

This dissertation uses a variety of methods to reach the five research objectives:

- Systematic Literature Review: used in two different moments. First, to identify PCS developed between 1999 and 2008. Secondly, to identify difficulties related to card-based systems in empirical papers;
- Case Study: to identify the problems faced by an organization which failed to implement kanban in its final process by a longitudinal study;
- Content Analysis: to analyze all the information difficulties identified in SLR and LCS in order to propose soft factors for card-based systems implementation;
- Expert panel: to refine the previous list by 6 experts.

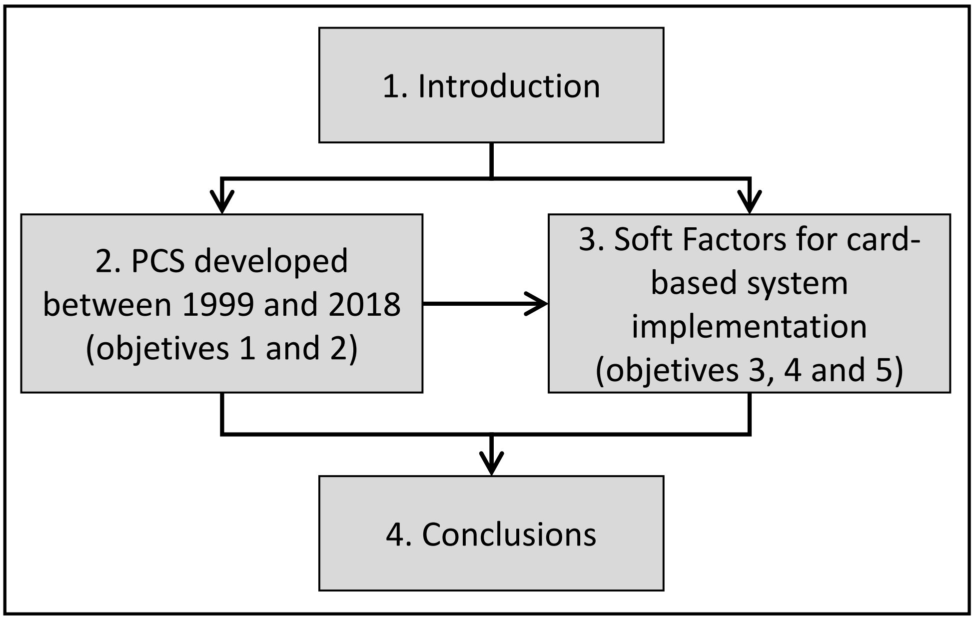
1.4 Overview of Dissertation Structure

This dissertation is structure in four chapters (Figure 1). Chapter 2 and 3 are written in article format, aiming to increase the visibility of research's results in international journals. Therefore, the author apologizes for eventual redundancies among the chapters.

Chapter 1 briefly presented the context and motivation of this research, as well as research question and objectives. An overview of research method and structure are also provided.

Chapter 2 aims to achieve objectives 1 and 2 of this dissertation. Therefore, a Systematic Literature Review (SLR) were conducted to identify new PCS's developed between 1998 and 2008, excluding simple extensions of classical PCS, such as variations of Kanban and POLCA. The SLR results in 13 new systems, which were presented in detail regarding how they work, their main characteristics and in which environments they have been proved to be useful. We also analyzed which systems have been further studied after its initial proposal and which ones have been reported to be implemented in real production systems. In addition, we identify that from the 13 PCS, 8 are card-based systems and 3 used cards partially. Therefore, it was defined to focus implementation difficulties of PCS in card-based systems (Chapter 3).

Figure 1 – Overview of Dissertation Structure



Chapter 3 aims to achieve objectives 3, 4 and 5. Therefore, first a SLR were conducted to identify human difficulties related to card-based systems implementation. However, as little difficulties were identified in literature, a longitudinal case study were also conducted in an organization which failed to implement kanban. Performing a content analyzed with the difficulties identified and based on soft factors for lean implementation, a list of soft factors for card-based systems is proposed. Lean soft factors were used as references because there are many studies that proposed list of those factors. Moreover, many card-based systems are based at least partially on Lean approach. Finally, this list was refined by 6 experts which came from university (professor), manufacturers (managers) and consulting (consultants).

Chapter 4 highlights the main contributions of this dissertation, research limitations and proposal for future studies.

2 SYSTEMATIC REVIEW AND DISCUSSION OF PRODUCTION CONTROL SYSTEMS THAT EMERGED BETWEEN 1999 AND 2018

Although there is a large literature about classical Production Control Systems (PCS) such as Kanban, CONWIP and Materials Requirements Planning (MRP), few articles deal with recent PCS, specifically the ones proposed after the emerged of the POLCA in 1998. Therefore, in this chapter, a Systematic Literature Review (SLR) is conducted to identified PCS's proposed over the last 20 years, as well as their characteristics and environments they proved to be suitable for. Moreover, the 13 PCS's identified are compared regarding 6 variables, in order to identify similarities and differences among them.

2.1 Introduction

Production Control Systems (PCS) are a key factor for effective manufacturing systems as they regulate the information and materials flows through the factory (MASIN; HERER; DAR-EL, 2005; KARRER; ALICKE; GÜNTHER, 2012). Therefore, the choice of an appropriate PCS is an important success factor for any organization (HASSAN; KAJIWARA, 2013). Consequently, many different PCS's emerged. This includes Kanban systems (e.g. Sugimori et al. (1977), Berkley (1992), Monden (1998) and Lage Junior and Godinho Filho (2010)); Constant Work-In-Process (CONWIP; e.g. Spearman, Woodruff and Hopp (1990), Framinan, Gonzales and Ruiz-Usano (2003), Prakash and Chin (2014) and Jaeglar et al. (2017)); Drum-Buffer-Rope (DBR; e.g. Goldratt (1990), Guide (1996) and Mabin and Balderstone (2003)); Periodic Batch Control (PBC; e.g. Burbidge (1996), Benders and Riezebos (2002)); Materials Requirements Planning (MRP; e.g. Orlicky (1975) and Mohebbi, Choobineh, and Pattanayak (2007)); Workload Control (WLC; e.g. Land and Gaalman (1998) and Land (2006)) and Paired Cell Overlapping Loops of Cards with Authorization (POLCA; e.g. Suri (1998) and Riezebos (2010)).

For these 'classical' PCS, there is a large literature available. Some papers present a literature review of different PCS, for example Stevenson, Hendry and Kingsman 2005, Liu and Huang (2009), Fernandes and Godinho Filho (2011) and Thürer, Stevenson and Protzman (2017). There is also a large number of works comparing different PCS by use of simulation, for example, Liu and Huang (2009), Koulouriotis, Xanthopoulos and Tourassis (2010), Sato and Khojasteh-Ghamari (2012), Silva et al. (2017) and Thürer et al. (2019).

However, all of this literature focusses on PCS's developed before 1998, the year when POLCA emerged. To the best of our knowledge, there is no study that summarizes the main advances concerning PCS in the last 20 years. Thürer, Stevenson and Protzman (2017), for example, only included card-based systems on their review. In response to this gap, this study provides a review and discussion of new PCS's that emerged since 1998. Our definition of new PCS's excludes extensions of classical PCS (for example, variations of Kanban, ConWIP and POLCA) that do not significantly change the nature of the original system. Therefore, the systems included in this chapter either differ significantly from existing ones (such as COBACABANA) or combine elements and characteristics of two or more existing systems (such as BK-CONWIP and B-CONWIP).

All new PCS's identified in the Systematic Literature Review were included in this paper, although there is a great difference among them regarding evolutionary stage and number of articles published. However, they all can provide interesting insights to the proposal of new PCS's as well as they can provided elements to understand why some PCS's have more success than others do. In terms of research, we seek to outline new search directions for future research on PCS's. In terms of practice, we hope that our study helps managers to find new solution to their day-to-day problems.

The remainder of this chapter is organized as follows. Section 2.2 describes the research method used in this chapter, Systematic Literature Review, and the main variables defined to compare different PCS's. In Section 2.3, the PCS identified in the SLR are described, with emphasis on how they work and the most suitable environments for each of them. Section 2.4 compares the PCS identified in the SLR according to their evolution and the variables defined in Section 2. Finally, Section 2.5 provides some conclusion arguments, limitations and suggestions for future researches.

2.2 Research Method

This study started by asking:

RQ What are the characteristics of Production Control Systems that newly emerged in the last 20 years?

A systematic literature review is considered the most adequate method to answer our question since it allows for understanding existing knowledge in more depth while minimizing bias in the selection of articles (TRANFIELD; DENIER; SMART, 2003; FAWCETT et al., 2014). The two subsections below outline the approach adopted for article selection and analyzes of the articles.

2.1.1 *Article Selection*

Article selection followed the four steps proposed by Tranfield, Denier and Smart (2003) and used in many articles, like Negrão, Godinho Filho and Marodin (2017), which are:

- Step 1 – Search in database: following the protocol presented in Table 1, search was conducted in Web of Science and Scopus. According to Thomé, Hollmann and Scavarda (2014), a SLR should search in, at least, two databases. Web of Science and Scopus were chosen because they are regularly updated and cover a wide breath of subjects (CHADEGANI et al. 2013; THOMÉ; SCAVARDA; SCAVARDA, 2016). The research results in 955 non-duplicated articles.

Table 1 - Research Protocol A

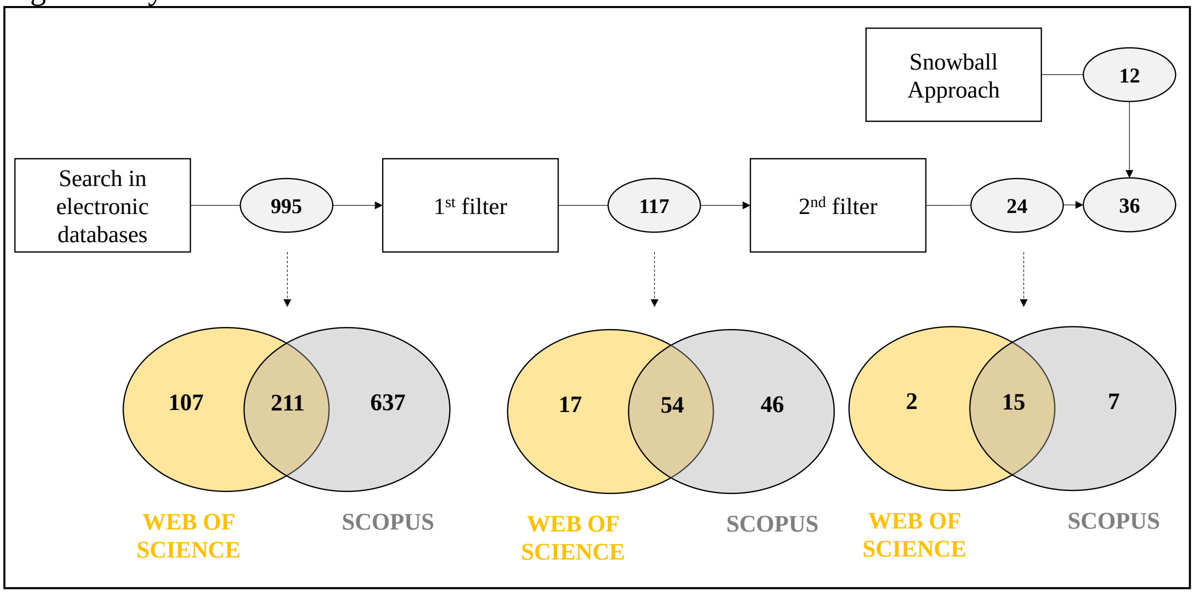
Research Protocol	
Database	Web of Science and Scopus
Publication Years	From 1999 to 2018
Document type	Journals
Language	English
Strings	"production control system*" "production system" AND "push*" "production system*" AND "pull" "card based" AND "production" "production system" AND "hybrid" "production control" AND "pull" "production control" AND "push*"
Inclusion criteria	• Articles featuring a new PCS • Applications or comparisons of PCS developed over the last 20 years
Exclusion criteria	• Evolution of classical systems, such as Kanban and CONWIP; • Application of sequencing rules to prioritize production; • Review literature of existing PCS

Source: Elaborated by the author.

- Step 2 – First filter: The title and the summary of the 955 articles were evaluated in order to assess whether they met inclusion and exclusion criteria of the research protocol. First of all, as our objective is to identified PCS's proposed from 1999 to 2018, papers which only review systems developed before 1999 were excluded. Papers which presents evolution of classical systems were also excluded because these systems do not match the definition of new PCS's presented in the introduction of this chapter. Moreover, PCS's are much larger than sequencing rules, which optimize work sequence in a specific work station or group of stations. Therefore, papers, which only deal with sequencing rules, were also excluded. Therefore, our inclusion criteria are papers which present proposals of new PCS (theoretical, simulation or empirical) or that compared PCS's in which at least one of them were developed from 1999 to 2018. The first filter resulted in 124 articles.

- Step 3 – Second filter: This filter consists of full reading of the 124 remaining articles, again applying inclusion and exclusion criteria defined in the research protocol. The second filter resulted in 24 articles. These three steps are summarized in Figure 2.
- Step 4 – Final Selection: To the 24 articles selected, 12 more were added using the snowball approach, resulting in 36 articles. Some articles were identified by citations in the 24 articles that resulted from the SLR. Others were included by searching for the name of the PCS's identified in the databases. Snowball approach added a significant number of articles to this review because many papers use specific key words to propose new PCS's, such as lot release rule, manufacturing control, production line control, materials management, among others. Therefore, we were not able to define a group of keywords that would systematically result in most of the 36 articles. Instead, we selected keywords that would result in the majority of them, and the others were identified by snowball approach.

Figure 2- Systematic Literature Review A



Source: Elaborated by the author.

2.1.2 Content Analysis

This stage involved extracting and documenting information from the 36 sources. To minimize subjectivity, the author: (i) cross-checked results; and, (ii) conducted regular meetings to resolve any emerging inconsistencies in interpreting the results. From our sample, 13 PCS were identified.

As a template for data collection, a simple matrix was used where, for each PCS (row), we asked (column):

- What are the characteristics of the system?
- How does the system work?
- In what productive environments did this system prove useful?
- What research was available involving the system?

To compare the 13 PCS's, two dimensions were selected: systems' characteristics and evolution. Regarding systems' characteristics, four variables were selected, as follows:

(1) Primary Control Variable: a system can either control WIP (Work in Process) or throughput. If a PCS control WIP, then it observes throughput. The opposite is also true (HOPP; SPEARMAN, 2008);

(2) Degree of Centralization: if order release is controlled by a central entity (e.g. production planner), than the PCS is Centralized. An example of a classical centralized PCS is MRP, as all orders are release by production planning. Local stations only execute the order. On the other hand, some systems are Decentralized, because the local production stations are responsible for defining when to start an order an even which order to start (not the central planning). This occurs, for example, in Kanban. In some PCS, there are more than one type of release authorizations. For example, in BK-CONWIP, an order is processed only if received ConWIP, Base Stock and Kanban authorization. It is possible that some of these authorizations are centralized and some are decentralized. Therefore, those systems are classified as mixed. For example, in BK-CONWIP, Kanban authorizations are decentralized (locally controlled by production stations), but ConWIP and Base Stock authorizations are centralized (controlled by the central production planning);

(3) Suitability to material flows: it is important to understand to what kind of environment a PCS is more suitable for in order to choose a more adherent system to the environment analysed. An important variable in the shop floor is

the flow of materials. Some PCS are more suitable to flow shop (flow of items occur in the same direction) and others to job shop (flow of items occurs in different direction) (Johnson and Montgomery 1971). However, in some cases, although a PCS is more adequate to a certain type of flow, it can also be applied in the other. An example is COBCABANA, initially proposed for job shops, but in later papers simulated successfully for flow shops;

(4) Card-based system: a PCS is classified as card-based if it was originally introduced based on card signals. But note that these signals can also be other physical entities (such as boxes) or even electronic signals (Thürer, Stevenson, and Protzman 2017). As DSSPL, DSSPL, DDMRP and Redutex were introduced using cards to trigger the work of some items or some production stages, they are classified as partially. As cards are used to control the stock or workload levels of the systems, not the throughput, all card-based systems identified in the review have WIP as primary variables. The opposite, however, is not true (all systems that have WIP as primary variable are not card-based). CONLOAD is an example, as it controls WIP, but does not use cards.

The first and second variables (primary control variable and degree of centralization) are presented by Lödding, Yu and Wiendahl (2003). The third (material flow) is adapted from Löoding, Yu and Wiendahl (2003). Originally, these authors classified the system flow complexity into high and low. However, given the predominance in literature of job shop and flow shop concepts, we will use these classes for the intermittent systems presented, as proposed by Johnson and Montgomery (1971). The two classifications, however, are integrated, since the materials flow of a job shop system is more complex and of a flow shop is simpler. Finally, the fourth variable (card-based systems) was included, given the importance card-based systems received over the last two decades in the literature and its wide application in real systems, especially for its implementation simplicity and visual control (LIBEROPOULOS; DALLERY, 2000; THÜRER; STEVENSON; PROTZMAN, 2017).

Understanding evolution of the systems is interesting because it can provide important insights about patterns to suggest a new PCS. In this dimension, two variables were selected:

(1) Number of articles published about a PCS's: we considered only papers that contribute clearly to the development of a PCS by a mathematical simulations, empirical application or comparison with other systems. Therefore, papers that only cite the system were not considered in the evolution analysis;

(2) Type of paper published: we classified the papers published about each system

into axiomatic or empirical, following the classification of Operations Management papers proposed by Bertrand and Fransoo (2002). This variable was important to further analyses how closed are literature and practice regarding the new systems identified.

2.3 Results: New Production Control Systems (PCS)

Table 2 presents the 13 PCS's identified in the SLR as well as classify them regarding the four variables of system's characteristic's dimensions. Figure 3, presents the systems evolution, with all 36 papers founded in the SLR about each of the 13 PCS's as well as their type (empirical or theoretical).

