Professional MBA
Automotive Industry

IDENTIFICATION OF AN APPROPRIATE METHOD FOR PRODUCTION PLANNING AND CONTROL SUITABLE FOR MAKE-TO-ORDER ENVIRONMENTS WITHIN SMALL & MEDIUM SIZED ENTERPRISES

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
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Vienna, 20.04.2020

Affidavit

I, **ING. LUKAS MIKLUSAK**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IDENTIFICATION OF AN APPROPRIATE METHOD FOR PRODUCTION PLANNING AND CONTROL SUITABLE FOR MAKE-TO-ORDER ENVIRONMENTS WITHIN SMALL & MEDIUM SIZED ENTERPRISES", 103 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 20.04.2020

Signature

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List of Abbreviations

MTO – Make to Order

MTS – Make to Stock

PPC – Production Planning and Control

BOM – Bill of Material

MRP – Material Requirements Planning

MRP II – Material Resource Planning

ERP – Enterprise Resource Planning

KANBAN – Scheduling system for lean manufacturing

CONWIP – Constant Work in Process

DBR – Drum Buffer Rope

S-DBR – Simplified Drum Buffer Rope

POLCA – Paired Overlapping Loop of Cards

WLC – Workload Control

TOC – Theory of Constrains

HVLV – High Variety Low Volume

ETO – Engineer to Order

SME – Small Medium Enterprise

RBC – Repeat Business Customizers

VMC – Versatile Manufacturing Companies

WIP – Work in Progress

VSM – Value Stream Mapping

CODP – Customer Order Decoupling Point

DD – Delivery Date

FIFO – First in First Out

APS – Advanced Planning System

SFTT – Shop Floor Throughput Times

PFS – Pure Flow Shop

GFS – General Flow Shop

GJS – General Job Shop

PJS – Pure Job Shop

CV – Coefficient of Variation

ROP – Reorder Point

DDP – Delivery Date Performance

SFTT – Shop Floor Throughput Time

SMED – Single-Minute Exchange of Die

5S – Five Sigma - Method for standardization of the workplace

MBA – Master Business Administration

APS – Advanced Planning and Scheduling

POKA YOKE – error proofing

POOGI – Process Ongoing Improvement

CNC – Computer Numerical Control

CCR – Capacity Constrained Resource

HL – High Level

LUMS – Lancaster University Management School

CEM – Customer Enquiry Management

PRT – Production Resource Tool

COR Corrected Order Release

IT – Information Technology

VAR – Coefficient of Variation

LT – Lead Time

DT – Delivery Time

QT – Queue Time

BRT – Batch Run Time

COT – Changeover Time

EPE – Every Product Every

PRONS – positive points

CONS – negative points

e.g. – for example

Abstract

Purpose: Main reason for this master thesis is research to define and select convenient method related with Production Planning and Control (PPC) for facilities based on Make to Order (MTO) for a Small Medium Enterprise (SME) with use reviewed theoretical methods. The goal was to increase flexibility and performance of a company towards the customer.

In today environment customers every day expect customized products in short lead time, with high quality and of course with competitive price. At first the problems had to be investigated and conducted a literature review where I identified the issues related of production planning and control. The identified issues cause problems for producers, since they are not able to produce such products in high volume of customized parts.

Despite that, the selection of an appropriate production planning and control is not simple choice, because many options are offered on the market. Due to the various environmental attributes, PPC methods is compared how they carry out in the contrasting version. Following main PPC methods has been evaluated: S-DBR (Simplified Drum Buffer Rope), KANBAN (It is a scheduling system for lean manufacturing.), CONWIP (Constant Work In Process), DBR (Drum Buffer Rope), POLCA (Paired Overlapping Loop of Cards) and WLC (Workload Control). The production planning and control methods have been described how they are behaving in various frameworks concerning to the manufacturing attributes, and what these methods can support better results for key indicators defined in facility based on Make to Order and how to be more competitive on the global market. Master thesis shows, that S-DBR is highly recommended for companies that would like to reach high due date performance (DDP).

Findings: The author identified PPC method, that is suitable for application in SMEs environment for an MTO manufacturing. The paper also informs about the implementation process of S-DBR and how can such simple PPC method improve performance of company in real case.

Added value: The main added value of the mater thesis is ensuring improvement of performance companies through right selection PPC method and its application into SMEs environment which is part of MTO manufacturing.

Keywords: Production planning and control (PPC), KANBAN, CONWIP (Constant Work In Process), WLC (Workload Control), POLCA (Paired cell Overlapping Loops of Cards with Authorization), DBR (Drum Buffer Rope), S-DBR (Simplified Drum Buffer Rope), TOC (Theory of Constrains), MTO (Make to Order), HVLV (High Variety Low Volume), Job-shop,

1. Introduction

1. 1. Background

This master thesis was executed to research the chance to get better production planning and control and improve performance of enterprises in Make to Order environment. This research should have positive impact to decrease internal lead times of jobs completion and increase on time delivery of customer orders.

Today customers call offs with demanding level of custom-made products, which are in line with their expectations that production to be in low volumes and high diversity of products. If manufacturing company has very fast response on the customer orders, so this firm is become more competitive on the market. It was written by Suri (1998), that customers' demands fluctuate daily and it is in such MTO environment unforeseeable. Mentioned circumstances screw makers to become everyday better to forecast customer call offs and be in line with them. Consequence of the customer requests for custom make products is that the number of products are produced within the identical product platform is getting bigger and bigger. This make more difficult production environments.

Mandatory is customer satisfaction, which must be with compliance with customer requirements and due to fact, various production systems have been needed to develop (Browne et al. 1981). One of the four main production frameworks (Figure 1) job shop production has been described by Kumar (2008). Job shop works with high level of custom-made products. The main concept of job-shop production was designed and executed by Browne et al. (1981). The job shop is a flexible system which main purpose is to handle fluctuating customer demands and requirements. As was written by Muda (2011) the Make to Order manufacturing with job shop system of work is dealing with increased requirements on complex customized products. The most sufficient production organization for Make to Order and job-shop environments is production organization which will immediately launch manufacturing process after reception of purchased order. Also, it is organization which allow to easy select type of product and design of product to fulfil customer specific requirements. Such manufacturing organizations is best fit for MTO and job-shop environment (Muda, 2011).