First, still in Section 3, each system will be presented in detail (Section 3). As we identified a strong tendency that new PCS are card-based (completely or at least a part of it), we thought it would be interesting to discuss individually the systems dividing them into 3 groups: card-based (3.1 to 3.8), partially card-based (3.9 to 3.11) and non-card-based (3.12 and 3.13).

Next, in Section 4, the PCS' will be compared regarding all four variables of systems characteristics and the two of systems evolution, in order to draw some conclusions on their similarities and differences.

Inverse Base Stock (IBS)

Little explored in literature, Inverse Base Stock (IBS) was proposed by Masin, Herer and Dar-El (1999). Apart from its conceptual proposal, there is no other study about IBS in literature. Therefore, this system stops at a very early stage.

IBS is part of the self-regulated WIP (SWIP) approach, also proposed by Masin, Herer and Dar-El (1999), which unifies several PCS such as Kanban, CONWIP, Drum-Buffer-Rope (DBR), Base Stock, among others. The main feature of SWIP is to group a set of equipment into a subsystem that shares the same number of containers or cards. In CONWIP, for example, the entire system shares the same number of containers, while in Kanban each pair of adjacent workstations is a subsystem.

The name Inverse Base Stock is due to the visual representation of this system, which is the mirror image of Base Stock (Figure 4). IBS releases a job on the first station only if cards are available for processing that order at all stations in the system. After being processed in a station, the order releases the card of that station.

Table 2 - The 13 PCS's classified according to the four variables of system's characteristics dimension

System	Acronyms	Year	Main Reference	Primary Control Variable	Level of Centralization	Complexity of material flow	Card-based
Inverse Base Stock	IBS	1999	Masin (1999)	WIP	Centralized	Flow shop	Yes
CONstant LOAD	CONLOAD	1999	Rose (1999)	WIP	Centralized	Flow shop	No
Customize Token-based system	CTBS	2000	Gaury, Pierreval, and Kleijnen (2000)	WIP	Both	Flow shop	Yes
Double Speed Single Production Line	DSSPL	2000	Stagno, Glardon, and Pouly (2000)	WIP	Centralized	Flow shop	Partially
Decentralised Work in Process	DEWIP	2000	Lödding and Wiendahl (2000)	WIP	Decentralized	Job shop	No
Behaviour Based Control	BBC	2001	Paternina-Arboleda and Das (2001)	WIP	Both	Flow shop	Yes
Gated MaxWIP	G-MaxWIP	2002	Grosfeld-Nir and Magazine (2002)	WIP	Centralized	Flow shop	Yes
Parallel Pull Flow	PPF	2004	Hunter et al. (2004)	WIP	Centralized	Flow shop	Yes
Control of Balance by Card Based Navigation	COBACABA NA	2009	Land (2009)	WIP	Centralized	Job shop	Yes
Demand Driven Materials Requirement Planning	DDMRP	2011	Ptak and Smith (2011)	Throughput	Centralized	Job shop	Partially
Basestock Kanban-Constant Work-in-Process	BK-CONWIP	2012	Onyeocha and Geraghty (2012)	WIP	Both	Flow shop	Yes
Redutex	-	2016	Serrato (2016)	Throughput	Centralized	Flow shop	Partially
Basestock-Constant Work-in- Process	B-CONWIP	2018	Hawari, Qasem, and Smadi (2018)	WIP	Centralized	Flow shop	Yes

Figure 3- Production Control Systems evolution from 1999 to 2018

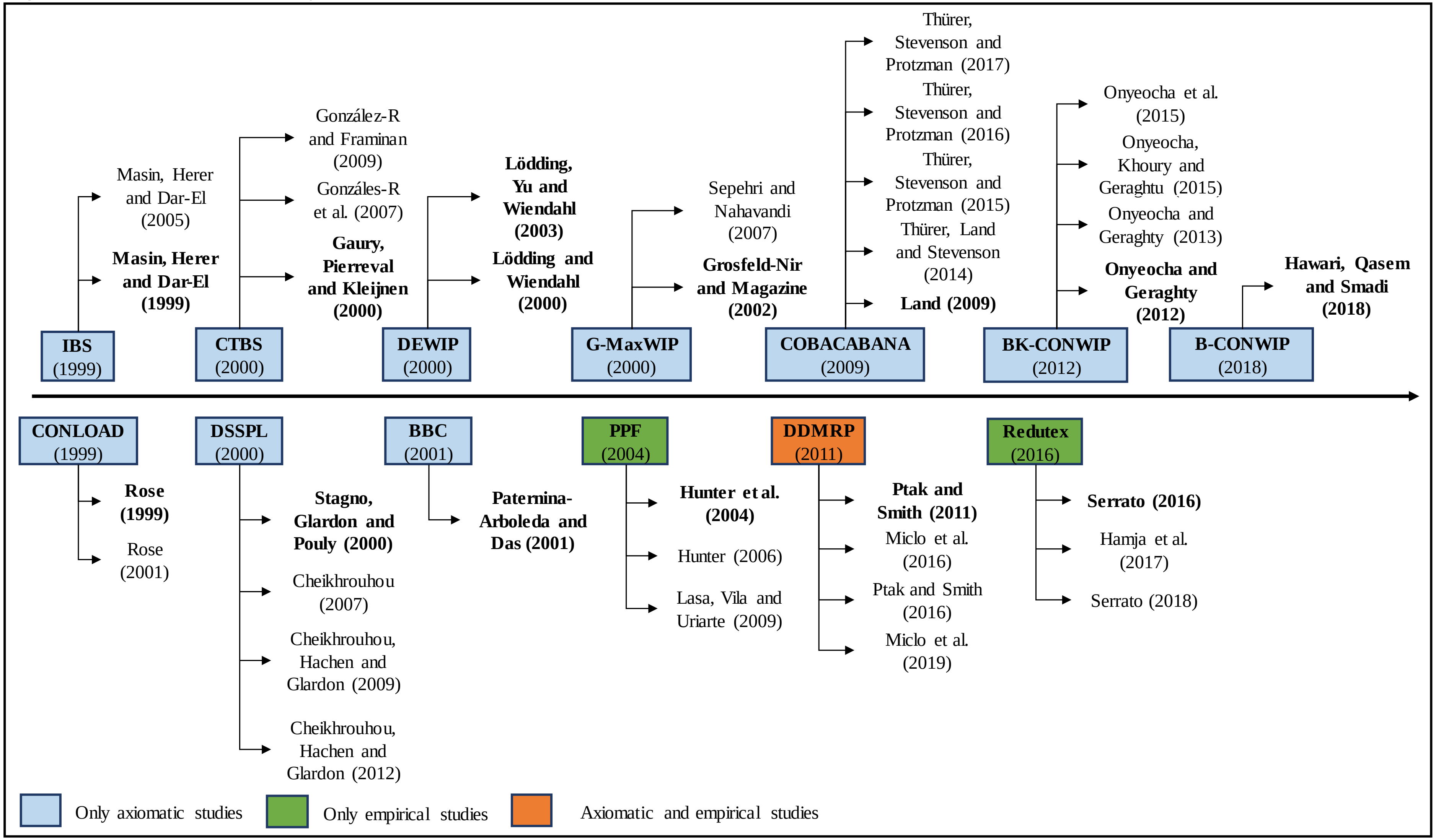
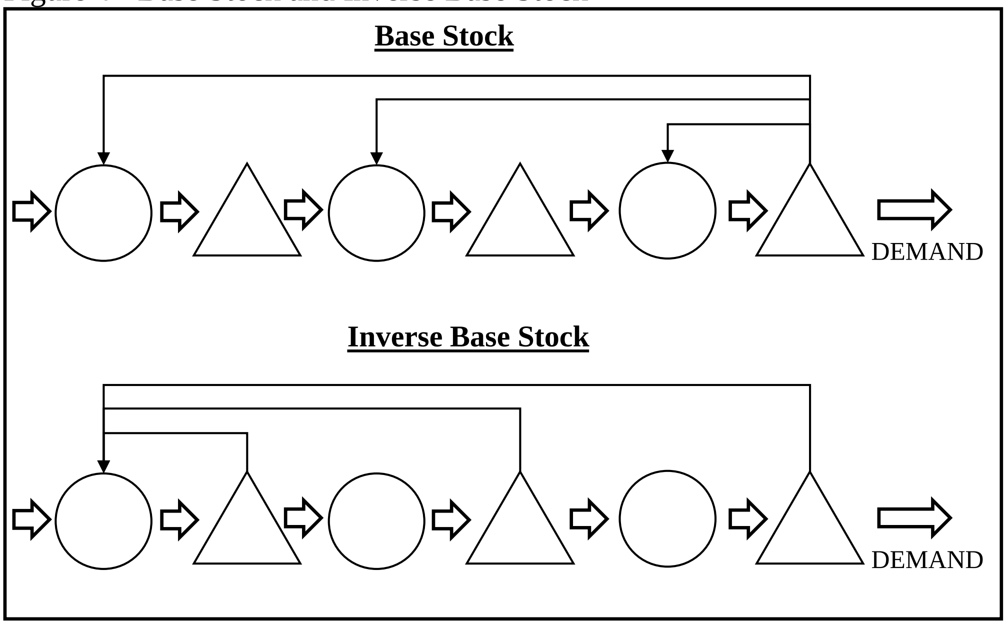


Figure 4 - Base Stock and Inverse Base Stock

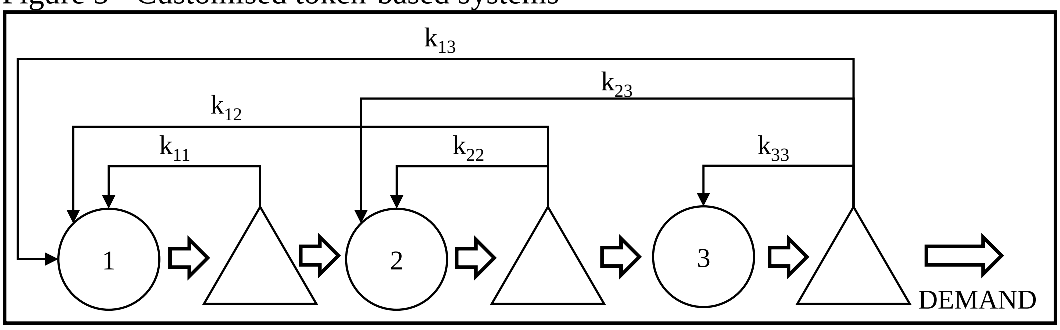


Source: Adapted from Masin, Herer and Dar-El (1999) and Masin, Herer and Dar-El (2005)

Customised token-based systems (CTBS)

Proposed by Gaury, Pierreval and Kleijnen (2000), the Customized token-based systems (CTBS) is a generalization of token-based systems, which generally use cards as token (GONZÁLES-R et al., 2007). According to Liberopoulos and Dallery (2000), this class of PCS is the easiest to implement and the most studied in the literature. As shown in Figure 5, CTBS considers all possible relationships between workstations. Specific systems, such as the CONWIP (loop k13 - between the first and last station), are CTBS special cases (GONZÁLES-R et al., 2007).

Figure 5 - Customised token-based systems



Source: Adapted from González-R et al. (2007).

In general, the selection of a PCS is based on an a priori approach, which means that a PCS is selected without considering the specific characteristics of the factory floor, such as processing times, set-up times, demand, machines workload, among others (GONZÁLEZ-R; FRAMINAN, 2009). CTBS, on the other hand, is based on a posteriori approach, which starts from a generic system that is shaped from the environmental knowledge. Therefore, CTBS consider all the space solutions in order to choose the best set of parameters (all possible loop structures and how many cards to keep in each of them).

To give an example, if CONWIP was chosen as the PCS, then only loop k13 will exist. Therefore, the task is to define how many cards to maintain in this loop. In an a posteriori approach, on the other hand, it is considered which loop structures should exist and how many cards to keep in each of them. González-R and Framinan (2009) accomplish this task using the cross-entropy method.

After its conceptual proposal, this system was further developed by Gonzales-R et al. (2007) and Gonzáles-R and Framinan (2009) which compared CTBS with other systems by simulation and proposed a method to develop the a posteriori approach using cross-entropy. However, no empirical study of this system was reported in literature.

Behaviour-Based Control (BBC)

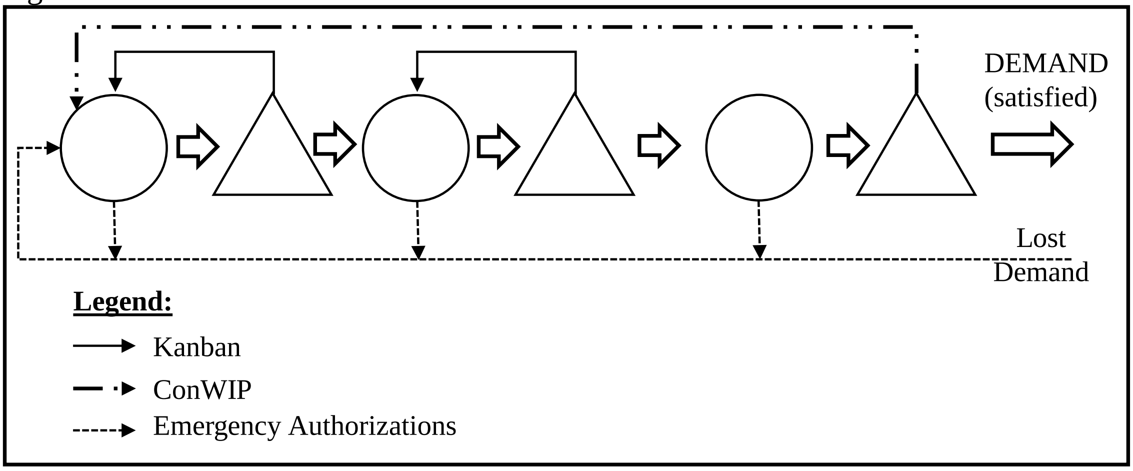
The Behavior-Based Control (BBC) system was proposed by Paternina-Arboleda and Das (2001). BBC is based on the reinforcement learning concept, in which decision-makers learn optimal control policies by receiving rewards and punishments as a result of their actions. Therefore, decision-maker chooses actions to maximize their rewards over time (KAELBLING; LITTMAN; MOORE, 1996)

The system has three types of authorizations (Figure 6):

- CONWIP authorization: whenever a demand is met, the CONWIP card returns to the first stage, authorizing the production of a new item;
- Kanban authorization: at all except for the last stage, there are kanban cards to restrict the buffer between stages;
- Emergency authorization: whenever a demand is not met or a machine breaks, an emergency authorization card is released. This card authorizes the production of an additional unit and cannot be reused.

Using simulation, Paternina-Arboleda and Das (2001) showed that in a repetitive flow shop environment, BBC presents better performance than other systems, such as Kanban, CONWIP Base Stock, Extended Kanban Control System (EKCS) and two-boundary hybrid control. However, this system was also not further developed and lack empirical studies to prove it can be useful in practice.

Figure 6 - Behaviour-Based Control authorizations

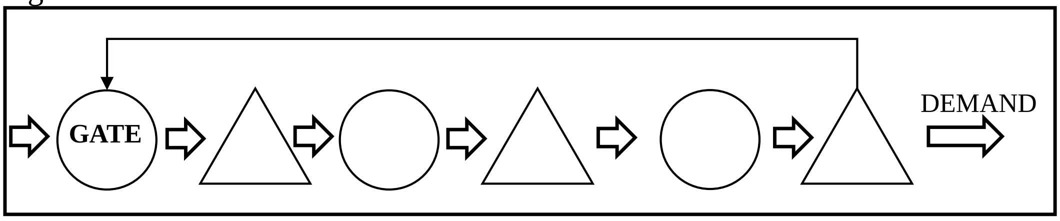


Source: Adapted from Paternina-Arboleda and Das (2001).

Gated MaxWIP (G-MaxWIP)

Gated MaxWIP (G-MaxWIP) is a hybrid PCS proposed by Grosfeld-Nir and Magazine (2002) in which all production stages are pushed, except for the first, which is pulled. The main characteristics of this system is that the first production stage is used as gate (Figure 7). This gate controls the entrance of materials into the system based on the system WIP. If WIP is below a certain defined level, the gate stays opened and lets materials enter the system. When WIP reaches a pre-set maximum WIP level, the gate closes. Then, two strategies can be used to open the gate: as soon as the WIP reaches a certain level or after a certain time interval.

Figure 7 – Gated MaxWIP



Source: Elaborated by the author.

According to Grosfeld-Nir and Magazine (2002), G-MaxWIP combines two of the most desirable features of PCS. The first one (pull) is to control the system WIP by opening and closing the gate. Regarding this point, G-Max WIP and CONWIP work similarly. The second one (push) is to allow resources to work unrestricted, increasing utilization. This is true, unless when the gate is closed. In this moment, some stages can become idle due to the lack of material to be processed (SEPEHRI; NAHAVANDI, 2007).

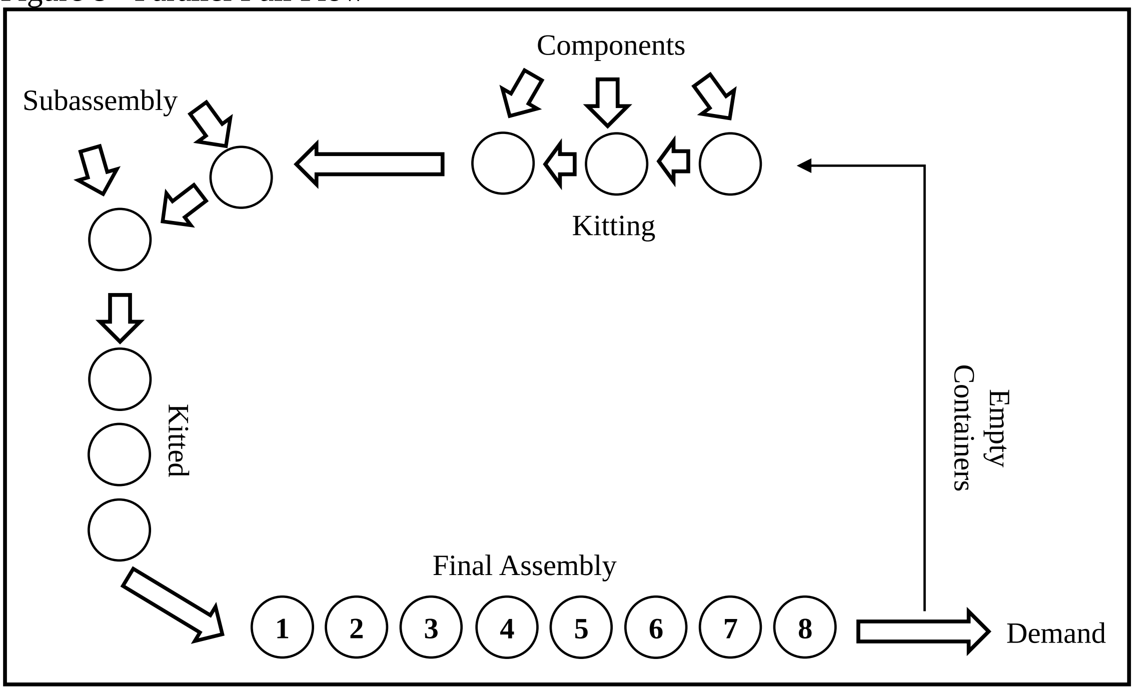
Sepehri and Nahavandi (2007) compared G-MaxWIP with CONWIP and CWIPL (critical WIP loops) through simulation studies, however no other development of this system was found in literature. Moreover, G-MaxWIP also lacks empirical studies.