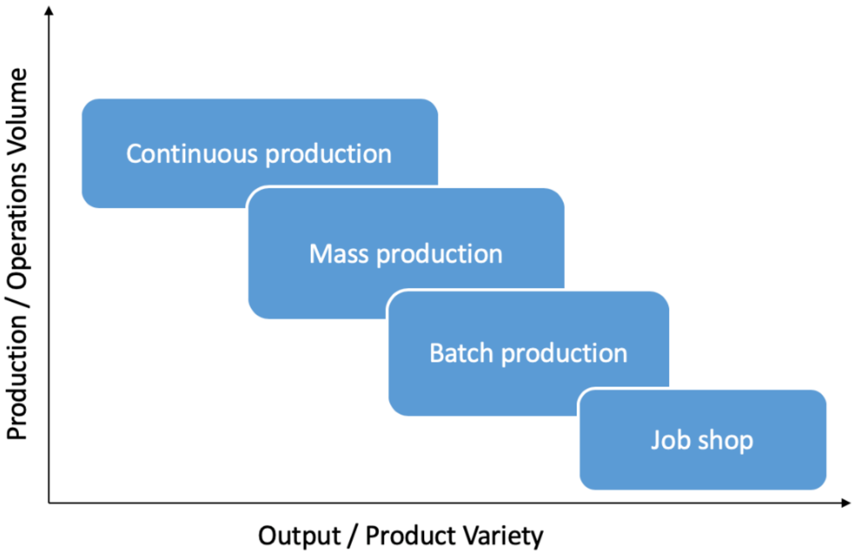


Figure 1: Classification of production framework (Kumar and Suresh, 2008)

According to Suri (2009), customer also anticipate that product must be delivered on time within the short period of time after reception of purchase order to the supplier and customer on top of that expect the best quality standards. Wiendahl (1995) wrote, that producer must be competitive and ensure production and delivery of product very fast, with intention decrease of lead time (LT). To get order from protentional customer, supplier must be the best in following attributes like competitive prices, high due date adherence and confirm top quality of delivered products (Hendry et al. 1993).

Complexity of production planning with along the control different operations processes in MTO and job-shop shop floor environments is very high, even though customer's specific requirements are fulfilled. Browne et al., (1981) also written, that previously mentioned approaches influence overall lead time of product. Effect of high demand with steady flow of material processing is inclining to the increased overall lead time of manufacturing process of each job-shop environment (Bennet, 2006). Main attributes which are influencing demand variability are time, quantity and product customization. In mentioned type of manufacturing environment custom made products to get decreased lead time is not easy to reach with comparison of high flow of material processing. It is assembly line process.

Reduction of lead time is crucial aspect to be competitive in the manufacturing market where SMEs placed are. It helps to each company to meet customer expectation, what is shortest lead time and be on time with delivery of final product. (Hopp et. al., 1990). According previously mentioned sentences can be concluded that production planning and control method is very important for manufacturing companies. Also, with finding improvements how to decrease lead time to tend be successful and competitive on the market. Altogether can be summarized of importance those facts and can be expressed research problem within Make to Order and job-shop environments.

1. 2. Problem definition

Scope of concern is MTO and job-shop manufacturing frameworks like a production system. Arisha et al. (2001) wrote, that production planning and control method in MTO and job-shop manufacturing contain an upper level of difficulty. Outcome of this is very long planning time. That is clear cause why production planning time takes so much time. There is no completely clear process step at the point of reception of purchase order from customer, because routing is not properly defined. Accordingly, there is complexity coming from quantities of parts in the Bill of Material (BOM), product mix (quantity of products), and quantity of cycles within production.

It was stated by Fernandes et al. (2009), that various call offs requirements coming from customers are causing main difficulty in the production planning of manufacturing along with keep under control of inventory stock of raw materials and stock of final products.

Paulo (2007) says, that is important to have under control all steps of reception of purchase orders, from order confirmation, order release into production process and order dispatch towards final customer. According his research it is not controlled through checking points. It means, that salaried workers do not know where purchase order from customer is and if the purchase order up to the present time stick to approved due date. In accordance of Paulo (2007), the manufactures during reception of purchase order from customer check their own availability of man, machine and material and moderate due date of order. This means, that negotiated lead time is forecasted at the time of reception of order and every operation is reflected on.

The main issue was identified in time of releasing of order into the shop floor. It was the production scheduling was identified as main issue in SMEs environment, because there is difficulty with the plenty of operations, which must be done and high variety of production mix with different complexity (Arisa, 2001).

Fernandes and Carmo-Silva, (2009) investigated, that the weak point of production planning in MTO manufacturing and job shop production have trend to work with long manufacturing times. It is caused by long preparation time of technology, very long changeover time, waiting times of machine and operators and availability of tools. All these mentioned attributes have tendency to influence total lead time for final customer as have been written by Hyer and Wemmerloev (2002).

Take to the account the issues described in previous sections through the reviewed literature above, the main goal of this master thesis is improve proper utilization of machinery, increase due date adherence and decrease lateness of orders towards of customers, ensure right production planning and control of orders through shop floor. Also increase addressability of important jobs in production of shop floor. Right selection of production planning and control method in the Make to Order of Small Medium Enterprise should help to that.

1. 3. Objective and research questions

The objective of this master thesis is to identification of an appropriate method for production planning and control suitable for make to order environments within small and medium sized enterprise. Achievement of objective to be done by reviewing of literature which is available and is oriented for PPC methods and these methods can be applicable in MTO and job shop environments. It should be linked with the practice to the characterized production environment, the goal is present suitable option for production manager to reach helpful PPC process.

Under the term of method is meant, that a manager does things in the right perspective and order. The production is properly planned and controlled in order to increased productivity of man and machine, performance is right monitored with effective feedback and finally optimum level of coordination.

According to the objective, the further research questions were introduced to find out scope of focus:

- **Research questions 1 (RQ1): Which Production Planning and Control (PPC) methods are relevant for Make to Order manufacturing and job shop manufacturing?**

This question is focusing to find which methods are existing and applicable in MTO manufacturing and job shop manufacturing.

- **Research questions 2 (RQ2): Which Production Planning and Control (PPC) method is well suited for a SMEs environment with MTO manufacturing?**

  Here to be find out suitable method for MTO and job shop in SME environment, which will be reviewed and defined.

- **Research question 3 (RQ3): How should the selected method be applied within SMEs environments for MTO manufacturing?**

  The aim of this question to find solution to apply selected method in MTO manufacturing with SME environment. The case study will be main tool to do this. It is contained in the Chapter 4.

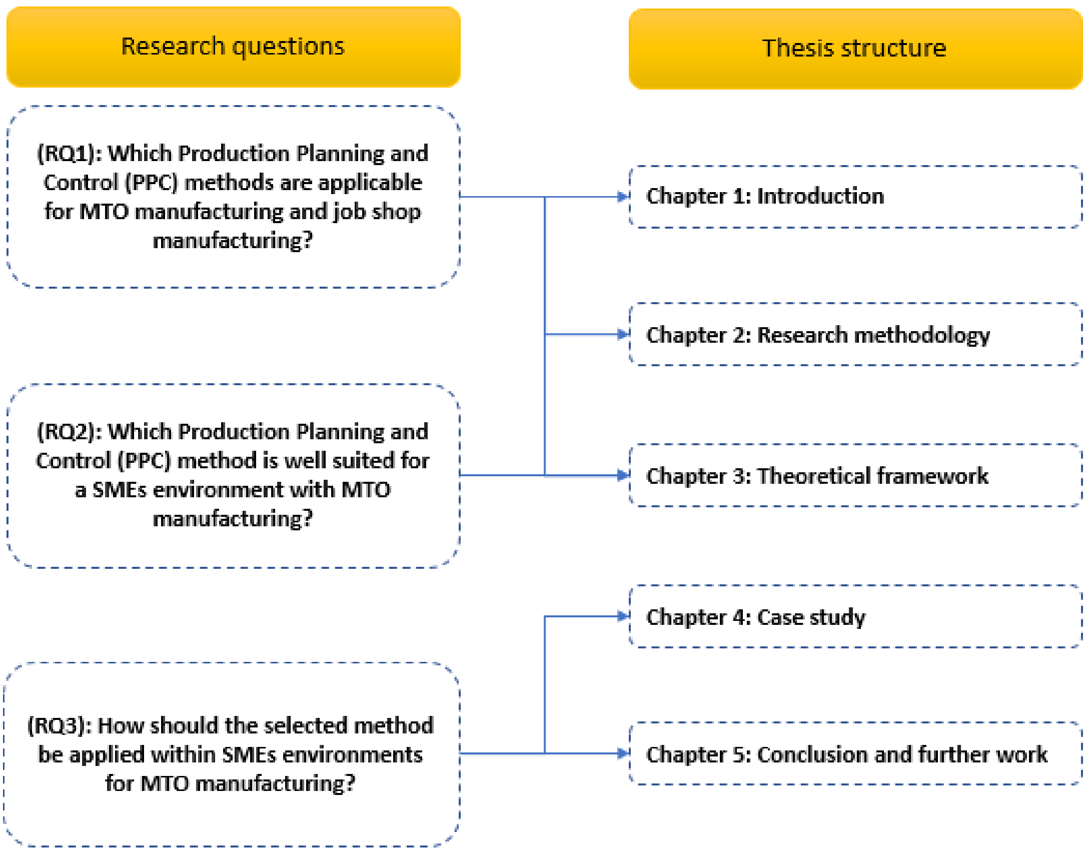


Figure 2: Relationship between research questions and thesis structure (Own work)

1. 4. Scope

Applicability of production planning and control methods in high variety and low volume manufacturing has two major area, that must be identified and mentioned:

Area 1: What and why are production planning and control methods judged?

Area 2: What are the main attributes of designated environment?

The history of production planning and control frameworks have been formulated for Make to Stock (MTS) production. The MTS production is possible in detail predict with high level of repeat. The MTS is easy to manage and monitor, but also Make to Order environment is very extremely custom-made industry (Stevenson et al., 2005).

Stevenson et al. (2005) is saying, product design should be included in the MTO environment as well and it is reflected on as a residual process of planning and control, like Engineering to Order (ETO).

1. 5. Outline

The main construction of this master thesis is introduced hereunder, and it is divided into sections with accordance:

List of abbreviations: this section presents crucial abbreviation and words, which help to reader to identify main terms and words.

Introduction: the background knowledge of the master thesis is carried through this section. Also designated week point of research and defined research issues, intend of the master thesis and research questions are designed there, in order to eliminate weak points of research. The section provides information about steps how the research effort was launched and ended.

Research methodology: is reviewed in this section, which gives to reader information about procedure how the research was treated, and which systematic methodology was used to come up to results with the purpose to get answer on created research questions. Defined research method shows also quality and reliability of defined method.

Theoretical background: in the following section is presented different theories with clarification of main parts of the past researches and theories which stick to the purpose of master thesis. First and second research question has been answered, here.

Case study: the section shows collected data, performed analysis which is needed for the conclusion. Later, the research questions are answered based on performed analysis. The section provides practical problems related to S-DBR application in SME environment. Application of S-DBR method provides answer for third research question, here.

Conclusion and further work: in the section discusses research of master thesis, research gap and collected data, which has been analysed and summarized.

Bibliography: following section provides overview of gathered articles, journals, books and other literatures.

2. Research methodology

Following chapter presented research methodology applied for case study which to be right for the master thesis. For this research methodology are used collected data based on technique suitable for achieve objectives defined for master thesis. Therefore, the chapter is splitted into three subchapters, what are: research process, research design and research quality.

2. 1. Research process

The research methodology is idea or plan how to come up with the plan to go through research work. The structure of research process guides the scientist how to treat his own research work and organize pre-established rules and processes, that help scientist to come to aim of master thesis/research work (Ghauri and Gronhaug, 2015). The systematic investigation must be performed, and the master thesis follows a process as is presented below (Figure 3):