Parallel Pull Flow (PPF)

Based on Lean principles, Parallel Pull Flow (PPF) was developed by Hunter et al. (2004) and it was not found any other reference to this system in literature, apart from Lasa, Vila and Uriarte (2009). Developed originally for furniture and wood components industry, PPF consists of a return-loop (rectangular or oval configuration), in which one side is used for kitting and staging carts and the other for final assembly.

When an item is assembled, the container returns empty to the purchased components area, where the necessary components for the assembly of the next final product are collected (Figure 8). The container also collects the required semi-finished items produced in subassembly lines. With all the necessary components, the container enters the assembly line and a sequence of activities is performed. Once the item is assembled, the final product is delivered and the container returns empty to the component area, collecting the necessary components for the next order (HUNTER; 2006).

Figure 8 - Parallel Pull Flow



Source: Adapted from Hunter (2004).

This system, little explored in practice and literature, is argued to be useful for environments where component availability is critical. The coordination between the subassembly lines and the assembly line can be performed by another PCS. Hunter et al. (2004)

suggests the use of Kanban systems.

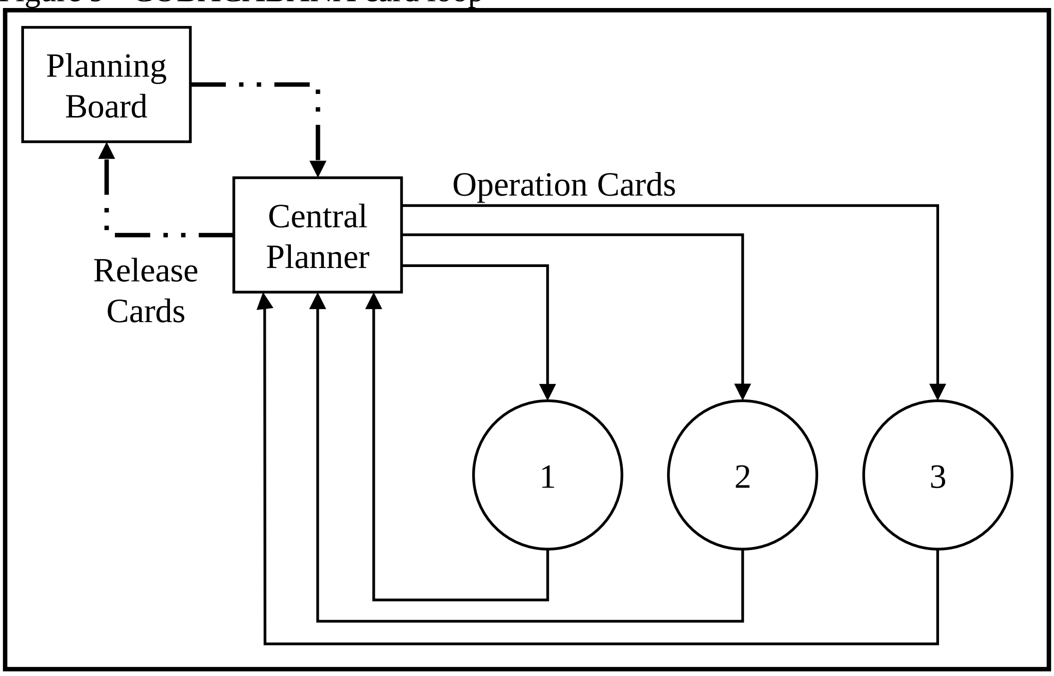
Control of Balance by Card Base Navigation (COBACABANA)

COBACABANA, an acronym for Control of Balance by Card Based Navigation, was proposed by Land (2009) and refined by Thürer, Land and Stevenson (2014). Unlike other card-based systems, COBACABANA uses the Workload Control approach, releasing orders based on the workload of critical stations (THÜRER; STEVENSON; PROTZMAN, 2017). Therefore, COBACANABA creates a card loop between the central planner and critical workstations (Figure 9).

By controlling the workload at stations, COBACABANA also focuses on controlling the throughput times of each station (LAND, 2009). COBACABANA uses a pair of cards:

- Release card: this card stays with the central planner and is used to calculate the workload in the shop-floor;
- Operation card: this card goes to the shop floor with the released order and return to the central planner after an operation is complete.

Figure 9 - COBACABANA card loop



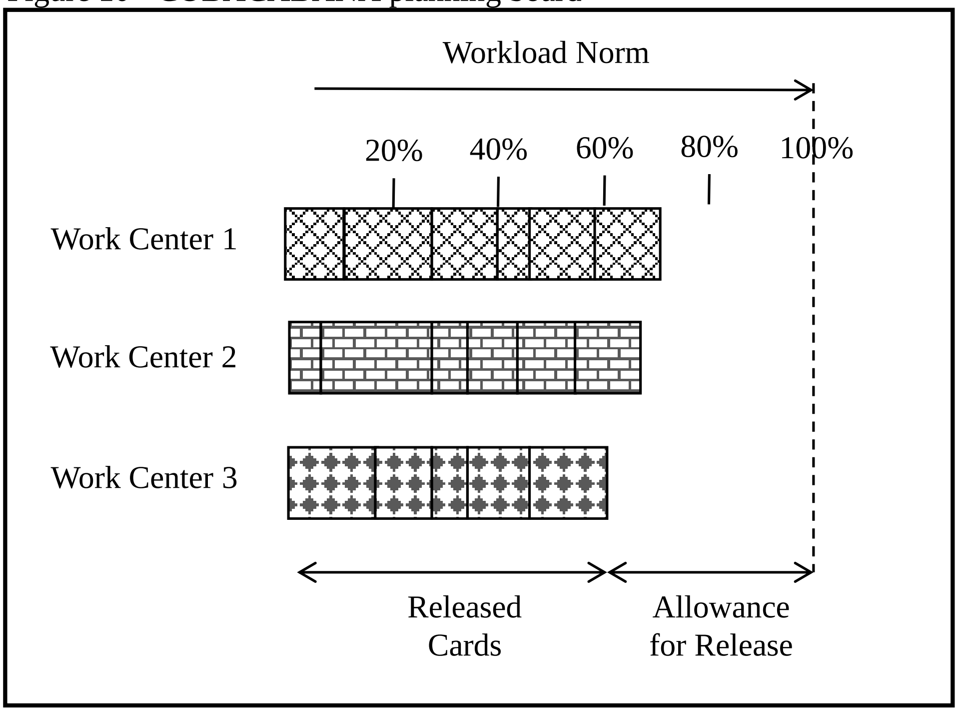
Source: Adapted from Thürer, Land and Stevenson (2014).

COBACABANA uses a centralized release orders function called pre-shop pool. In this pool, orders are sorted according to their due date (THÜRER; LAND; STEVENSON, 2014). Before releasing an order on the shop floor, the planner evaluate whether this order will not exceed the capacity limits set for critical stations. If the order violates these limits, the planner considers releasing the second order and so on, until all the orders in the pool were considered.

To assess if there is available capacity at the stations, the planner compares the current workload with the workload limits on the planning board (Figure 10). For each operation card release, a release card (of the same workload) is placed on the board. Each time an operation card returns to the planner, a release card with the same workload is removed from the board.

According to Thürer, Stevenson and Protzman (2017), orders in COBACABANA can be released periodically (Original COBACABANA) or continuously (Continuous COBACABANA). In the first case, orders are released at fixed time intervals or also releases an order without load considerations whenever the first station in the routing of the order is starving. In the second case, release decisions are taken whenever an operation is completed or a new order arrives at the pre-shop pool.

Figure 10 - COBACABANA planning board



Source: Adapted from Thürer, Land, and Stevenson (2014).

Regarding the environment, COBACABANA was originally proposed for high-variety job shop contexts, but studies show a good system performance even in pure flow shop (THÜRER; STEVENSON; PROTZMAN, 2015). However, to the best of our knowledge, there is no empirical study of this system was reported in literature.

Basestock Kanban-CONWIP (BK-CONWIP)

BK-CONWIP was developed from HK-CONWIP (Hybrid Kanban-CONWIP). The HK-CONWIP was proposed by Bonvik, Couch and Gershwin (1997), with the aim of offering a system that would respond to an environment with a greater variety of products, controlling the total inventory of the system (CONWIP cards), but also the stock of each stage, except the last one (Kanban cards). Therefore, two production authorization cards are used. Several studies show that HK-CONWIP performs better Kanban and CONWIP, such as Geraghty and Heavey (2004) and Wang, Cao and Kong (2009). HK-CONWIP was originally developed for a single product and several studies have assumed the possibility of replicating it for various products (ONYEOCHA et al., 2015).

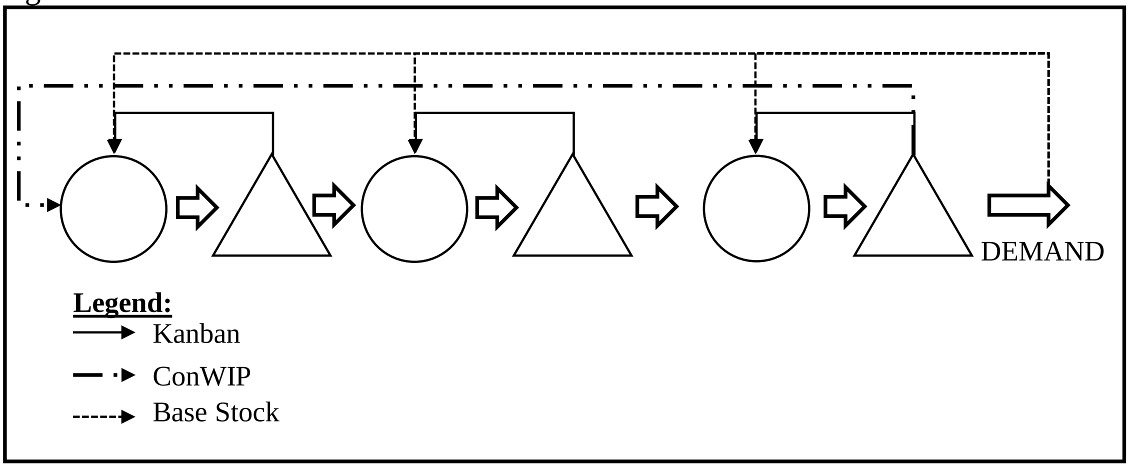
In a multi-product PCS, two different authorization policies can be used: Shared Kanban Distribution Policy (S-KDP) or Dedicated Kanban Distribution Policy (D-KDP) (BAYANT; BYZACOTT; DALLERY, 2002). While in D-KDP each card is specific to authorize the production of a single product, in S-KDP a card can be shared by a set of items (in this policy, the specific item to be produced is selected according to demand and materials availability). This makes S-KDP more flexible to variations in demand than D-KDP.

As shown by Bayant, Buzacott and Dallery (2002), Onyeocha and Geraghty (2012) and Olaitan and Geraghty (2013), several pull systems such as Kanban, CONWIP, Base Stock and HK-CONWIP have a bad performance when operating S-KDP in a multi-product environment, due to the method they adopt to transmit demand variations to the system. In this context, Onyeocha and Geraghty (2012) proposed the Basestock Kanban-CONWIP (BK-CONWIP) as an alternative to HK-CONWIP, in order to allow this system to work with the S-KDP policy. As Onyeocha, Khoury and Geraghtu (2015) state, BK-CONWIP is suitable for environments with high production mix flexibility and can operate with both the S-KDP strategy and the D-KDP strategy.

In BK-CONWIP, demand information is globally transmitted to all production stages (ONYEOCHA et al., 2015). The system has three control parameters (CONWIP cards, Kanban cards and Stock levels). As well as in the HK-CONWIP, CONWIP authorization cards are used to control the stock of the whole system and Kanban authorization cards to control the inventory on each stage. The Base Stock level in finished products is used to control the overall flow of demand information into the system.

When an order enters the system, demand information is sent to all production stages and special information to the last stage, so that it releases a CONWIP card to satisfy the demand. If raw materials and capacity are available, production starts simultaneously at all stages. If not, production starts, but is interrupted at the stage with capacity restriction or lack raw materials. As soon as the final product arrives in stock, the CONWIP card returns to the buffer (Figure 11).

Figure 11 - BK-CONWIP



Source: Elaborated by the author.

Apart from Onyeocha and Geraghty's articles, other references to BK-CONWIP are restricted to conferences. However, this system presents an interesting initial evolution, which includes a simulation study (ONYEOCHA et al., 2015). However, this system also lacks empirical studies in order to understand how it will react to real production environments.

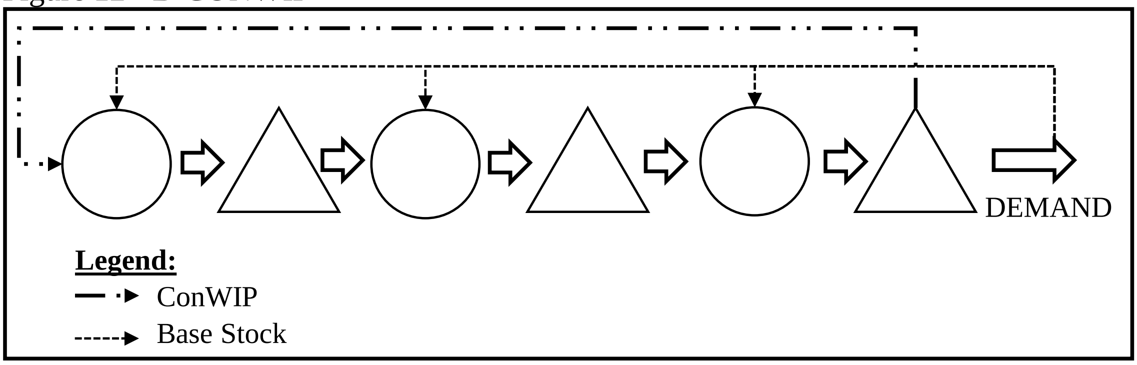
Basestock-CONWIP (B-CONWIP)

The Basestock-Constant Work-In-Process (B-CONWIP) was proposed by Hawari, Qasem and Smadi (2018) from BK-CONWIP. Apart from its proposal article using simulation, no other reference to B-CONWIP was found in literature. The objective of this system is to minimize WIP and to achieve specified service levels. Like BK-CONWIP, B-CONWIP can operate with S-KDP and D-KDP policy, and has two control parameters:

- Base Stock levels: Minimum inventory level at each stage so that it meets all unanticipated demand;
- CONWIP authorization card: limits WIP throughout the system.

The main difference between BK-CONWIP and B-CONWIP is that B-CONWIP does not use kanban cards between the stations (Figure 12). A balancing algorithm to control the stock of each productive stage is uses instead. According to Hawari, Qasem and Smadi (2018), the control of WIP levels of both systems is similar, with the advantage of B-CONWIP being simpler, especially in environments with many productive stages and many products.

Figure 12 - B-CONWIP



Source: Elaborated by the author.

The authors also claim that when demands increase, B-CONWIP is more appropriate if the priority is the service level, while BK-CONWIP is the best option if WIP control is the most important variable.

Double Speed Single Production Line (DSSPL)

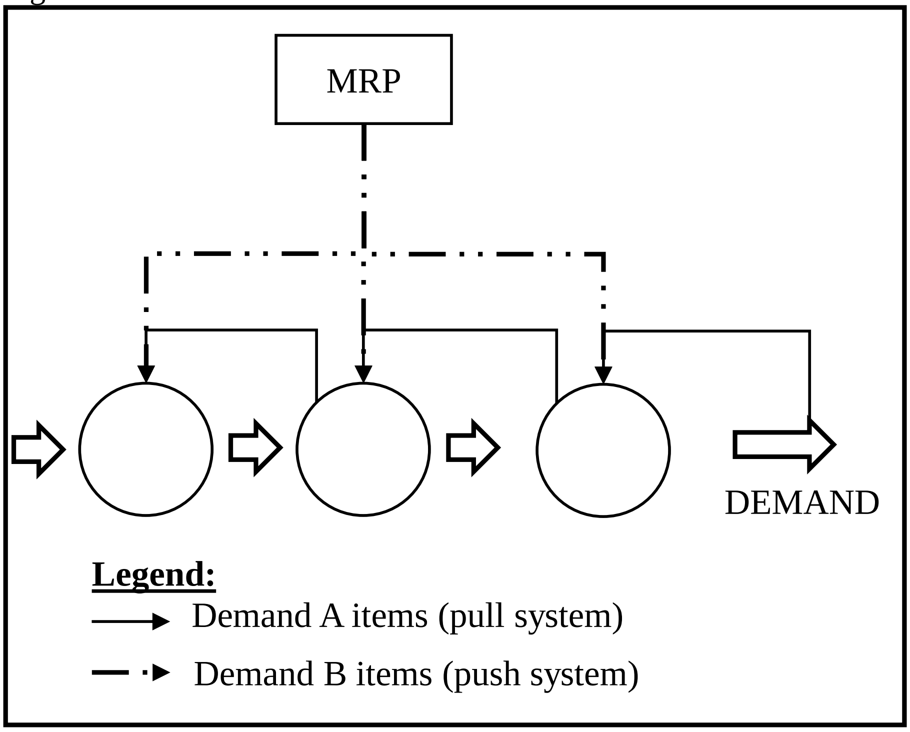
The Double Speed Single Production Line (DSSPL) is a hybrid PCS proposed by Stagno, Glardon and Pouly (2000). It was developed for industries with many distinct products (and small variety among them) and a wide variation in demand. Its main distinction from others PCS is its selectivity in allocating products to resources. Items are segregated into two groups:

- A-products: small number of products, with high production volume and fairly regular demand;
- B-products: large number of products, sold in small quantities and with irregular demand.