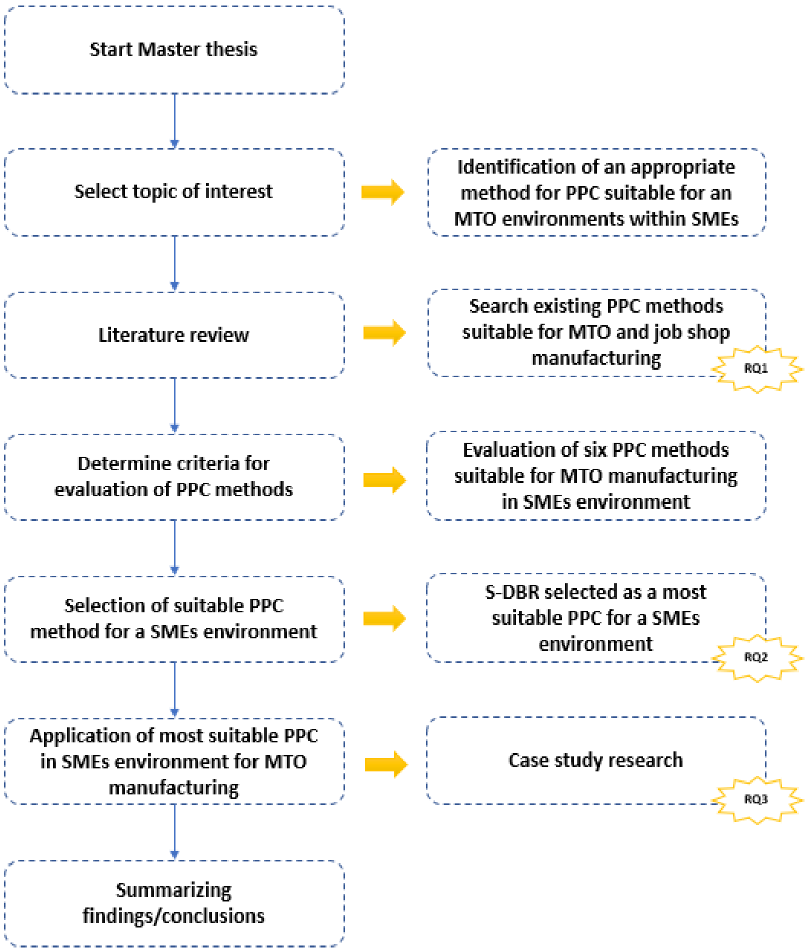


Figure 3: Graphical description of the research methodology (Own work)

The framework of theory is designed to fulfil the research and define purpose of this research. Where the major three parts of chapter are:

- **Environmental Properties:** presenting the different key characteristics of MTO industry.
- **Production approach:** presenting the explanation of current production planning approaches like pure pull, push and hybrid form.
- **Production plan and control:** presenting main tool for managing production and manufacturing of products on shop floor in small manufacturing enterprise (SME).

Based on the theories is possible to better understand the case study, objectives and purpose of master thesis. To support and satisfy the purpose of the master thesis on desired research level, a case study was selected. The procedure and research design are reviewed in the next subchapter.

2. 2. Research design

Following research work is focusing to recognize an adequate method for production planning and control suitable for MTO in SMEs environments. It was necessary to understand what production plan and control (PPC) does means and what MTO and job shop production are. Then, literature search about PPC, MTO and job shop mainly on Science Direct and SCOPUS was performed. Web search and database were the essential methods for literature search. The details are mentioned in subchapter 3.1. Literature Review. Later were determined and selected of criteria for evaluation of PPC method. With this determination and selection, has been selected suitable PPC method for SME and design method for application of selected PPC method in MTO environment. To confirm idea and method, has been decided to use case study in order to obtain higher research quality of master thesis.

Since was mentioned previously in the literature search and case studies. There are the two most appropriate research designs for this idea, which give more strength in order to support qualitative part of research. The case study is chosen as the best and most suitable validation for the research in this master thesis.

Yin (1994) declares, that research can have single case and multiple cases. Due to that reason, it has been chosen only single case study method. Bearing in the mind the single case study method, MECASYS s.r.o. company was selected because company has a job-shop layout with MTO production environment.

2. 3. Research quality

Yin (2008) already explained, that the validity of research is dividing into two types of validity:

- **Internal validity** – quality of research work realized. The quality of master thesis/research work present directly thru the method, research approach, design and the data collection techniques, which has been used Yin (2008).
- **External validity** – quality level of generalization of the conclusions. In the initial step of topic finding interest was applies preceding available study, which help scientist to issue another research problem and define the purpose with issuing of research questions. Based on that a theoretical framework has been linked to objective of master thesis and research questions refer to the related literature.

3. Theoretical framework

The chapter focuses on the literature, which is evaluated to be applicable to the scope of this master thesis. It means into that the literature used for case study based on this theoretical framework is part of MTO and job shop for small manufacturing enterprises. In addition, how various production planning and control methods can be applied on the attributes, which regularly take place in the described environment. A theoretical framework provides to the readers understanding of theoretical part and gives overview to the research topic as well.

1. 1. Literature Review

For this thesis were used web databases Science Direct and SCOPUS which are on the world's leading source for scientific and technical research. Also, Semantic Scholar academic search engine from the most trusted sources. Deepdyve largest online rental service for scholarly research. For searching of literature has been used combination of following letter of words like “PPC”, “production planning and control”, “SME”, “small manufacturing enterprise”, “MTO”, “make to order” and ”production planning" This searching has been done with various combination of these words or letters of words. When it was sure that literature is correct related to the purpose of master thesis, it has been used keywords and papers. It was ensured that purpose of master thesis is established on correct literature.

Table 1 provides the overview of search phrasing with all keywords defined to be suitable for purpose of master thesis.

Keywords 1	Keywords 2	Keywords 3
ppc OR sme OR production planning and control OR small manufacturing enterprise	AND “mto” OR “high variety” OR “low volume”	
ppc OR sme OR production planning and control OR small manufacturing enterprise	AND “mto” OR “high variety” OR “high volume”	
ppc OR sme OR production planning and control OR small manufacturing enterprise	AND “make to order” OR “job shop” OR “mto” OR “high variety” OR “low volume”	

ppc OR sme OR production planning and control OR small manufacturing enterprise	AND “make to order” OR “job shop” OR “mto” OR “high variety” OR “low volume”	AND tools OR techniques OR practices
ppc OR sme OR production planning and control OR small manufacturing enterprise	AND “make to order” OR “job shop” OR “mto” OR “high variety” OR “low volume”	AND tools OR techniques OR practices OR polca OR conwip OR wlc OR kanban

Table 1: Initial search Keywords (Own work)

Later, have been performed additional searches according to reviewed literature linked with PPC in HLV, MTO and other environments. Additional searches were made with the search words: TOOLS, TECHNIQUES, PRACTICES, POLCA, S-DBR, CONWIP, WLC and KANBAN also synonyms of the complete definitions without any acronym. The fundamental logic of additional searches has been fact that first searching PPC with MTO gave me link to the main PPC methods for MTO in SME.

3. 1. Evaluation of the literature review

During the literature review have been realized, that it is very essential to do good decision to choose of PPC methods, which are suitable for small manufacturing enterprises in Make to Order environment. This choice should be made based on how applicable the production planning and control approach in this environment is. That’s why were identified some of the production planning and control approaches and set up following criteria for selection, which help to make decision for a further research.

Criteria are:

1. Selection based on pull-push and hybrid environment Gaury et al. (2001).
2. Applicability in Make to Order industry Stevenson et al. (2005).
3. Ability to manage highly customized products (non-repeat production) Stevenson et al. (2005).
4. Applicability to SME companies Stevenson et al. (2005).