In DSSPL, items A are produced quickly through a pull system and items B are controlled by a push system (Figure 13). Through this segregation, it is possible to reduce lead time and stock levels of items A without significantly affecting items B. However, since items A correspond to a high volume, this change has a significant impact on the overall system result. An application of DSSPL is presented by Cheikhrouhou, Hachen and Glardon (2009).

Stagno, Glardon and Pouly (2000) also mention that the classification criteria can be the type of customer, with A clients being the most important ones. Therefore, a product is A when produced for some clients and B when produced for others. Other classification criteria are also possible. However, an assumption of DSSPL is that demand for A-products is sufficiently stable, otherwise a pull system could not be successfully implemented.

Figure 13 - DSSPL



Source: Adapted from Cheikhrouhou (2007).

This system was also study by Cheikhrouhou, which compared DSSPL through simulation with other PCS (CHEIKHROUHOU, 2007; CHEIKHROUHOU; HACHEN; GLARDON, 2012). However, no empirical study was reported in literature.

Demand Driven Materials Requirement Planning (DDMRP)

Demand Driven Materials Requirement Planning (DDMRP) is a hybrid PCS proposed by Ptak and Smith (2011). This system aims to combine the best practices of MRP II, Lean Manufacturing and Theory of Constraints (MICLO et al., 2019). According to Miclo et al. (2016), DDMRP has been developed since 2000 and has already been implemented in some United States companies. In literature, empirical and simulation articles of DDMRP can be founded.

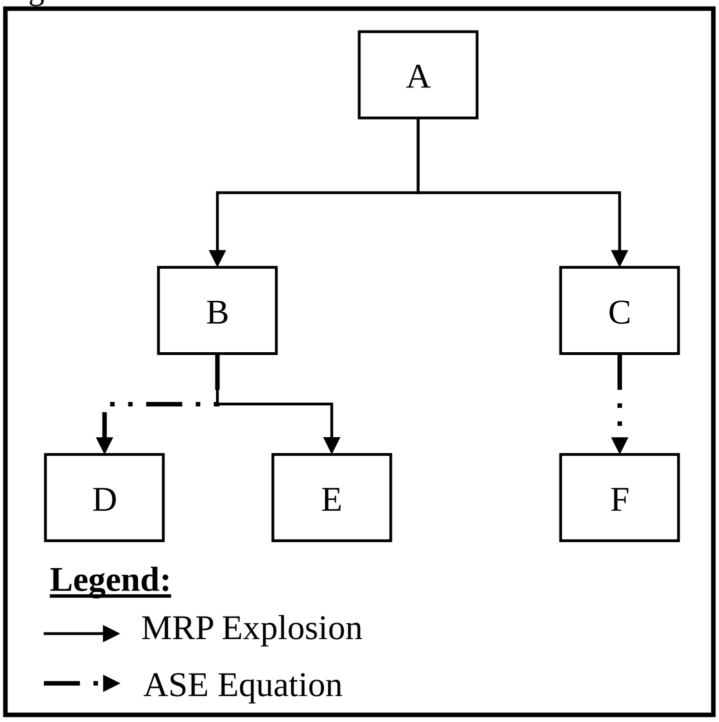
DDMRP is based on four basic principles (PTAK; SMITH, 2016):

- Decoupled Lead Time: Some pre-defined Bill of Materials components are kept in stock (in Figure 14, items D and F are kept in stock);
- Decoupled Explosion: For components held in stock, the requirements are not generated by the traditional MRP explosion, but by the ASE;
- Available Stock Equation (ASE): calculated daily, projects future stock based on actual demand (not forecast) and orders in production. The ASE is compared

to 3 buffer levels: red (safety stock), yellow (every time the ASE reaches the yellow zone, a new order is released for the stock to reach the top of the green zone) and green (replenishment size);

- Relative priority: color of the card according to the zone in which the item is located. The orders also show a percentage of the stock projected by the ASE vs maximum stock of the item (top of the green zone).

Figure 14 - DDMRP



Source: Elaborated by the author.

According to Ptak and Smith (2011), the implementation of DDMRP occurs in 5 steps. They are divided into: modeling the environment (Steps 1, 2 and 3), Plan (4) and Execute (5). The stages are:

(1) Strategic Inventory Position: to evaluate, from a financial point of view, if an item of the Bill of Materials should or not be maintain in stock. The main function of the buffer is to absorb variability. Therefore, unlike a normal MRP, in DDMRP unbuffered items are pushed, but buffered items are pulled, replenishing inventory;

(2) Buffer Profiles and Levels: to size green, yellow and red zones based on the following equations:

$$\text{GreenZone} = \text{Max}\ (\text{YellowZone x Lead Time Factor; LotSize}) \qquad (1)$$

YellowZone = ADU x ASRLT x PAF (2)

RedZone = YellowZone x LTFactor x (1+Variability Factor) (3)

Which:

- ADU (Average Daily Usage): daily average demand, estimated by demand forecast;
- ASRLT (Actively Synchronized Replenishment Lead Time): the longest unprotected sequence, considering the sum of lead time of the bill of material, of a buffered item;
- PAF (Plan Adjustment Factors): used to raise or lower the ADU, allowing to smooth seasonality. It should be defined based on the master plan capacity analysis.

(3) Dynamic Adjustments: to adjust the zones with changes in sales forecast;

(4) Demand Driven Planning: to create production and purchase orders;

(5) Visible and Collaborative Execution: to control the orders generated.

REDUTEX

REDUTEX is a hybrid system developed by Serrato (2016) which aims to reduce customer lead time. It consists of 8 steps and is based on Lean (steps 4, 5 and 8) and Theory of Constraint (steps 1, 2, 3, 4 and 6) principles. Step 7 is particular of REDUTEX. The focus of the system is small and medium enterprises (SME) in which low technological knowledge is used (TENG; JARAMILLO, 2006); for example the textile industries in Central Mexico.

The sequence of REDUTEX steps are:

(1) Identify the Restrictive Resource Capacity (RRC): to identify the resource that need to work with 100% of the daily capacity to meet demand;

(2) RRC optimization: to optimize the set ups in the RRC to increase the total production of the system;

(3) Synchronize rhythm with the RRC: all other resources must work at the same pace of the RRC. To do this, is necessary to adjust work shifts. Half shifts can be used (half of the time on one equipment, half on another);

(4) Create a smooth and continuous flow throughout the process: material must flow gradually into the system and there should be no accumulation of inventory between departments. To do so, it is essential to define an appropriate transference batch between processes (Figure 15);

(5) Create a supermarket: The supermarket at REDUTEX system is based on the

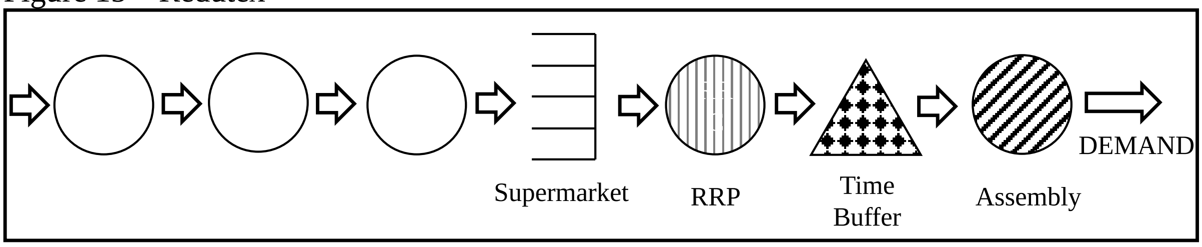
concept that the more, the better, because it ensures RRC to work at full capacity. All resources before the supermarket (RRC included) are pushed and the ones after it are pulled;

(6) Create a time buffer: The time buffer is usually located before an assembly department and is a protection against fluctuations and delays in previous processes. In the example of Serrato (2016), it is located together with the supermarket. The time buffer purpose is to ensure that the components necessary to next day program are available. If not, the supervisor must verify at which point of the process they are and which actions are necessary to make them available at the assembly time;

(7) Control production through automated dual card system control: the system uses cards to identify and track products in the factory. The card follows the flow of the product throughout the entire factory and is transferred to the next department when the entire lot has been processed in the previous one. Regarding the card design, the right side contains barcodes and the left side information about each department. The card specifies product’s type, size, color, department, production lot, transfer lot and operator;

(8) Visual quality control: in a board for each department, the results of batch inspection are visually displayed. A green point indicates a batch that meet specifications, yellow one within specifications limit and red a batch that does not meet specifications. Serrato (2016) suggests organizing the board in this way: columns (types of defects evaluated) and lines (batches evaluated).

Figure 15 – Redutex



Source: Elaborated by the author.

Even though it is a recent PCS, other references to Redutex include Hamja et al. (2017) and Serrato (2018), however none of these articles contributes to further developed Redutex. Therefore, this system first lacks simulation studies comparing it to other PCS. Secondly, it also lacks empirical studies, as Serrato (2016) is a unique example.

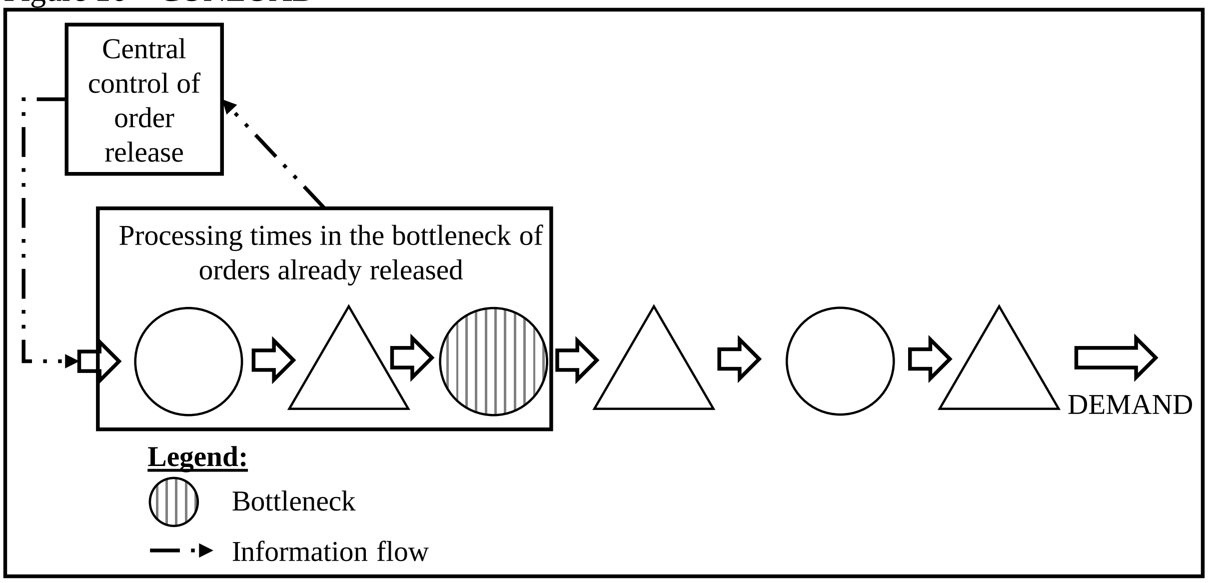
Constant Load (CONLOAD)

CONstant LOAD (CONLOAD) is a PCS developed by Rose (1999) to overcome the difficulty of other systems, such as CONWIP, to deal with changes in product mix, in the transition period when one item is discontinued and another is introduced (ROSE, 2001). Such changes are very frequent in the semiconductor industry, where there are a large number of products with a very short life cycle due to technological changes.

CONLOAD was developed merging concepts of CONWIP and Workload Control (ROSE, 1999). Instead of controlling the WIP (like CONWIP), CONLOAD controls the bottleneck load. The bottleneck load is equal to the processing times in the bottleneck of all orders that already have been released but have not yet been processed in the bottleneck. Therefore, a job enters the system only if its processing time in the bottleneck plus the processing time in the bottleneck of all orders already released do not exceed a predefined workload (Figure 16).

A constraint of CONLOAD is the necessity to know products' cycle times with high accuracy (ROSE, 2001). If this cycle time is overestimated, the bottleneck will become idle. If it is underestimated, the bottleneck will be overloaded and there will be accumulation of orders in front of this resource.

Figure 16 – CONLOAD



Source: Elaborated by the author.

Rose (1999) compared CONLOAD to CONWIP and Workload Regulation and found that CONLOAD is more efficient in maintaining the utilization level of the bottleneck while WIP evolves more smoothly over time.

CONLOAD was little study in literature and, as many other systems of this review, lacks empirical studies.

Decentralized Work in Process (DEWIP)

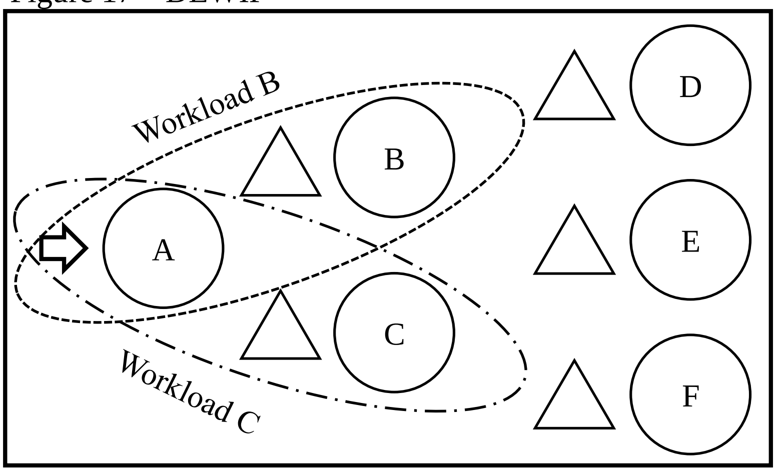
The Decentralized Work in Process (DEWIP) was developed by Lödding and Wiendahl (2000) for job shop environments with the aim of offering smaller and more reliable lead times (LÖDDING; YU; WIENDAHL, 2003). Although there are many simulation studies about this PCS, no empirical study was found in literature.

The motivation to develop DEWIP arose from the fact that, although there are several decentralized systems whose primary control variable is WIP (Kanban and POLCA, for example), none of them is suitable for environments with complex flow of materials.

In DEWIP, all orders are programmed by a Central PCP, which sets production priorities. However, the actual moment when each operation starts is controlled by WIP as follows:

- The operator of a work center A checks the first order that needs to be produced and asks for authorization for the next work center (go-ahead request) (Figure 17);

Figure 17 – DEWIP



Source: Elaborated by the author.

- The downstream work center operator (B) verifies the workload of its own center (direct WIP) as well as the production authorizations already provided to upstream centers (indirect WIP). If releasing the new order, the total WIP (direct + indirect) exceeds a pre-set threshold, authorization is not provided;
- If authorization is provided, center A starts production and reduces its WIP,

providing authorizations for the upstream work centers;

- If authorization is not provided, the operator of center A searches for the next order that is not processed in center B (which is possible because the environment is a job shop) and requests authorization for another center (C).

This evaluation is performed in all work centers, establishing control loops between them. The only exception is critical resources, for which authorizations are always provided.

2.4 Comparison of New Production Control Systems (PCS)

After presenting the 13 PCS's and classifying them according to the six variables defined in section 2.2 (Table 2 and Figure 2), the main findings will be discussed. Regarding the systems evolution dimension, first it can be observed that each system was developed by only one or two groups of authors. These can be one of the reasons why these systems is still little known in practice.

Secondly, it is important to highlight that while some systems were developed almost 20 years ago others are much more recent. Therefore, while B-CONWIP still have a high probability to thrive, chances for IBS are much slower. In our analysis, we could not find any prediction to the success of a PCS's, however it may be due to the systems characteristics itself, to the journal it was published, to the group of authors that proposed the system, among other possibilities.

Thirdly, we observed that almost all PCS have been developed only in theory, specifically by mathematical simulations. PPF, DDMRP and Redutex are the only counterexamples, that is, systems that have been developed from practice. This can be explained by the advances in computing, which made simulation faster and able to work with more data, and, therefore, closer to reality. However, this scenario also led to an unwanted effect, that is, many PCS do not have empirical studies showing their application in practice. Therefore, theory and practice of PCS may be taken different paths.

Fourthly, we only find theoretical and empirical studies about one of the 13 PCS's (DDMRP). This is a problem even for PPF and Redutex, as theoretical studies, such as computer simulation, could help to optimize systems parameters, increasing the chances of an empirical successful implementation of these PCS's. Moreover, it reinforces the idea of theory and practice of PCS following different paths.

Regarding the system's characteristics dimension, first we noticed predominance of systems (7 out of 13) which present WIP as primary control variable, are designed for flow shop environments and are card-based. In our understanding this is due to Lean influence, as

Kanban and CONWIP, two of the most well known PCS's, also present this characteristics. DDMRP (not included among the 7 systems because is primary control variable is throughput) also contributes to this view, as it combines MRP principles with Lean. The predominance of systems based on Lean may be a result of the success of this approach in the Western World, especially after its large diffusion by famous book The machine that changed the world (Roos, Womack, and Jones 1991; Bhamu and Sangwan 2014).

Secondly, we observed that the 13 PCS's came from a much more homogeneous manufacturing approach than classical systems. While many of the former are based on Lean, classical systems came from a much more heterogeneous manufacturing approach, such as Lean (e.g. Kanban, CONWIP), Theory of Constraints (e.g. DBR), Quick Response Manufacturing (e.g. POLCA), Mass Production (e.g. MRP), among others. Therefore, PCS's are becoming more similar one to the others.