According these criteria’s further research was focused to the following PPC methods: Simplified Drum Buffer Rope (S-DBR), Workload Control (WLC), KANBAN, Constant Work in Process (CONWIP), Drum Buffer Rope (DBR) and Paired Cell Overlapping (POLCA).

3. 2. Environmental Properties of MTO production

The environment in which they are, needs to be identified and analysed, before addressing appropriate PPC methods. The first aspect is, that manufacturing environment is characterized by point in which the order or demand placed in the shop floor configuration is. There are couple of order penetration points, five concepts to be described by Stevenson et al. (2005) also showed with the graphical representation (Figure 4):

1. **Design to Order** – new product development where organizations make engineering and manufacturing a product to match the given customer requirements.
2. **Engineer to Order** – there are changes to standardized products and offered to customers only with made to order.
3. **Make to Order** – related to the only manufacturing based on the order or call off.
4. **Assemble to Order** – parts and sub-assemblies are made on stock. Based on the reception of order or call off the required parts are taken from stock and assembled to order.
5. **Make to Stock** – products are produced in advance of demand which stick to the prediction. Orders are taken from stock.

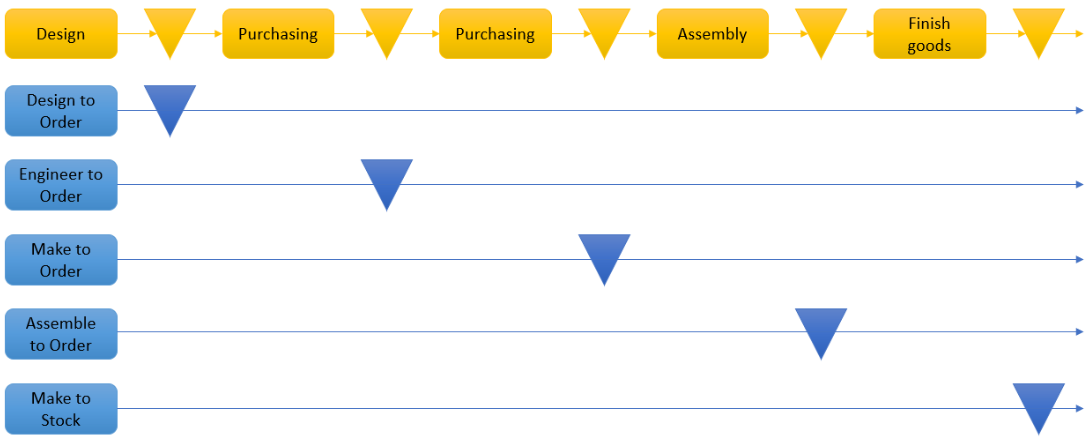


Figure 4: Order penetration point (Stevenson et al.,2005)

The second aspect to describe the production planning and control environment is the shop floor configuration. Stevenson et al., (2005) considered four shop floor configurations these include.

1. **Pure Flow Shop (PFS)** - work travels in one side thru a sequence of workstation in a clear order.
2. **General flow shop (GFS)** - work always travel in one side but jobs are a admitted to visit a subset of workstations, allowing limited customization, relevant to RBC.
3. **General Job Shop (GJS)** - is explained as giving multi-directional routing, but with a authoritative flow direction
4. **Pure Job Shop (PJS)** - routing defined with the sequences are irregular. Jobs may begin and end at any workstation.

The main divergence among the job shop and the flow shop is the direction of material flow. To be more familiar how such shop floor looks like, it is illustrated on the simple picture below (Figure 5).

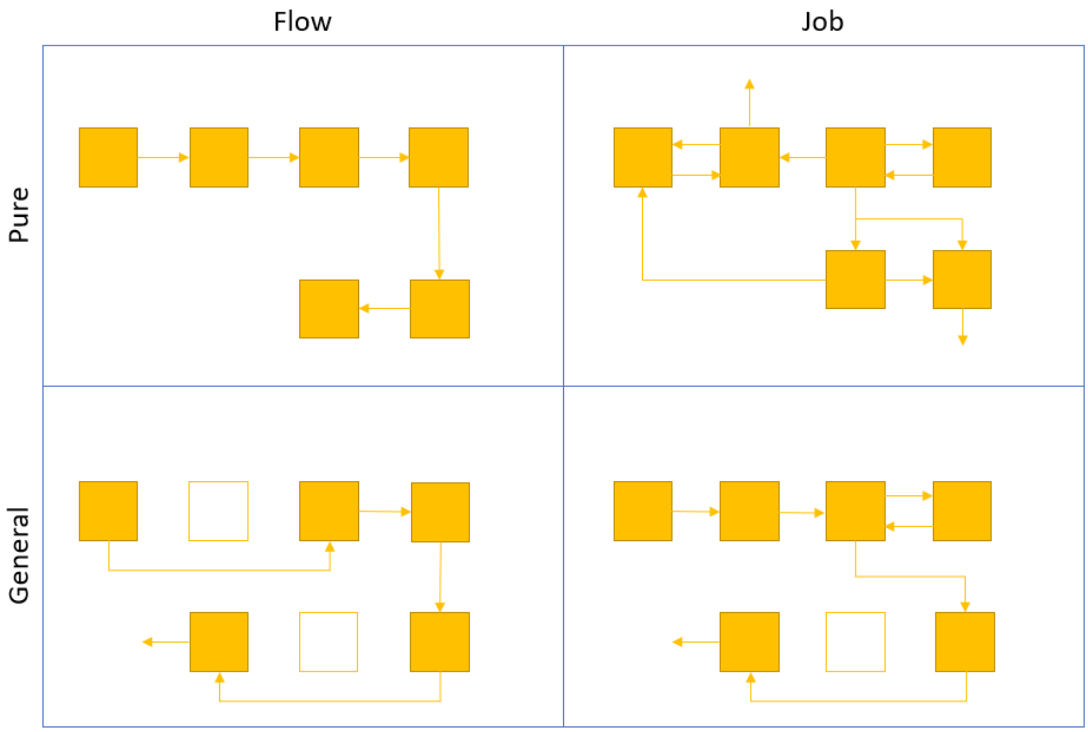


Figure 5: Graphical representation of shop floor layouts (Hurtl and Preusure, 2009)

Next aspect is definition of the size of enterprise, which is made by evaluation of income and number of workers. In the Make to Order environment there are various essential attributes in contrast to Make to Stock, for instance the importance of proper and well-aimed delivery date during quotation of customer at inquiry level demand.

A more in-depth description of MTO manufacturing is presented by Stevenson et al. (2005). They specified MTO like Repeat Business Customizers (RBC) and Versatile Manufacturing Companies (VMC) (Figure 6). RBC offers custom-made products endlessly over the period of time, while the VMC offers a high variation of products with various demands, which are manufactured in small lot sizes and no recurrence. With contrast of difficulty of each classification is not joint together. The fundamental operative problems in the MTO environment is capacity planning, order management (acceptance/rejection), and due date performance.

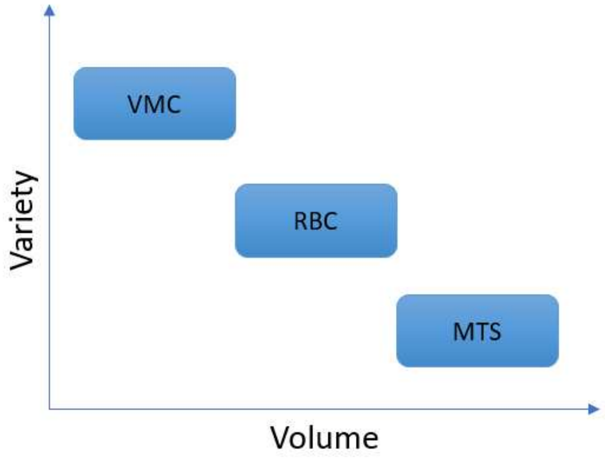


Figure 6: Classification of manufacturing based on the Volume and Variety (Own work)

3. 2. 1. Description and characteristic of the Make to Order manufacturing

The Make to Order (MTO), or made to order, is a business production strategy that typically purchaser to purchase products which is customized to customer specification. Manufacturing is identified to as a pull system and manufacturing process start only after reception and confirmation of customer order. The product is a mix of actual manufacturing designs and mounted together. The MTO manufacturing is described to make all production process, when the customer order is received. The major pros of the MTO system is the ability to fulfil order with the exact product specification required by the customer.

3. 2. 2. Criteria for determining applicability of PPC methods

By Stevenson et al. (2005) has been determined specific criteria for applicability of PPC method:

1. Criteria: Integrating of the **customer inquiry level** for delivery date establishment and capacity planning.
2. Criteria: Integrating of the **job entrance** and **job release** level, focused on the due date performance.
3. Criteria: Ability to handle extraordinary customized products (It's non-repeat manufacturing).
4. Criteria: Ability to provide PPC, when the workshop routings are fluctuating.
5. Criteria: Applicability to small medium enterprises.

The purpose of Production Planning and Control (PPC) systems is to get better performance in main parts of production. It is reduction of Work in Progress (WIP), minimization of shop floor throughput times (SFTT) and lead times (LT), lower inventories, improvement of respond to the changed demand, and improvement of due date performance (DDP), which are written by Stevenson et al., (2005).

Implementation of material resource planning (MRP) in the high variety and low volume (HVLV) environment, the dimension of enterprise is very essential attribute to be successful. To join the existing MRP system into the HVLV environment rapidly expand the cost of application. The costs are the main barrier to implement the ERP system in small medium enterprise markets said by Stevenson et al. (2005).

The selection between KANBAN – scheduling system for lean production in just-in-time production environment, CONWIP – pull-oriented production planning and control systems and DBR – where the system is working based on the increased throughput by adjusted the production buffers by a rope and controlled of movement by a drum. As Darlington et al. (2015) already wrote, that Value Stream Mapping (VSM) also known as material and information-flow mapping and existing MRP, which is described as a system for the practical capacity planning of all resources available in the company, work in process (WIP) control. The Value Stream Mapping

(VSM) is a path to visually present the variable routing in the complex nature for instance depends on route a product, quantities of processes are taking to the account and on variety routings among products.

3. 2. 3. Summary of Characteristics in MTO Manufacturing

Too many processes show a higher diversity, when the customer order decoupling point is shifted upwards. The main reasons are because the organization of processes and steps be dependent on the unique within the customer placed orders. Mentioned consequences is moving from MTO and ETO. Even if the different attributes can be same, ETO counts with the design, when the purchase order from customer is received and accepted. From engineering point of view the processes need to be completed, when a specific product can be unfamiliar at the time of order reception. It has effect to properly estimate cycle time and routing, also rising the risk of the rework and engineering. When something is not going in proper way in related to planning, effect will extend into the internal value stream. It will affect lead time, on time delivery performance, quality of product and also inventory.

3. 3. Production approach

During the last century a lot of production-planning approaches have been developed. They are characterized as a pure pull, push or a hybrid form. In next sentence to be explained shortly what these productions approaches are:

Pure Push – is system designed for complex production planning environments. It used as the Material Requirements Planning (MRP) (Stevenson et al., 2005). But Bertrand & Muntslag (1993) recognized that the use of MRP in some cases is not successful, due to often problematic issues regarding the functionality of MRP/MRPII. For success implementation strategy is identification of company size.

Pure Pull – production process is scheduled with accordance of the needs. Often referred to as a 'Pull' production approach is demands travel upstream and pull products down the line by authorising production based on the presence of KANBAN cards which are limited in number. In this category are include CONWIP, KANBAN and ToC.

Hybrid form – according Land (2004) Workload Control (WLC) is one of the few concepts that has been designed specifically for SMEs production on receipt of a customer order and has been extensively researched. WLC method is good example for hybrid form. SMEs require simple PPC frameworks that are structured along the basic decision points in the flow of orders, for example order acceptance, release, and dispatching. Land & Gaalman, (2009) said, that applicability of WLC concepts is different due to performance in various conditions of shop. Further investigation of parameters setting, and other aspects is required.

The push-based system should be applied for products with a small doubt of demand, because the prediction is going to show a good orientation what should be produced and kept in the company inventory said Harrison et al., (2005) and for products with high weightiness from point of economies scale in reducing of costs. And on opposite is pull system, which is designed for products with high doubt of demand and decreased importance from point of economies scale.

The production method of a manufacturing organisation can be described with the different way of considered sources, for instance: materials, man and machines. It is input which is transferred into required outcome, when the policies and controls issued by the operation management. As Kumar and Suresh (2008) wrote, production method, is devided into areas. They are classified according to volume and diversity of products:

1. Job-shop production
2. Batch production
3. Mass production
4. Continuous production

These groups of categories endeavour to produce the right value of products at the right time with application of production strategies chosen and preferred by operation management of company. Nevertheless, mentioned four methods are be much different from one another in term of setup, benefits and obstacles.