Thirdly, among the 13 systems, DEWIP and COBACABANA are different because they are the only ones designed for job shop environments. Curiously, both systems were developed from the Workload Control approach, but in COBACABANA there is also a strong influence of Lean regarding visual control and the role of cards. This is interesting as production shop floor are becoming more and more complex. Therefore, we expected in next years more PCS's for job shop will be proposed.

2.5 Conclusions and Research Agenda

2.5.1 Conclusions

PCS's are a key determinant of the effectiveness of manufacturing systems. Consequently, many different PCS's emerged and a broad literature on PCS's exists. While many researchers and managers are aware of some major PCS's, more recent advances in the field of PCS are less known. In response, this study asked: What are the characteristics of Production Control Systems that newly emerged in the last 20 years? Using a systematic literature review, 13 new PCS could be identified. Their key characteristics, mechanisms and environment in which they are adequate were then discussed.

Among the PCS, 7 out of the 13 presented WIP as primary control variable, are designed for flow shop environments and are card-based. Those characteristics are also presented by Kanban and CONWIP, two of the most important PCS based on Lean approach, which focus on tool's simplicity and on the importance of people, making the system easy to be implemented. Therefore, there is a clear movement to approximate theory and practice, that is, to implement PCS.

However, it was also observed that many new PCS were developed from simulation studies and lack empirical results, distancing theory from practice. Therefore, two contrary movements are occurring at the same time, making PCS's simpler to be implemented, but lacking studies to test the effective of those systems in practice.

In terms of research, we seek to outline new search directions for future research on PCS's, in special, showing the necessity of more empirical studies about PCS's proposed in the latest 20 years. In terms of practice, we hope that our study helps engineers and managers to find new solutions to their day-to-day problems, knowing a larger number of PCS's, and to apply systems more adherent to the productive environment in which they are inserted, increasing the probability of success of those PCS's.

A major limitation of our study is that we not discuss in depth each PCS's. However, we preferred to include all the 13 PCS's identified in the SLR in order to show all the possibilities available instead of choosing only some of those systems by any research criteria. In the research agenda, we proposed more studies about each PCS's regarding implementation, applicability, comparison among systems, among others. Moreover, our study only identified articles written in English, so PCS's proposed in other languages were not included in this paper and could be added in future studies.

2.5.2 Research Agenda

Due to the limited body of existing research about new PCS's and following some of Stevenson, Hendry and Kingsman (2005) suggestions as well as based on emerging topics such as Industry 4.0 (ZHONG et al., 2017; ZHENG et al., 2018), sustainability (GONG; KAO; PETERS, 2019) and circular economy (JABBOUR et al., 2018), some research key areas are proposed to their development as well as some potential research questions (Table 3).

Table 3 - Research gaps and future research directions

Subject	**Motivation**	**Potential research questions**
	Understanding the new PCS's	
Implementation of PCS's	For the majority of the PCS's presented in this paper, there is no empirical study reporting the implementation of one of the 13 PCS.	For each of the 13 PCS's: What are the difficulties to implement the system? Does the system need any adaptation to be implemented? Does the system achieve the expected results of simulation studies?

Subject	Motivation	Potential research questions
Understanding the new PCS's		
Applicability of PCS's	As there is a lack of papers about recent PCS's, it is important to verify their suitability in different environments in order to increase their chance of success in empirical implementations.	Which environment are adequate to each system? Which environment are not? How each system can be adapted to be suitable for an environment different of its initial proposal?
Comparison	Comparison studies of new PCS's are limited to some systems, such as Kanban, BK-CONWIP and B-CONWIP. It is essential to compare them in order to understand their performance differences in some key indicators, such as stock levels and throughput rates.	For a given environment: Which PCS's (new or classical) is better to control WIP? And throughput? And a combination of both metrics?
PCS's in complex environments		
Collaboration	As production shop floors become more complex, it is necessary to understand how PCS's can be combined in order managers could choose solutions more adherent to their environment.	How new and old systems can be combined horizontally (different production stages) and vertically (in different levels of the hierarchical production planning)?
PCS in Supply Chain	As competitions against supply chains, instead of single organizations, are becoming more usual, it is important to studied PCS is this wider environment.	How can a PCS be applied to whole supply chains? How companies shared information among themselves to take shop floor decisions?
Environmental forces		
Technology and Industry 4.0	Technology development can affect greatly actual PCS's as well as the proposal of new ones. For example, big data and analytics can become extremely complex centralized PCS's, while internet of machines can push new systems to a decentralized direction.	How the use of technologies, especially the ones emerging with Industry 4.0, can affect the development and choice of PCS? How can artificial intelligence, internet of things and machine learning become feasible decentralized systems on which each machine could take decisions based on the past experiences and communicate one with the other?
Sustainability	Questions such as carbon emission, reduction of waste and energy economy, among others, can lead to different objectives of PCS in the next years, because traditional ones do not focus on these questions. For example, a PCS focus on reducing carbon emission may neither control throughput rates nor WIP, but a third metric. This could lead to a new group of PCS, focusing on optimizing sustainability objectives.	How efficient is each PCS to deal with carbon emission metric? And with energy economy? How can a new PCS be developed seeking to optimize carbon emission?
Circular Economy	The objective to maximize the circularities of products can also affect the choice and development of new PCS.	How can real time communication between market conditions and the machine themselves predict better deliver times to clients, optimize set ups, increase efficiency, reduce stocks and revise expected lead times based on the shop-floor scenario? How PCS's will deal with remanufacturing, as it increases the number of materials entry points on shop floor as well as production routings?

Subject	Motivation	Potential research questions
Proposal of new PCS's		
Characteristics of new PCS	As identified the carachteristcs of PCS's developed over the last 20 years, it is interesting to evaluate how actual forces will influence the proposal of new PCS's in the next years.	What will be the characteristics of PCS in the next 10 or 20 years? Will they still be based on Lean or another approach will become predominant? How systems will deal with the increasing complexity on production environments?

Source: Elaborated by the author.

3 SOFT FACTORS FOR CARD-BASED SYSTEMS IMPLEMENTATION: A MULTI-METHOD STUDY

Many articles discuss Production Control Systems (PCS), but implementation is still a problem in practice. Among the PCS, card-based are the most studied and implemented ones, sharing, as a common feature, a strong human influence on their operation. Therefore, understanding which soft factors (related to human aspect) are critical to a successful card-based system implementation is a relevant issue. This chapter proposes this list as well as a soft factor house, based on a systematic literature review, longitudinal case study, content analysis and interviews with experts. The factors are classified as exclusive to this theme or classic management factors, as well as in relation to the organizational level in which it operates (organization, implementation group, or individual). With those factors, we aiming to help managers in increase the success in implementing a card-based system.

3.1 Introduction

As a significant part of the capital of industrial organizations is in manufacturing, managing these resources efficiently is essential for building or maintaining competitive positions. In this environment, Production Planning and Control (PPC) plays a fundamental role in deploying organization's strategic plans in manufacturing tactical and operational plans, as well as in connecting production and purchase of materials to customer needs. In the heart of PPC, there are the Production Control Systems (PCS's), which regulate information and materials flows through the factory (KARRER; ALICKE; GÜNTHER, 2012).

Although PCS's is a mature topic in literature, most of the papers have focused on mathematical approaches to optimize the parameters of each system (PONS; 2010; HENDRY; HANGANG, STEVENSON, 2013). Implementation, however, remains a complex problem (RAZMI; AHMED, 2003). Most implementation studies only describe the system logic inside a business environment, such as Golmohammadi (2015) and Leonardo et al. (2017), but do not systemically address difficulties during the implementing phase, providing a list of critical success factors (CSF) in which managers must focus their attention on (ROCKART, 1979; HOWELL, 2009).

Among PCS's, card-based systems, like Kanban (e.g. Monden (1998) and Lage Junior and Godinho Filho (2010)), Constant Work-In-Process (CONWIP; e.g. Spearman, Woodruff and Hopp (1990), Paired Cell Overlapping Loops of Cards (POLCA; e.g. Suri (1998)) and Control of Balance by Card Based Navigation (COBACABANA; e.g. Thürer, Land and

Stevenson (2014)), are the most studied and implemented ones (LIBEROPOULOS; DALLERY, 2000). A characteristic shared by those systems is the strong human influence on its operation (SALEM et al., 2006; LIU; HUANG; 2009).

CSFs may consider in different areas of a PCS. Following Hendrick and Kleiner (2001) definition, a socio-technical system is composed of four subsystems: human, technical, work organization and external environment. In this research, we are specifically interested in the human and work organizations subsystems, which correspond to the soft factors (ABDULLAH; ULI; TARÍ, 2008). Therefore, techniques concerning the definition of the number of cards, for example, were not considered in this study. However, apart from Pons (2010), soft factors like workers motivation, support from top management and communication has been rarely studied in the specific context of card-based systems (MARODIN; SAURIN, 2013). Therefore, we ask: What are the soft factors for card-based systems implementation?

In response to this gap, the objective of this is study is to propose a list of those factors. Through a Systematic Literature Review (SLR) and a longitudinal case study, we identified many problems associated with card-based system implementation. Afterwards, a content analysis using the summarizing technique was conducted to classify the information, constructing a list of 14 soft factors, as well as defining the meaning of each of them. Finally, the list was reviewed by a panel of 6 experts, adding a fifteenth factor, and it was validated by company's employees and the experts.

The final list contains factors as diverse as management support, implementation during low demand period and card's material quality. In the list, we tried to maintain the factors as generic as possible, not including specific factors suitable for particular environments. Therefore, additional factors can be included for each individual implementation. In terms of research, we seek to highlight the importance of human factors on card-based system implementation, asking for more studies in this field. In terms of practice, we hope that the list helps companies to increase the success in implementing card-based systems and that managers know in advance which soft factors they should concentrated their attention during the implementation process.

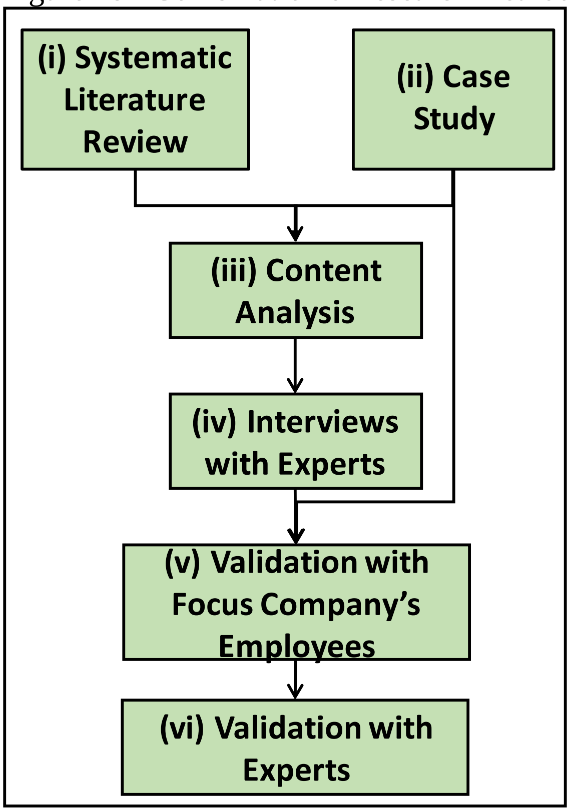
The remainder of this chapter is organized as follows. Section 3.2 gives an overview of the research methods and presents the details of each research method (systematic literature review (SLR), longitudinal case study (LCS), content analysis, expert panel and final validation with focus company's employees of the LCS and with the experts. Section 3.3 present the main results of this research in two moment. First of all, the list of factors that results from the content analysis as well as evidences of each factor found in the SLR and in the LCS. Secondly, the refined list of factors and descriptions by the experts' panel. Section 3.4 discuss if the factors are specific to card-based systems or not and why some factors were not identified in the SLR. Moreover, three propositions were stated and explained and a house of soft factors is proposed. Finally, some conclusion arguments, limitations and suggestions for future researches are presented in Section 3.5.

3.2 Method

3.2.1 An overview of the research method

This chapter used a combination of methods to propose a list of critical soft factors to the implementation of card-based systems as shown in Figure 18. First, a Systematic Literature Review (SLR) was conducted to identify empirical papers that mention difficulties and problems related to human aspects during card-based system implementation. In some cases, also solutions to those problems are described, e.g. a simulation environment to employees learn how a PCS works, reducing their fear of failure.

Figure 18 - Combination of research methods used in this study



Source: Elaborated by the author.

However, even though conference papers were included in the analysis and searches were conducted in three databases, the SLR resulted in only 8 articles. First, this is due to the fact that many articles only describe how the system works on a specific environment, giving little attention to how it was implemented. Secondly, articles tend to focus on positive aspects of the implementation, not highlighting problems that have occurred.

Therefore, we also conducted an inductive longitudinal case study in a multinational manufacturer which failure to implement kanban in the three-final mini-factories of its production chain, in order to identify more difficulties related to human aspects on card-based systems implementation. The case is unique, as having free access to the company, the author has followed all the implementation process and continued to observe company's environment for six years after the decision to interrupt kanban implementation. Rich data were collected from many sources, including semi-structure interviews with company's employees realized six years after the project interruption. The case selected resulted in a failure implementation, what is unusual to be reported in literature, but could provide interesting evidences for the difficulties faced in practice during a card-based system implementation.

With a large material available, the next step was to classify the difficulties and problems into soft factors critical to the implementation of card-based systems. This was done by carrying out a content analysis using the summarizing technique based on lean soft factors. In addition to the 14 factors identified, a description of each factor meaning was proposed and examples of each factor found in the SLR and in the case study are presented.

After that, this list was revised by a panel of 6 experts carefully selected from three different areas: university (professor), manufacturers (managers) and consulting (consultants). Individually, they analyzed if the name and description of each of the 14 soft factors were clear, as well as if they represent a critical soft factor for card-based system implementation. Also, we ask if another soft factor should be included in our list. Analyzing their answers, we proposed a final list of 15 factors.

Finally, the list was evaluated and discussed with three people in the focus company that had taken part in the project as well as with the six experts. The analyzed each factor name and description and agreed the proposal contains all the relevant information about kanban project implementation in the company.

The specifics of each method are detailed in the following subsections.

3.2.2 Systematic Literature Review (SLR)

This study started by asking:

RQ What difficulties related to human aspects are faced in practice to implement a card-based system?

To minimize the bias in article selection (TRANFIELD; DENIER; SMART, 2003; FAWCETT et al., 2014), a SLR was conducted using the four steps proposed by Tranfield, Denier and Smart (2003) and used in several papers in literature (e.g. Negrão, Godinho Filho and Marodin (2017)). In step 1, we followed Thomé, Scavarda and Scavarda (2016) recommendation for research quality to use at least two databases in order to minimize bias on articles selection. Due to the low number of articles resulting in the research, we decided to conducted searches in three databases (Web of Science, Scopus and Engineering Village). Following the protocol presented in Table 4, the researches results in 525 non-duplicated results.

Table 4 - Research Protocol B

Research Protocol	
Database	Web of Science, Scopus and Engineering Village
Publication Years	From 2009 to 2019
Document type	Journals and Conference Papers
Language	English, Portuguese and Spanish
String	("kanban"OR"conwip"OR"polca"OR"cobacabana"OR"card-based")AND("empirical"OR"pratical"OR"case study"OR"implementation"OR"action research")
Fields	Title, keywords and abstract
Inclusion criteria	• Practical initiatives to implement a card-based system; • At least one reference to a difficult find during the implementation process or on an existing system related to human aspects.
Exclusion criteria	• Simulation or mathematical analysis of the systems; • Implementation of card-based system in software companies, as in those situation difficulties find in manufacturing is not presented; • Only reference to hard factors, such as investments, resources and calculating the number of cards in each production stage.

Source: Elaborated by the author.

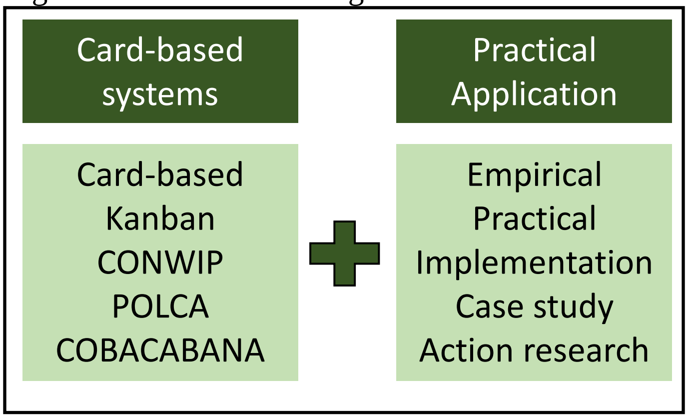
The research string was built by combining two groups of word (Figure 19). The first one refers to card-based system (the most relevant ones, as almost no material was found about other systems, such as Gated MaxWIP, Parallel Pull Flow and Basestock Kanban CONWIP), and consist of the word card-based itself as well as the name of the four well-known card-based system (Kanban, CONWIP, POLCA and COBACABANA). The second group contain words related to the practical application of those systems (empirical, practical and implementation) and empirical methods (case study and action research).

It was also important to highlight the necessity to include conference papers in the search, as through an initial review it was identified that many empirical studies reporting card-based systems implementation are presented in this type of document.

Steps 2 and 3 consist of two filters. In the first one, the author read the title and the summary of the 525 results to assess if they met inclusion and exclusion criteria of the research protocol. This filter results in 118 articles and conference papers (Figure 20).