After review of all categories mentioned above, this master thesis will focus to deeply look into of the manufacturing organisation. The manufacturing organisation called job shop is working a managing with various product which have low volumes. Usually, job-shop production consists from the machinery which do specific operation. Every product must go thru at the least one and at any time several manufacturing operations. And every product has his own material stream fluctuated in the manufacturing environment. Concerning the MTO and MTS production strategies, a job shop has all the time attributes of MTO environment, because products are customized. The strategy, which is described, the products to be pulled thru production without any stocks needed in the storeroom. The benefit resulted into any negotiation of inventory costs. For instance, is presented process of MTO manufacturing in Figure 7.: supplier, raw-material inventory, planning department, manufacturing, quality assurance, packing, customer shipping, delivery to customer and planning department.

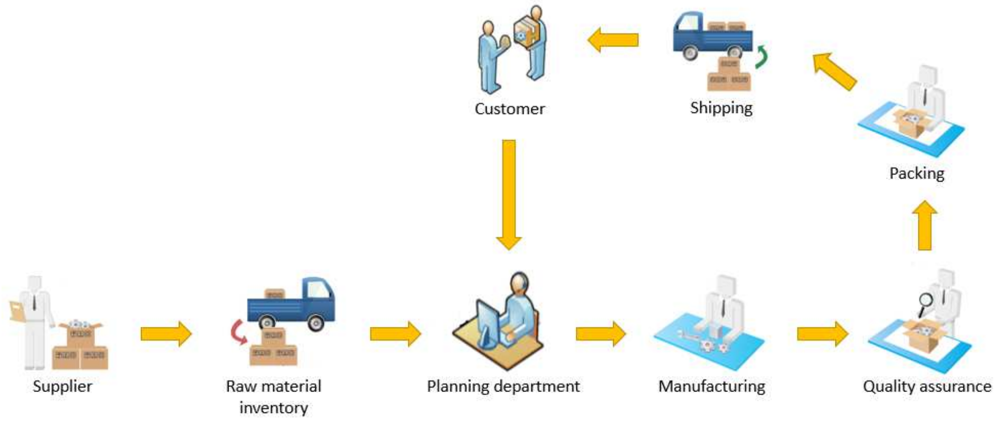


Figure 7: Flow chart of MTO manufacturing (Own work)

In any case, producers at any time keep the safety stocks for their main customers, which result that the job-shop environment is both a make to order and make to stock manufacturing. For instance, is presented process of job shop manufacturing in Figure 8.: supplier, raw-material inventory, planning department, manufacturing, quality assurance, packing, finish good storage, customer shipping, delivery to customer and planning department.

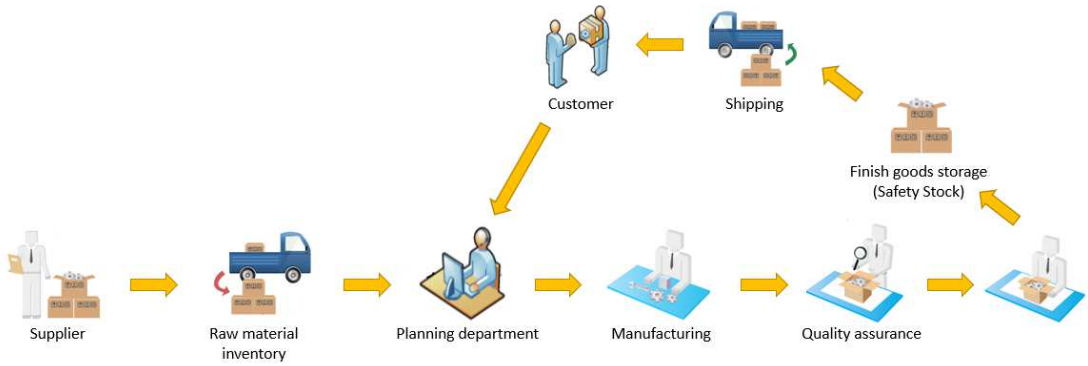


Figure 8: Flow chart of Job-shop with safety stock manufacturing (Own work)

In MTO manufacturing, the products are pushed into the market instead of applying of pull system from customer. It means, that everything what is produced is immediately consumed. The MTS manufacturing is presenting the not custom-made products in increased demands. It is manufacturing system, which is identified like opposite to the job-shop manufacturing. A job-shop environment is described to produce extremely custom-made products, with a widely differ products. Though product volumes may differ from company to company according to the customer demands. It is generally low demand.

The products, that are produced very widely, and production planning is becoming risky, when is requiring plenty of time for re-planning and when finally, is resulting into increased production lead time. The biggest benefit of the job-shop manufacturing is high usage of machines and workers, where failure of one specific machine will not create problem, because the job might be placed to a corresponding machine in manufacturing shop-floor. It has impact in a reduction of production lead time.

Pros:

1. Increased flexibility of machinery and man usage.
2. Widely diversity of products can be manufactured.
3. High usage of the workers' prospective.
4. Control can be made very under stable and beneficial
5. Plenty of chances to usage the workers knowledge and experiences about the products and production evolution.

Cons:

1. Production planning and control is risky.
2. Can required a large number of times consumed on re-planning.
3. Increased frequency of changes on machinery
4. Increased difference of material flow makes material processing risky.
5. Increased inventory stock asks huge space warehouse.

Job shop manufacturing organization has many pros and cons. This approach for production of components is recognized for all who assembly products and deliver products around all system e.g. retailers, wholesalers, consumers. In the next subchapter to be presented meaning of production planning and control with theory from previous research.

3. 4. Production Planning and Control (PPC)

Production planning and control framework are fundamental instruments to meet increased customer anticipations and needs in current extremely competitive market.

After knowledge of application value stream mapping (VSM) to high variety and low volume environment, the most improvements are possible to do in manufacturing process thru the tools like single minute exchange die (SMED), error proofing (POKA YOKE, standardization of the workstation (5S) and other corresponding techniques and tools, that have been mentioned by Irani (2011). The most complicated areas for production planning and control application and improvement are disposition change wrote Strøm (2017).

As has been written before the main intend of production planning and control framework is to improve performance in the main areas. What are: decrease of work in progress (WIP), reduce shop floor cycle time, improve reaction in customer volume change, stock move down, shorter manufacturing lead time, improvement in delivery date performance and also decrease lateness, which have been written by Stevenson et al., (2005).