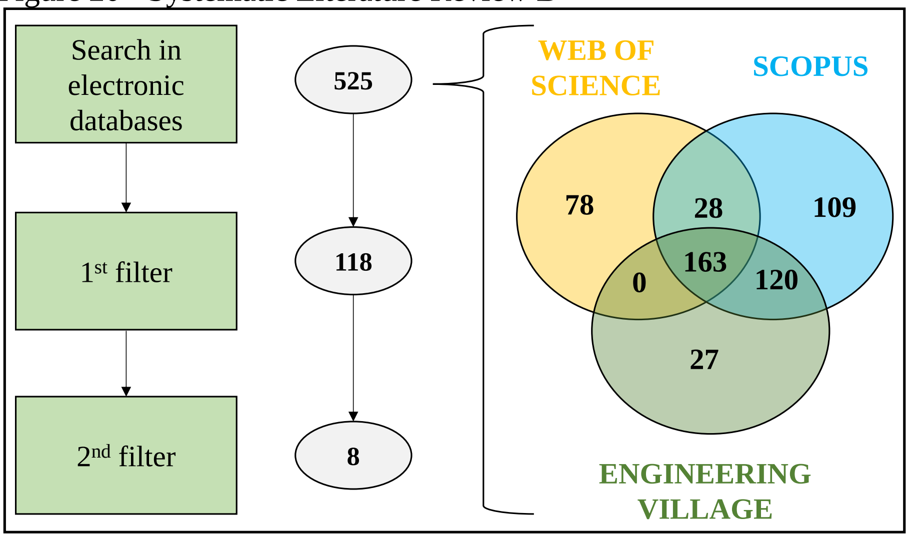
In the second filter, the author read the full text of the remaining articles and conference papers, applying the same inclusion and exclusion criteria. This process results in only 8 articles and conference papers. The large number of exclusions in the second filter is because, in many cases, only reading the full article it was possible to identified if the authors mention some difficult in implementing a card-based system or not during the implementation process.

Figure 19 – Research String



Source: Elaborated by the author.

Figure 20 - Systematic Literature Review B



Source: Elaborated by the author.

Finally, in Step 4 (Final Selection), no additional material was added using the snowball approach, a very unusual situation on SLR articles. This is because when a problem or difficult during the implementation of a card-based system is presented in the material selected, if there is discussion or comparison, it was only with theory. Therefore, it was not possible to identified other empirical studies from the ones that resulted from SLR.

The 8 articles and conference papers and selected are presented in Table 5 with a brief summary of their content.

Table 5 - Systematic Literature Review Results

Paper	Summary
Krishnamurthy and Suri (2009)	Describes the implementation of POLCA and main difficulties find during the process at three different manufacturers: machine parts motor control centers and aluminum extrusion.
Slomp, Bokhorst and Germs (2009)	Presents the implementation of CONWIP and takt time concept into a strip manufacturing. A game software was developed to gain acceptance of supervisors and planners in the new PCS.
Prachař et al. (2014)	Describes the implementation process of kanban at a manufacturing company, highlighting the problems related to human factors and how the company overcome them.
Prakash and Chin (2014)	Shows how a hybrid kanban-CONWIP was implemented into a supplier of a well-known aircraft, emphasizing the importance of employees training.
Crop et al. (2015)	Describes the cultural changes necessary for CONWIP implementation in a hospital, specially overcoming concern about underutilization of resources.
Papalexi, Bamford and Dehe (2016)	Highlights the fears of kanban implementation success in the pharmaceutical sector.
De Vries and Van der Poll (2018)	Emphasizes the necessity of empowerment and training for operators to run kanban cells in a pump-engineering organization.
Sánchez-Partida et al. (2018)	Presents the human difficulties to operate kanban when production levels change frequently.

3.2.3 Longitudinal Case Study (LCS)

As identified in the SLR, a small number of difficulties in implementing card-based systems are reported in literature, even though many companies do not have success on this process. Therefore, the author conducted an in-depth inductive case study to identify more problems and create a large database for further analysis (details are provided in Appendix A). Case study was chosen as research method because it has no strict limits, favoring the exploration of a phenomenon (YIN, 2014) and the proposal of new ideas to construct or refine a theory (EISENHARDT, 1989; BARRATT; CHOI; LI, 2011; CHILDE; 2011).

The Research Question of the case study is similar to the one of the SLR:

RQ What difficulties related to human aspects did the select case (company) faced to implement a card-based system?

The case study presented in this paper is longitudinal as data was collected in three different phases. In the first phase, the author followed for 8 months the entire implementation process of kanban in 2012. However, at that time it was not clear for company managers and employees the main reasons for the unsuccessful implementation. Between 2012 and 2018 (Phase 2), the first author visited the focus company on a weekly basis, as he was participating in other projects companies. However, in his visits he also collected additional observations and conducted informal conversation with company’s employees.

In 2018 (Phase 3), six years after the company decided to interrupt the implementation, the author came back to the company and interview key people during the implementation process. At this time, it was more much clear what were the problems faced during the implementation process as well as what could have been done different. All this information creates a reach data based to create an in-depth understand of the factors that lead to kanban implementation failure, making possible information triangulation (VOSS; TSIKRIKTSIS; FROHLICH, 2002).

Unit of Analysis

In this research, the unit of analysis represents an initiative to implement a card-based system in a specific part of a production system (DUBÉ; PARÉ, 2003). Therefore, the initiative must be time limited, that is, there is a starting moment when the company decide to implement a card-based system and an ending moment when the card-based system is working (success) or when the company decide to interrupt the implementation process (failure).

It must also be space limited, as the focus will be only on the areas of implementation of the card-based system, that is, specifically the processes that will be coordinated by the implemented system. This is important to highlighted, as in long production chains, not all the process need to be coordinated by the same PCS.

Case Selection

A case must be selected following some criteria, such as: the studied phenomenon is presented, relevance to answer the research questions and access of the researchers the necessary information (MILES; HUBERMAN, 1994). Following those criteria, the author selected a manufacturing company first because the author had unrestricted access to the company and to its information databases, what make it possible to conduct a longitudinal study collecting data in multiple phases. The company was starting to implement kanban at the beginning of data collection for this study, what was very convenient to the author. Moreover, as the implementation was not well succeeded, the case become more interesting, as literature usually reports only success cases. However, a failure case is more adequate to understand the difficulties face during an empirical kanban implementation.

The selected company is an organization that produces a high diversity of consumer goods. The plant analyzed in this study is located in Brazil and, even though it produces only a single category of products, there is a high diversity of final goods and a highly verticalized production chain, divide in different mini-factories. Those mini-factories present characteristics very different one from the others. Therefore, kanban was not suitable for all of them and its implementation initiative occurs only in the end of the productive process (three final mini-factories). From now on, they will be called Mini-Factory 1, Mini-Factory 2 and Mini-Factory 3 (final assembly).

The selection of kanban over other possible PCS, such as CONWIP and POLCA, was mainly based on production manager knowledge of PCS. However, the author verified through McCarthy and Fernandes (2000) classification that kanban is a suitable system to the specific production environment where it was implemented. Therefore, the selection of the PCS cannot be attributed as a cause of failure of system's implementation.

Before the beginning of kanban project, production control was performed by an unstructured combination of the explosion of the needs generated by the MRP (*Manufacturing Resources Planning*) with manual controls on the factory floor for order prioritization. With the decision to implement kanban, a team was formed, consisting of the supervisor of Production Planning and Control, two analysts of the area and an external consultant. This team conducted the role implementation process for 8 months, when production manager decided to interrupt the project.

Data Collection Phases

The focus company began implementing Kanban in 2012, after its directors set a target to reduced stock levels. Therefore, Lean philosophy as well as other lean tool, such as 5S, kaizen, SMED (Single Minute Exchange of Dies), were not implemented in the company when Kanban project started.

Phase 1

As stated before, data were collected in three different moments. In the first one (kanban implementation in 2012), observation and analysis of project documents are the main sources of information. Observations were made by the author over the entire implementation process (8 months), during which they visited the company on average 4 days a week. The author followed most of the meetings and definitions of the project team, until the project was interrupted by the managers.

Moreover, the author had access and analyze all company 212 electronic documents related to this process, which consists of minutes of meetings, presentations, files in Excel, photos, records of activities, project schedule, among others. The material was content rich and it enabled the researchers to raise a large number of difficulties throughout the implementation project.

Phase 2

As the author continued to visit the company after kanban implementation was interrupted, as they were participating in other projects, they continue to observe shop floor dynamics and informally talked with employees as kanban. For them, it was a frustration the result of the implementation process and they wanted to understand the reasons behind it. They took notes of all the insights they had during this period, what consists of another important information reference for this study analysis.

Phase 3

The main source of information of this phase are semi-structured interviews. Six employees were selected based on two fundamental criteria: they should be in the organization at the time of the project and have participated directly or indirectly in the project. To these criteria was added a third one: the selected collaborators should represent the main areas related to the implementation of kanban in the organization, namely: PPC, Mini-Factory 1, Mini-Factory 2 and Mini-Factory 3. They main characteristics of each of the six employees are presented in Table 6.

The interviews were done over three weeks and lasted between 20 and 40 minutes, divided in two parts. In the first one, the authos reviewed basic question about the interviewee's profile, such as: area he was working at the time of the project time, what was his participation during the kanban project, among others. Secondly, the author talked with the interviewee about kanban and production problems, understanding why the interviewee think kanban did not work in the final mini-factories of the production chain as well as what he/she think that could have been done different.

Table 6 - Case study: interviewees' characteristics

N	Participated in the project	Area during the project	Was on a leadership position during the project
E1	Directly	Production Planning and Control	No
E2	Indirectly	Production Planning and Control	No
E3	Indirectly	Mini-factory 1	Yes
E4	Indirectly	Mini-factory 2	No
E5	Indirectly	Mini-factory 2	Yes
E6	Indirectly	Mini-factory 3	Yes

Source: Elaborated by the author.

For improving reliability, the author took notes during the interview and, at the end of it, they read them aloud in order to the interviewee confirm if the notes corresponded to what he said. In case of any inconsistence, the researchers review their notes in the presence of the interviewee. All the interviews were conducted in person by the author inside a meeting room in the focus company. The interviewee received guarantee that none of his answers would be directly identified to him in any research report.

Case Insights

Analysis the information collected, it was possible to identified that while in Phase 1 the reasons behind companies' failure were obvious (e.g. card were made of a non-resistant material and employees had access to print new kanban cards without any control) or generic (e.g. production do not want to collaborate with PPC and employees do not want to follow "kanban rules"), in Phases 2 and 3 the reasons become more concrete and deep (e.g. companies priorities during the implementation was other - production volume -; employees did not understand the benefits of the new system, so they were afraid it was only a mechanism to control closer their performance; employees did not want to perform complex set ups, because their performance were mainly measured regarding daily delivered volume). Therefore, much of the case study information used in the content analysis refers to data collected in Phase 2 and 3. However, observations of Phase 1 were essential to discuss the reason provided by company's employees in deep with them.

It is also important to emphasize that hard factors, such as the suitability of the system to the environment, financial support and correct sizing the number of cards, did not contribute significantly to the failure of the process. For example, company support to system implementation with the necessary knowledge (external consultant) and money (no restriction was observed or reported).

3.2.4 Content Analysis

The 8 articles selected in the SLR and the case study information were then analyzed in order to, from difficulties and problems faces in real card-based systems implementation associated with human influence, identify soft factors critical to a successful implementation of those systems. To accomplish this task, a content analysis was conducted. This method consists in the use of techniques to clarify and systematize the content of data collected to produce knowledge (CESTARI et al., 2018), measuring variables in their natural state (NEUENDORF, 2002).

Two approaches can be used in a content analysis: closed and exploratory (CESTARI et al., 2018). In the first one, categories of analysis and classifications are pre-defined. In the second, categories are created and revised simultaneously to material analysis. In our study we the exploratory approach, as codes were not clear before the analysis of the material. Our objective is in line with Haapanen and Tapio (2016) which uses qualitative content analysis to identify central themes from a text mass.

Seeking the advantages of using a computer-assisted text analysis software, in this research we use QDA Miner 5 (WALLER; FAWCETT, 2013; GAUR; KUMAR, 2018). To code the material, we defined a procedure based on Haapanen and Tapio (2016) and Friel and Villechenon (2018). First, we evaluate if a sentence represents a difficult or problem related to human influence to implement a card-based system. If so, we tried to summarize the content in the most compact form possible without losing meaning (meaning units).

Second, we group meaning units into 14 groups, associating a soft factor with each of them. During this process, we have to condense and abstract texts further to identify the core content (HAAPANEN; TAPIO, 2016). This step was especially difficult because soft factors nomenclature varies greatly among the author. Moreover, some difficulties could be related to different factors. However, we tried to focus on the most relevant one.

It is also important to highlight that the focus of this research was mostly on manifest content, as latent content is more ambiguous and are open to multiple interpretations, what would increase the difficult of the analysis (GRANEHEIM; LUNDMAN, 2004; KRIPPENDORF, 2004). Therefore, if a soft factor is implied in an interview, but not clearly stated, it was not included as a soft factor in this study.

Finally, we also create a detailed explanation of each soft factor, following Mir et al. (2018) recommendation. The 14 factors and their meaning will be presented in Section 3.3.1, together with experts of evidences identified in the SLR and in the LCS.

3.2.5 Experts Panel

A panel with six experts were then conducted to further refine the initial proposal of 14 soft factors, as well as to increase research validity (CARDOSO; LIMA; COSTA, 2012; SHROUF; MIRAGLIOTTA, 2015). Experts were carefully selected, coming from three different areas: university (professor), manufacturers (managers) and consulting (consultants) (SILVEIRA et al., 2017). All of them have a large experience in card-based system, as a user, researcher or having participated in at least one implementation. Most of them are industrial engineers with at least ten years of experience. Details characteristics of each expert are briefly provided in Table 7.

Table 7 - Case study: experts' characteristics

Expert	Brief Description
Expert 1	Expert 1 is a university professor who has been researching in the PPC area for more than 20 years and has published more than 30 papers in important journals, many of them about PCS's. He has baccalaureate degree in industrial engineering and a doctor degree in PPC.
Expert 2	Expert 2 is a university professor who has been researching in the PPC area for more than 10 years. During his master, he studies kanban variations and its implementation in real cases. He has baccalaureate degree in industrial engineering and a doctor degree in PPC.
Expert 3	Expert 3 is a consultant of PPC with more than 30 years of experience. He has led kanban and CONWIP implementation projects in more than 10 different organizations. He has baccalaureate degree in industrial engineering a doctor degree in PPC.
Expert 4	Expert 4 is a consultant with more than 20 years of experience. He has a baccalaureate degree in management and a doctor degree in organizational culture.
Expert 5	Expert 5 work as a production planner in a multinational company and has been part of a kanban implementation project. He has a baccalaureate degree in industrial engineering and a master's degree in PPC.
Expert 6	Expert 6 work as a production supervisor in a large multinational factory and has more 20 years of experience in his position. He has a baccalaureate degree in industrial engineering.

Source: Elaborated by the author.

The panel consist of a round of individual assessment and was based on Silveira et al. (2017). First, we contacted each selected expert, explained our study and asked if he/she would like to collaborate. Secondly, we sent them a list of the factors and their definitions, as well as the pieces of evidence found in the SLR and in the LCS in order to clarify any possible doubt (Appendix B). For each soft factor, we included the following questions:

- Do you agree this is a soft factor critical for card-based system implementation? If not justify;
- Do you agree with its name? If not, what would be a better name?
- Do you agree with its description? If not, what would be a better description?

Then, we also asked a more general question to assess model completeness:

- Do you think any soft factor are missing? If so, what it would be? Give an example of it.

Three of the experts proposed the inclusion of a 15th factory (clear definition of responsibilities), which was incorporated by the author in the final list.

Seeking results convergence all answers were analyzed and factors were adjusted according to general opinion of the six specialists. Their opinion about each question of each factor was classified in: (N) No change, (R) Refinement in semantics and syntax and (C) Change in the factor focus.

This analysis is similar to the one performed by Silveira et al. (2017). However, in our study, each expert has only access to the initial proposal, but not to the opinion of others experts who had already took part in the panel. If three or more experts recommend to refined or change the factor name, the authors evaluate their justifications and together agreed to conducted changes in the factors or not. Table 8 illustrate this procedure for the second question (factor name). For the other questions, the procedure was similar.

Table 8 - Experts Panel: procedure to revise the initial proposal

Soft Factor	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Cultural change	R	C	R	C	N	N
Clear motivation to implement a card-based system	C	N	N	R	R	N
Management support	N	N	N	R	R	R
Implementation during low demand period	R	C	N	N	C	N
Conducting a pilot project	N	N	N	N	C	N
Computer and physical simulation	N	C	N	N	R	N
Employees training	N	N	N	N	N	N
Employees empowerment	N	N	N	N	N	N
Employees discipline	N	R	R	N	R	N
Employees involvement	N	N	N	N	N	N
Control the number of cards on the shop floor	N	C	N	N	C	N
Cards' material quality	N	C	N	N	C	N
Cards' information quality	N	N	N	N	R	N
Physical adaptations in the factory	N	N	N	N	C	N

(N) No change;

(R) Refinement in semantics and syntax;

(C) Change in the factor focus.

The refined list by means of expert panel (factors, their names and their definitions) will be presented in Section 3.3.2.

3.2.6 Validation with Company's Employees

After refining the list with experts, the authors returned to the company in which they had conducted the case study to present the results, evaluate if the employees agree with the result and understand if the final list miss any important information of the case study.

To perform these tasks, a session was conducted in the company's headquarters, lasting around two hours. Three of the company's employees, who were part of the six employees interviewed in phase 3 of the case study, participated in the session. They had been members of the kanban project or their jobs were directly involved with kanban activities. First, the author presented all the fifteen factors, their definitions and pieces of evidences found in the SLR and in the LCS.

Secondly, the employees had 40 minutes to analyzed if agreed with the results and if some additional information should be included. Some points were raised by the employees and discussed with the author. However, in consensus, the decided these points were already touch by some of the soft factors, so that the final list represents all the information collected in the company.

3.2.7 Validation with Company's Employees

Finally, we returned to the six experts' interviews individually to presented the final results, also looking for any missing information. The procedure was similar to the one conducted with company's employees. Some minor issues were raised and discussed, but the experts agreed the list represented all the factors the understand were important to a card-based system implementation.

3.2.8 Research Quality

According to Yin (2014), four tests are commonly used to determine the quality of an empirical social research, namely: construct validity, internal validity, external validity and reliability. In this research, construct validity is evidenced through the use of multiple sources of evidence and the review of the data obtained by the interviewees, including a final validation with company's employees.

Regarding internal validity, success stories from literature were compared with a case in which the company failed to implement a card-based system, aiming to understand the intensity each soft factor was practiced in each situation.

External validity refers to the potential for generalization of findings to other situations. In this research, only a single case was conducted. However, other cases of literature were also used in the analysis (SLR) and the soft factors proposed after the content analysis were review by a panel of experts.

Reliability is based on the research protocols for each research method used in this research, which were described in detail through section 3.2, including how data were collected. Also, it was specified in which order research methods were conducted (Figure 9).

This research also follows the eight primary strategies for qualitative research validation proposed by Creswell (2014):

- Triangulation between different data sources as well as by different research methods were used to build a chain of evidences and to converge several sources into a single's soft factors list;

- Member check, as data from interviews were confirmed by the interviewees;
- Thick description, as the context of the case study as well as the research problem is specified in detail through this paper. Also, the motivations of the main stakeholders in the LCS are described;
- The bias the research bring to this study is specified when the author mention the frequency of his visits, the fact that he continues visiting the company after the project failure and his relationship of talking freely with many members of the company;
- Negative and discrepant information are largely present in the LCS, as the kanban implementation was not successful. By presenting contradictory evidence, the research become more realistic and valid;
- Use of a prolonged time in the field to understand in-depth the phenomenon studied, as data of the LCS were collected from a period of 7 years;
- Peer debriefing strategy, as the author discuss with its peers in university the development of this research;
- Use of external auditors (panel of experts) to revise the factors proposed.

3.3 Results

3.3.1 An initial list of soft factors based on SLR and LCS

As explained in section 3.2.5, conducting a content analysis on difficulties in card-based system implementation in the 8 articles selected in the SRL and in the LCS, 14 soft factors were identified. A table with the factors names and definitions as well as excerpts identified in the SLR and in the LCS are provided in Appendix B. This appendix was sent to experts' analysis in order to refine the initial list. Below, each of the 14 factors are presented in detail.

As the case study analyzed is an unsuccessful card-based system implementation, most of its meaning units represent problems faced over the implementation and could be understand as possible reasons for the process result. On the other hand, in general literature only presents examples of good practices on card-based systems implementation. Therefore, while SLR meaning units are mostly positive, case study meaning units are mostly negatives.

Cultural change

To implement a card-based system, an organization needs to break some of its paradigms. For example, it may be necessary to reduce the level of centralization of PPC and to change focus from equipment's utilization to work in process levels. In CONWIP, for example, if the PCS works correctly, a machine would not work 100% of the time. However, in a case presented by Crop et al. (2015), employees were concerned about the underutilization of the treatment machine and violate CONWIP rules, producing without necessity (an available container and card). This attitude broke the entire logic of the system and prevents the company to achieve the expected results of CONWIP.

In the LCS, we also notice resistance to PCS's implementation. Production supervisors resisted to not controlling the scheduling of their mini-factory, as they understood this movement as a way to reduce their power in the company, increasing the importance of PPC department. Therefore, they manipulate the cards, not respecting kanban priorities.

Clear motivation to implement a card-based system

The reasons and the expected benefits of implementing a card-based system should be clear to all employees in order to they know why the company decided to implement that systems. Krishnamurthy and Suri (2009) presents a case in which a company (AEC) knows clearly its objectives in implementing POLCA (to improve the coordination between work centers, to improve their delivery performance and to reduce the work in process inventory between operations). This, however, was not observed in the LCS. The project team reports that employees understand kanban tasks only as a way for managers controlling their performance, as managers did not communicate them the importance of that project. Therefore, the project team had to fight to employees accomplish the new tasks so that kanban works.

Management support

Managers should support the project team during the project, reinforcing their leadership. This was a big issue in the LCS, as PPC was just starting as a formal department in the organization analyzed. Manager support was insufficient and the project team was not listened by production supervisors.

Implementation during low demand period

Implementing a new tool is a risk for a company. In order to mitigate this risk, it is interesting to implement a card-based system during a low demand period, when eventual failures can be correct without affecting service level. This was done in the case presented by Prakash and Chin (2014), but not in the LCS, as kanban was implemented in a period in which production supervisors were focus on delivering higher production volume. Therefore, the first difficulties suffer during the implementation encourages employees to reduce their implementation efforts.

Conducting a pilot project

Conducting a pilot project is a way to reduce risks and to gain confidence in the new system. Therefore, it is interesting to first implement a card-based system in a small portion of the shop floor. Krishnamurthy and Suri (2009) and Papalexi, Bamford and Dehe (2016) report an increase in employee's enthusiasm and confidence in the system (POLCA and kanban, respectively) after it was implemented as a pilot. On the other hand, in the LCS, kanban was implemented in all 3 mini-factories during the same time, involving more than 100 machines. Therefore, difficulties accumulate and distrust in kanban increased up to the point the manager decided to stop the implementation.

Computer and physical simulation

Another way to gain confidence in the system is by simulating it in a computer (SLOMP; BOKHORST; GERMS, 2009) or physically (PRAKASH; CHIN, 2014). Therefore, employees and managers could literally see how it will work, answering many of their doubts. In the LCS, no simulation of kanban was conducted.

Employees training

Training is an essential step in a card-based implementation in order to employees understand system's principles and rules, as reported by success cases like Krishnamurthy and Suri (2009) and Prachař et al. (2014). In the LCS, the training of employees was very fast and superficial, raising doubts about how the system would work in practice. For example, employees returned a card from mini-factory 3 to mini-factory 1 before the reorder point because they were afraid of lack of material.

Employees empowerment

Managers should give employees autonomy to make decisions on the shop floor consistent with the card-based system being implemented. While de Vries and van der Poll (2018) report employees running cells and Kanban in self-directed teams, in the LCS employees said they felt managers did not trust them, because every day someone went to the shop floor to see if employees were doing kanban tasks correctly.

Employees discipline

Employees should follow the systems rule, regarding the difficulties it may bring. For example, in the LCS as well as in Slomp, Bokhorst and Germs (2009), it was observed difficulties in making employees follow cards' priorities when they have to make complex set ups or producing difficulties orders. Moreover, in the LCs, it was observed that employees resist sending each card to mini-factory 1 as soon as they reached the reorder point. Instead, they waited until they accumulate some cards to spend less time walking in the factory. With this attitude, while in some moments there were almost no cards in the board, suddenly there were many in the red zone, breaking kanban priorities' mechanism.

Employees involvement

Employees should be part of the implementation team and should be involved in decision-making since the beginning of the implementation process. Papalexi, Bamford and Dehe (2016) reinforces the importance of all stakeholders being involved in the implementation while de Vries and van der Poll (2018) highlights the importance of a teamwork and participation of all relevant departments in the implementation team. In the LCS, on the other hand, we observed that production members were not involved in the beginning in the project. Moreover, according to a production leader "The project had several problems and when implementation started, we (factory employees) said it would not work, but nobody listened to our opinion".

Control the number of cards on the shop flor

Considering cards were correctly size, it is important to control if they were not lost in production as they could result in a lack of material. Therefore, Prachař et al. (2014) suggest conducting regular cards inventory. In the LCS, many evidences related to this factor were observed. First, in more than one occasion we noticed employees taking kanban card home in their pocket by mistake. Therefore, the system work by a least a production shift with one less card for a given product.

Moreover, there were also problems related to excess of cards, as factory's employees had access to kanban card files. This permission was given with the aim that production could reprint some damage card. However, it was used to control the number of cards of each product in the factory, which bring no control to PPC.

Finally, factory employees made it difficult to PPC control kanban cards because they were afraid of losing their job. Therefore, they hide cards as PPC was not able to perform card inventories.

Card’s material quality

Cards must be made of resistant and durable materials, such as laminated cards (KRISHNAMURTHY; SURI, 2009). Otherwise, they could be damage and lost in production. This was observed in the LCS, as Stocks hooks rip kanban cards.

Card’s information quality

The cards must contain all the necessary information but, at the same, they should be as simple and visual as possible. Lack of information or difficulty to understand can make employees not follow the system or reduce their confidence on it. This was a positive point in the LCS, as cards layout, even though company do not use kanban system anymore, are still used in production. Moreover, employees also agreed that the layout was very good.

Physical adaptations in the factory

Changes in the shop floor may be necessary to facilitate card-based system operation (e.g. layout changes and purchase of boards and containers). In the LCS, it was observed that containers size was not adequate to kanban cards quantity. Therefore, usually, more material was delivered than the amount requested. Moreover, employees need to walk on one side of the shelves to check if the stock was empty and then walk on the other side to remove the necessary cards.

3.3.2 Refining the list by means of expert panel

After analyzing the opinion of the six experts, the initial list of final soft factors was refined into Table 9. From the initial list, some modification occurred in five factors, either in the name other in the definition. Moreover, another factor was included in the list “Clear definition of responsibilities”.

Regarding the changes performed, Cultural change became Paradigms change. Four specialists recommend some modification in the name of this factor. One of them argued that the factor did not represent all the organizational cultural dimensional, according to Hofstede (1980). Therefore, cultural was replaced by paradigms. Moreover, we also decided to soften part of description replacing “to break some of its paradigms” by "to be able to rethink some of its paradigms".

Table 9 – Soft factors list refined by experts

N	Soft Factor	Definition
1	Paradigms change	The organization needs to be able to rethink some of its paradigms to implement a card-based system (e.g.it may be necessary to change focus on equipaments utilization and to reduce PPC centralization).
2	Clear motivation and implement a card-based system	It should be clear to managers and employees what goals the organization seeks to achieve with the implementation of a specific card-based system as well as the expected benefits.
3	Top management support	Managers and executives must support the project team, giving them autonomy to make decisions.
4	Implementation during low demand period	During a low demand period, failures in the system can be corrected without affecting service level.
5	Conducting a pilot project	Implementing the selected card-based system in only a small portion of the shop floor is essential for employees and managers to gain confidence in the system. The pilot project also allows an apprenticeship that can be used to continue the deployment in the rest of the operation
6	Computer and physical simulation	Simulation is a cheap way to test a system under specific conditions on the shop floor, bringing confidence to managers and employees.
7	Employees training	Training of employees is essential so that they understand principles and rules of the card-based system being implementated.
8	Employees empowerment	Employees must have autonomy to make decisions on the shop floor consistent with the card-baserd system being implemented.
9	Employees discipline and commitment	Employees must follow all the rules of the implemented card-based system regardless of the difficulties these rules may bring, such as complex set ups.
10	Employees involvement	Employees should be part of the implementation team and should be involved in decision-making since the beginning of the implementation process.
11	Control the number of cards on the shop floor	Considering an adequate number of cards where size, is important to control those cards in the shop floor in order to reprint lost cards as well as to remove cards when necessary.
12	Cards' material quality	Cards must be made of resistant and durable materials.
13	Cards' information quality	Cards must transmit all the necessary information to employees being as simple and visual as possible.
14	Physical adaptations in the factory	Changes in the shop floor may be necessary to facilitate card-based system operation (e.g. layout changes and purchase of boards and containers).
15	Clear definition of responsabilities	Each member of the project or sponsor need to know what their responsibilities are as well as what are the responsibilities of the other members.

Source: Elaborated by the author.

In the second factor's definition, it was highlighted that it should not only be clear what are the organization goals but also the expected benefits from achieving these goals, as the benefits can also be a source of motivation for a company to implement a card-based system.

In the third factor, name and definition were modified to emphasize that top management support is essential to implementation success together with medium management support. Moreover, four of the six specialists recommend excluding the following extract “giving them autonomy to make decisions", because they understood this extract is part of another factor (employees empowerment). Following their recommendation, we eliminated this extract of the factor definition.

Regarding the fifth factor (Conduction a pilot project), the following phrase was added in the definition “The pilot project also allows an apprenticeship that can be used to continue the deployment in the rest”. This phrase was suggested by one of the specialists and reinforces the factor objective of gaining experience and practical knowledge from implementing a card-based system in each part of the shop floor.

Finally, also modifications occurred in the ninth factor (Employees discipline). First, commitment was added together with discipline in the factor name. Because employees should not only respect the rules, be understand why they need to follow them in order to the system works as planned.

Moreover, an additional factor was included in the soft factors list. This factor was recommended by three specialists who argued that each member of the project or sponsor need to know what their responsibilities are as well as what are the responsibilities of the other members. Otherwise, for each new task, the project team will have to discuss who will perform it. This occurred in the organization focus of the case study, as it was not clear what tasks are responsibilities of the production department and what are of the PPC. Therefore, some tasks were not performed while others received attention.

3.4 Discussion

3.4.1 Findings

The proposed factors can be divided into two large groups. The first one contains classic management factors, which were already presented by other authors such as Hu et al. (2015), Netland (2016) and Knol et al. (2018) (Table 10). The literature about these factors is extensive as they are critical to the implementation of any tool.

A second group includes 3 factors relevant specifically to the implementation of card-based system. They involve unique features of card-based systems, in particular card-related elements (factors 11, 12 and 13). Although empirical studies sometimes cite or present the importance of one or more of these factors, to our knowledge, there was not a single list containing all factors. Therefore, the importance of this study.

Table 10 – Comparison between card-based systems and Lean soft factors

N	Soft factor proposed	Specif for card-based systems
1	Paradigms change	No
2	Clear motivation to implement a card-based system	No
3	Top management support	No
4	Implementation during low demand period	No
5	Conducting a pilot project	No
6	Computer and physical simulation	No
7	Employees training	No
8	Employees empowerment	No
9	Employees discipline and commitment	No
10	Employees involvement	No
11	Control the number of cards on the shop floor	Yes
12	Cards' material quality	Yes
13	Cards' information quality	Yes
14	Physical adaptations in the factory	No
15	Clear definition of responsabilities	No

Source: Elaborated by the author.

Among the proposed factors, three of them were found only in the LCS, that is, no article among those selected in the SLR referred to this factor. The first is factor 3 (top management support), which we suspect employees are afraid to criticize their bosses, especially senior management, to outside researchers. In the case study, however, it was possible to identify this factor because through the seven years of data collection the researcher became really closed to company's employees.

The second factor, card's information quality (factor 13), although not identified in the studies selected in the SLR, presents vast material in the literature (e.g., SERRATO, 2016). Therefore, it does not present a different result from literature.

Finally, factor 14 (physical adaptations in the factory) presents physical difficulties for the system to function as intended. The fact that SLR studies do not present this factor may be related to the fact that it is directly related to the implementation project team. Therefore, it may be easier to attribute difficulties to more generic groups, such as the entire organizations (e.g., factors 1, 2 and 3) or employees (e.g., factors 7, 8, 9 and 10) than to a specific group involved in the project.

Factor 15 (clear definition of responsibilities) included by the panel of specialists is also a classic management factor. Its addition reinforces the implementation project planning, given the high complexity and the need for task division. This factor was observed in the SLR and in the LCS, but in the author view when performing the content analysis, it was already touched by factor 3 (top management supported). After the position of the specialist, the author decided to revise their opinion and include it as a new factor.

3.4.2 Propositions

Given the LCS observations, the result of the final list of soft factors and the discussions previously presented, three propositions are formulated.

P1: Card-based systems are largely influenced by humans so that soft factors are critical to implementation success of those systems.

Many tasks in a card-based system are performed by shop floor employees, such as moving cards from one place to the other when a certain situation occurs (e.g., reorder pointing) and starting production only when some conditions occur (e.g., there is an available container and an available card) (SPEARMAN; WOODRUFF; HOPP, 1990; SURI, 1998; THÜRER; LAND; STEVENSON, 2014). This situation is different from computerized systems, such as MRP, when most of the tasks are centralized and performed by computer algorithms. Therefore, it can be argued that there is a great human influence on card-based systems and understand how to motivate and engage employees (soft factors) are critical to success in implanting those systems (SALEM et al., 2006; LIU; HUANG; 2009).

In the LCS, it was observed that employees were afraid of kanban implementation, as they understood it only as a way for managers controlling their performance because of problems in communicating employees the motivation of the company to implement kanban. Therefore, they resist to its implementation.

Another example, also observed in the LCS, is that employees took kanban card home in their pocket by mistake. These affects all the systems as the number of cards of a given item is a fundamental parameter for kanban operation. Therefore, controlling the number of cards and employees' discipline are fundamental factors for kanban successful implementation.

P2: Soft factors for card-based systems implementation involve classic management factors and specific factors (e.g., card's information quality).

Many studies proposed soft factors for the implementation of a given tool. Some of those factors are generic and could be applied to basically tool, such as management support, employee's involvement and communication (HU et al., 2015; NETLAND, 2016; AZYAN; PULAKANAM; PONS, 2017; KNOL et al., 2018). However, there are also specific factors, which had been rarely studied in the context of card-based system (PONS, 2010). Therefore, in this studied three specific factors are proposed: control the number of cards on the shop floor, card's material quality and card's information quality. Although not sophisticated, these factors can have a great negative impact on a card-based system operation.

Card’s material quality is important because first it reduces the probability of card’s damage and lost, helping in the control of the number of cards in the shop floor. Secondly, it gives importance to the system in the shop floor, showing the system will be operating for a long time, as cards are not temporary.

Moreover, card’s information quality, containing all the information in a simple way, is essential to employee’s involvement in the system, as they first need to understand the system (and specially the cards) to then perform their tasks correctly.

P3: Soft factors for card-based systems implementation involve factors at the organization level, at the implementation group level and at the individual level.

Following Blakeney (1983) analysis of organizational behavior, the factors proposed can be classified into three groups. The first one includes factors that involves the whole organization. For example, paradigms change and clear motivation to implement a card-based system (factors 1 and 2). Moreover, all the organization employee’s need to trust in the system being implement. Therefore, factors 4 and 5 are also part of this group. Furthermore, employees not involved in the project will primarily evaluate its physical parts. Therefore, we also included factors 11, 12, 13 and 14 in the organization level.

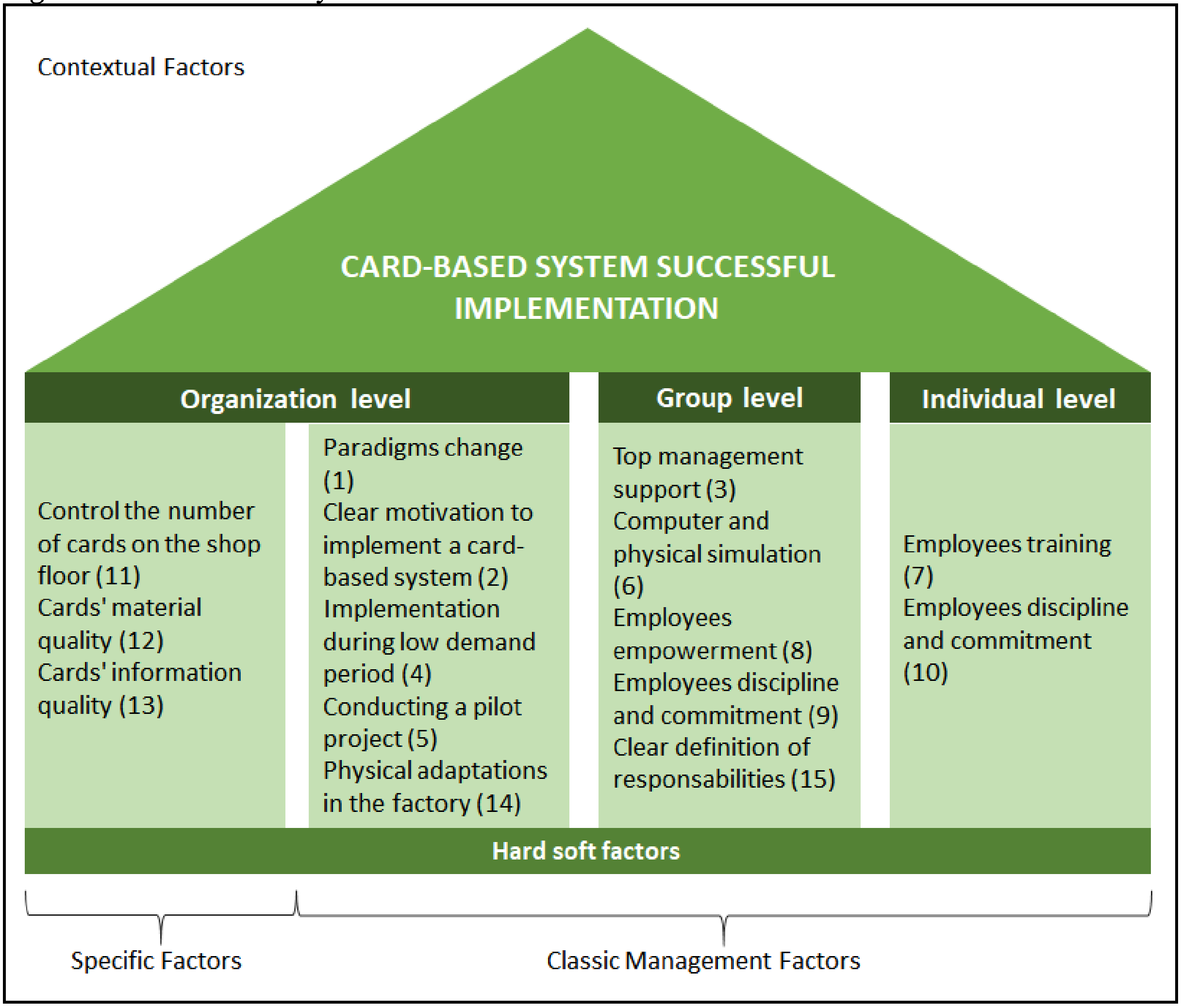
The second level is the implementation group, which includes all the employees involved during the planning and execution of the project. For this group, the support of top management is essential (factors 3), so that they will have the necessary resources to the project as well as the importance of the project will be highlighted to the entire organization. Simulation of the system is also important to refine concepts as well as to test alternative solutions (factor 6). Note that we considered this factor at the group level as its primarily objective is not to gain confidence in the system as factor 5, but to understand and adapt it to the organization’s contextual factors. Empowerment (factor 8) is essential for speeding decision-making and for formalizing group authority in the project. Involving employees in the project group removes barriers and resistance to the project and the changes necessary to be made in the organization. In addition, factor 15 (to clearly define the responsibilities during the implementation) is also at this level.

The third level involves factors that are important at the individual level. In this paper, individuals are all people who participate in the implementation project. First of all, they need training (factor 7) to understand the system and what need to be done to implement it. Secondly, employees’ discipline and commitment to the project is essential for its success.

3.4.3 Card-based soft factors house

Following propositions 2 and 3 classifications, we constructed Figure 21 which summarizes this paper results. As "houses" are used in the literature for many different topics (e.g., Lean house), we proposed a card-based system's soft factors house. Hard factors are the basis of our house, because without the necessary investment and resources (in general), soft factors will not be sufficient for successful implementation.

Figure 21 – Card-based systems' soft factors house



Source: Elaborated by the author.

The house has four pillars. The first one involves factors specific of card-based systems and are the main contribution of this paper. All of those factors are classified in the organization level. The other factors are placed on their level (organizational, group and individual) as explained in proposition 3.

The house is surrounded by contextual factors, which need to be understood to adapt the system and the way it will be implement to specific characteristics of the organization.

3.5 Conclusions and Research Agenda

3.5.1 Conclusions

As there is a strong human influence on card-based systems, understand which soft factors are critical to the success in implementing those systems is essential. Through a combination of research methods, this paper proposes a list of 15 soft factors. The list involves classic management factors (e.g. Lean approach - top management support, employee's empowerment and paradigms change) as well as factors specific to card-based systems (e.g. cards' information quality, card's material quality and control the number of cards on the shop floor). The factors proposed are generic, so additional factors can be included due to contextual variables and conditions specific to the environment studied.

For literature, this paper contributes by highlighting the importance of human factors in the implementation of card-based systems, by identified specific soft factors critical to card-based systems implementation and by presenting a case of failure in the implementation of kanban, something unique given that most studies report only success stories. In addition, we aim to ask for more research in this topic with reduced work in the literature.

For practice, the proposed list aims to increase empirical success in the implementation of card-based system. Therefore, a larger number of empirical works on this subject is expected, given the reduced number of articles reporting empirical cases of PCS's, especially the most recent ones (Chapter 2).

3.5.2 Limitations and Research Agenda

A major limitation of our study is that only a single case was conducted. However, due to the longtime of data collection (7 years), it was not feasible to conducted more than one case with the same depth level. In our view, reducing data collection time or the number of data sources would not provide the information necessary to propose the chapter's final list. Moreover, the reduce literature about PCS's soft factors did not provided substantial elements to compare or discuss the findings of these articles. Therefore, we expect future studies enhance this paper analyzing and refining our proposed listed in different card-based production environments.

As a research agenda, we proposed to answer the questions presented in Table 11.

Table 11 –Research Agenda

Question	Possible Methods and Brief Explanation
What is the result of a card-based systems implementation that followed all the 15th soft factors proposed in this paper?	Action research, case study or design science reporting an empirical implementation study
How do the proposed factors related among themselves? Are some factors more important than others are?	Surveys correlating the factors
How do contextual variables affect the importance of each factor?	Surveys correlating the factors and some contextual variables
What other factors can be added to this list?	Professional opinions, panel of specialists, case studies, actions research, among others
Is any of the 15th factors proposed specific to a certain environment or production characteristics?	Surveys, case studies or panel of specialists with companies in different industries
How soft factors related to hard factors in the specific context of card-based systems implementation?	Action research, case studies or surveys correlating these two group of factors
Does all the soft factors have the same level of importance to all card-based systems?	Surveys or case studies comparing the results obtaing in different systems, such as Kanban, CONWIP and POLCA
Whar are the soft factors for PCS's not based on cards? Which of those factors is similar among card and non-card based systems?	Longitudinal case studies analysing the implementation of non card-based systems empirically.

Source: Elaborated by the author.

4 CONCLUSIONS

Although PCS is considered a mature topic in literature, in this dissertation two gaps were identified. First, although there is a large literature available about classical PCS's (e.g., MRP and kanban), few papers address new systems, that is, the PCS's developed after the emerge of POLCA in 1998. Moreover, to the best of our knowledge, there is no paper that systematically review all the systems developed between 1999 e 2008. Therefore, in Chapter 2 of this dissertation, an SLR was conducted, identifying 13 PCS's and briefly describing their key characteristics, mechanisms, environment in which they are adequate and research stages.

Among those 13 PCS's, seven have WIP as primary control variable, are designed for flow shop environments and are card-based. Those characteristics are also shared by kanban and CONWIP, two of the most important PCS based on Lean approach, which focus on tool's simplicity and on the importance of people, making the system easy to be implemented. However, it was also observed that many new PCS were developed from simulation studies and lack empirical results, distancing theory from practice. Therefore, two contrary movements are occurring at the same time, making PCS's simpler to be implemented, but lacking studies to test the effective of those systems in practice.

Therefore, as many of the new system as well as important classify PCS's are card-based, a second research gap was identified. While many papers deal with many mathematical paper approaches to optimize the parameters of each system, few papers deal with soft factors (human influence) related to the implementation of those systems. Human influence on card-based systems is key, as many tasks of those systems are performed by shop floor employees.

To the best of our knowledge, there is no list of specific soft factors for the implementation of card-based systems. Therefore, in Chapter 3, we proposed this list through a content analysis of implementation problems found in empirical articles as well as in the information collected in a longitudinal case study. This list involves classic management factors as well as specific card-based systems factors. Moreover, factors are generic, so additional factors can be included due to contextual variables and conditions specific to the environment studied.

As final results of this dissertation, in terms of literature, we seek to:

- Highlight the existence of alternative PCS's to the classic and commonly studied in undergraduate courses systems;
- Encourage further studies about new PCS's;
- Highlight the importance of soft factors in card-based systems implementation.

In terms of practice, we seek to:

- Increase the repertoire of PCS’s known by managers and the possibility of implementing systems more specific for each productive environment;
- Increase the success in implementing card-based systems.

For future studies, in Chapter 2, we proposed a research agenda for PCS's which involves implementation studies as well as the relationship of PCS with other recent topics, such as Industry 4.0, Sustainability and Circular Economy. To this list, we also suggest empirical implementation studies to verify the adherence of the proposed list to different environments. In addition, surveys could be conducted to correlate the factors and assign their importance as a function of contextual variables.

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APPENDIX A – CASE STUDY RESEARCH PROTOCOL

Research question	What difficulties related to human aspects did the select case (company) faced to implement a card-based system?
Unit of analysis	Initiative to implement a card-based system
Organisation	High diversity consumer goods manufacturer which tried to implemented kanban on the three final-minifactories of its production chain
Timeline	2012 to 2019
Data sources	Phase 1: Direct Observation and Project Files; Phase 2: Direct Observation and Informal Interviews; Phase 3: Semi-structured interviews.
Examples of Key issues	Why the employees thinking the initiative was not well success? What they think the company could have done differently? Do managers support the initiative? Do managers share with employees the reason to implement kanban? Were the employees involved in the initiative?

APPENDIX B – INITIAL LIST OF FACTORS ANALYZED BY THE EXPERTS

Soft Factor	Definition	Excerpts from systematic literature review	Excerpts from case study
Cultural change	The organization needs to break some of its paradigms to implement a card-based system (e.g.it may be necessary to change focus on equipaments utilization and to reduce PPC centralization).	"If the ConWIP process is executed correctly, the following week's schedule for the treatment machine appears empty. As a result, forgetting about the ConWIP process, MDs sometimes became concerned about underutilization. This resulted in MD's violating the ConWIP rules and setting too many CT appointments for new patients outside of the system. The end result was an overflow of patients between the CT and treatment steps [...]" (CROP et al., 2015).	Each production supervisor wanted to continue controlling the scheduling of his mini-factory, resisting to kanban introduction
Clear motivation to implement a card-based system	It should be clear to managers and employees what goals the organization seeks to achieve with the implementation of a specific card-based system.	" [...] AEC wanted to implement POLCA in order to improve the coordination between work centres, improve their delivery performance, and reduce the work in process inventory between operations" (KRISHNAMURTHY; SURI, 2009).	"The manager didn't communicate the importance of the project to factory employees. We (project team) had to fight to employees accomplish the new tasks so that kanban works"
			"All employees were trained to operate kanban, but they understood the new tasks they need to perform only as a way for managers controlling their performance"
Management support	Managers must support the project team.		Production department was stronger than the PPC at 2012, as PPC was starting at that time as a formal department in the organization. Without the manager's support, the PPC was not listened by production supervisors
Implementation during low demand period	During a low demand period, failures in the system can be corrected without affecting service level.	"The implementation is purposely planned on a low demand season to ensure the allocation of sufficient time for production readjustment during unforeseen events" (PRAKASH; CHIN, 2014).	"The factory priority at 2012 was not that (to implement kanban). The supervisors focus was to deliver a higher production volume."

Soft Factor	Definition	Excerpts from systematic literature review	Excerpts from case study
Conducting a pilot project	Implementing the selected card-based system in only a small portion of the shop floor is essential for employees and managers to gain confidence in the system.	"Interestingly, after the introduction of the pilot kanban project, the employees were very positive and appreciated the results. A technician characteristically said: 'we could not imagine that a better management of our stock could save this amount of money'" (PAPALEXI; BAMFORD; DEHE, 2016).	Kanban was implemented in all the three mini factories at the same time. The implementation team was not able to deal with all the process happening in the factory.
		"The success of POLCA implementation in one area of the facility increased the enthusiasm for implementation in other areas of the facility and extending POLCA to other areas is being considered" (KRISHNAMURTHY; SURI, 2009).	
Computer and physical simulation	Simulation is a cheap way to test a system under specific conditions on the shop floor, bringing confidence to managers and employees.	"[...] since not everyone involved fully understood the proposed system – it was met with some skepticism from supervisors and planners – we developed a game to give an insight into the basic workings of the system" (SLOMP; BOKHORST; GERMS, 2009).	No simulation was conducted to employees understand how the system would work.
		"A manual simulation activity for operators enables a hands-on experience on the flow of cards and their effects on running individual processes. In manual simulation, a layout of the shop floor and respective locations of the kanban boards are projected onto a large whiteboard. Markers that represent each set are positioned according to the actual quantity and position for a given day" (PRAKASH; CHIN, 2014).	
Employees training	Training of employees is essential so that they understand principles and rules of the card-based system being implemented.	"Prior to launching the POLCA system, the team conducted training sessions for all the personnel who would be affected" (KRISHNAMURTHY; SURI, 2009).	The training of employees was very fast and superficial, raising doubts about how the system would work in practice.
		"[...] we propose that all employees who work with the system Kanban should attend at training to know the main principles of Kanban" (PRACHAŘ et al., 2014).	Employees returned a card to mini-factory 1 before the reorder point because they were afraid of lack of material.

Soft Factor	Definition	Excerpts from systematic literature review	Excerpts from case study
Employees empowerment	Employees must have autonomy to make decisions on the shop floor consistent with the card-based system being implemented.	"Workers are empowered through multi-skilling and to run cells and Kanbans in self-directed teams" (DE VRIES; VAN DER POLL, 2018).	"Every day someone came to the shop floor to check if we were doing kanban tasks correctly. [...] We felt that they (managers) did not trust us."
Employees discipline	Employees must follow all the rules of the implemented card-based system regardless of the difficulties these rules may bring, such as complex set ups.	"Workers are stimulated to work on the right orders; they cannot ignore tedious or difficult orders anymore [...]" (SLOMP; BOKHORST; GERMS, 2009)	Employees chose the next card to be processed according to the set up time, not respecting kanban priorities.
			Employees wait until they accumulate some cards to only them return the cards to the mini-factory 1. Therefore, it was observed that in some moments there were almost no cards in mini-factory 1 board, but on others there were several cards in the red zone. This situation gerenerates great discomfort between the mini-factories.
Employees involvement	Employees should be part of the implementation team and should be involved in decision-making since the beginning of the implementation process.	"The successful implementation of the kanban system requires the participation of all stakeholders involved in the supply chain." (PAPALEXI; BAMFORD; DEHE, 2016)	"The project had several problems and when implementation started, we (factory employees) said it would not work, but nobody listened to our opinion"
		"Teamwork in all areas has led to active and focused participation by team members. Permanent teams of the organisational development team of the organisation assist the departmental teams and the flow-line teams (mini-business teams) to improve and sustain the Lean process [...]." (DE VRIES; VAN DER POLL, 2018)	"The lack of production members in the project team was, in my view, key to the not successful implementation of kanban"

Soft Factor	Definition	Excerpts from systematic literature review	Excerpts from case study
Control the number of cards on the shop floor	Considering an adequate number of cards where size, is important to control those cards in the shop floor in order to reprint lost cards as well as to remove cards when necessary.	"It is also important that staff is aware that any mistake or loss of Kanban cards can endanger the continuity of material flow and supply of materials to the customer. To prevent this it is proposed implementing the inventory control of Kanban cards in circulation, either single inventory requiring stopping the material flow or continuous control, when the number of Kanban cards in circulation is controlled using the identification numbers of each Kanban card" (PRACHAŘ et al., 2014).	Employees take kanban card home in their pocket by mistake.
			Factory employees had access to kanban card file and could print new cards, although PPC had the responsibility of sizing the correct number of cards for each production mix and volume.
			Factory employees made it difficult to PPC control kanban cards because they were afraid of losing their job.
Cards' material quality	Cards must be made of resistant and durable materials.	"The POLCA cards were made out of laminated cards" (KRISHNAMURTHY; SURI, 2009).	Stocks hooks rip kanban cards.
Cards' information quality	Cards must transmit all the necessary information to employees being as simple and visual as possible.		Despite the project failure, employees agree that kanban cards contain in a simple way all the necessary information.
			After 7 years of the failure implementation, kanban cards layout is still the same as the project proposal.
Physical adaptations in the factory	Changes in the shop floor may be necessary to facilitate card-based system operation (e.g. layout changes and purchase of boards and containers).		Containers size were not adequate to kanban cards quantity. Therefore, usually, more material was delivered than the amount requested.
			Employees need to walk on one side of the shelves to check if the stock was empty and then walk on the other side to remove the necessary cards.