The production planning and control framework with addressing of previously specified performance targets consists of material needs planning, demand management, capacity planning and detail scheduling and sequencing of orders in SME (Strøm, 2017). According the literature review, the master thesis is going to concentrate and identify, which production planning method is the suitable for planning and sequencing of customer orders in SME. It is going to be done by reviewing of available PPC methods as mentioned in previous chapter. It is in connection to the high-variety, low-volume and manufacture to order or job-shop

The MRP, ERP and APS production planning and control methods are not part of master thesis, due to the difficulty of its system.

Corresponding to previously search and basic criteria further research was focused to the following PPC methods:

- Simplified Drum Buffer Rope (S-DBR)
- Workload Control (WLC)
- KANBAN
- Constant Work in Process (CONWIP)
- Drum Buffer Rope (DBR)
- Paired Cell Overlapping (POLCA)

The planning and controlling are major elements of the in PPC system. These elements are very important for every company. The company needs to now order flows and each process steps in their own system. It means order acceptance, release, sequencing, processing, shop floor dispatching and follow up.

Evaluation of proper PPC method in make to order environment was performed before by Thürer et al., (2016a, Stevenson et al., 2005), but Marcos Buestán (2019) put together overview of these applicable criteria. (Table 2)

Scope	Criteria for supporting PPC selection	References
Product Characterisation	Level of customisation	Berry and Hill (1992) Vollmann (1997) MacCarthy and Fernandes (2000) Stevenson et al. (2005)
	Product mix	Berry and Hill (1992) Vollmann (1997) Silver (1998) Stevenson et al. (2005)
	Product structure	MacCarthy and Fernandes (2000)
	Number of products	MacCarthy and Fernandes (2000)
Processing Characterisation	Process pattern	Larsen and Alting (1993) Silver (1998) MacCarthy and Fernandes (2000) Henrich et al. (2004) Stevenson et al. (2005)
	Releasing control	Stevenson et al. (2005)

	Volume batch	Berry and Hill (1992) Vollmann (1997) MacCarthy and Fernandes (2000)
	Type of layout	MacCarthy and Fernandes (2000)
	Setup/Processing time ratio	Henrich et al. (2004)
	Organisation control	Vollmann (1997) MacCarthy and Fernandes (2000)
	Information requirements	Larsen and Alting (1993)
	Planning capacity	Kingsman (1996)
	Shop floor personnel criteria	Maurice Bonney (2000)
	Processing time lumpiness	Henrich et al. (2004)
	Processing time variability	Henrich et al. (2004)
	Routing length	Henrich et al. (2004)
	Routing flexibility	Henrich et al. (2004)
	Level of convergence	MacCarthy and Fernandes (2000) Henrich et al. (2004)
Market Requirements	Due date planning requirements	Kingsman (1996) Olhager and Wikner (2000) Stevenson et al. (2005)
	Order winner	Berry and Hill (1992) Larsen and Alting (1993) Stevenson et al. (2005)
	Demand change. Total volume	Berry and Hill (1992) Larsen and Alting (1993) Vollmann (1997)
	Demand changes. Product mix	Berry and Hill (1992) Larsen and Alting (1993) Vollmann (1997)
	Speed on delivery	Vollmann (1997)
	Schedule changes	Vollmann (1997)
	Arrival intensity	Henrich et al. (2004)
	Interval arrival time variability	Henrich et al. (2004)
	Due date adherence	Henrich et al. (2004)
	Variability of due date allowances	Henrich et al. (2004)

Table 2: Overview of applied criteria's in earlier literature (Marcos Buestan 2019).

Criteria's mentioned above is combination of product characterization, process characterization and market requirements. This master thesis will take appropriate weigh between characterisation degree of specific detail and degree of implementation in selected environment. Criteria's must provide the best fit to the company where PPC method would be implemented. Due to this reason scale for evaluating (Table 3) and following criteria for evaluation of PPC methods were defined. See below:

1. Product Structure
2. Product mix
3. Level of customization
4. Process pattern
5. Setup time
6. Level of training
7. Due date adherence
8. Repetitiveness level
9. Volume demand variability

As Buestan et al. (2019) said appropriate assessing has two steps. The first is the evaluation of the company considering where PPC method to be implemented and the second evaluation of PPC methods, which PPC methods fit to the aspects of the company for each evaluated criterium.

Score	Categorization	Description
6	The best similarity	Criterium of PPC method excellently fit to an enterprise's aspects. It is crucially impacting the completion of its objectives.
3	Better similarity	Criterium of PPC method is inline with an enterprise's aspects. It ensures the completion of its objectives.
1	Neutral similarity	Criterium of PPC method isn't in dispute aspects of an enterprise. It doesn't influence the completion of its objectives.
-3	Worse similarity	Criterium of PPC method isn't appropriate for an enterprise's aspects. It has negative impact to the completion of its objectives.
-6	Bad similarity	Criterium of PPC method is in opposite to an enterprise's aspects. It crucially endangers the completion of its objectives.

Table 3: Scale for evaluating criteria applying a PPC method at a company (Marcos Buestan et al. 2019)

The stability and applicability of a production planning and control for a company is according to how variable appearance of the company ensure fundamentals of the production planning and control. An explanation of mentioned criteria is discussed in the following subchapter.

3. 4. 1. Product characterization

In previous studies have been product characteristics evaluated as an important input to manufacturing strategy which has impact on the production planning and control of design (Olhager & Rudberg, 2002). Base on mentioned studies, that the most discussed area in PPC environment are product issues called volume or product mix.

In the following sentences, is shown short overview of selected criteria related to the product area as has been described by Marco B. et al. (2019).

Stage of customisation: This is a competence occurred in many companies on the market as part of their own strategy. Each level of customization the selected PPCs is facing of various product and process challenges. Vollmann (1997a), wrote, that the product customisation in a company uses two levels: custom or standard part. On other hand MacCarthy and Fernandes (2000) defined a broader classification. The classification consists of the four elements:

- **Customised products** – the customer is responsible for complete product design.
- **Semi-customised** – the customer makes a small portion of final product design.
- **Mushroom customisation** – a large of basic products are manufactured based on the customer specific needs.
- **Standard products** – the customer doesn't change and influence product design.

Product Mix: This is the level of product variety produced by a company. Silver et al. (1998) defined four categories that present the variety of products. The categories are:

- **Custom** – Few of products
- **Many products** – Low demand
- **Several major products** – High demand
- **Volume commodity** – Very high demand

Product Structure: This category describes product complexity from point of bill of materials (BOM) complexity. The product has been categorized by MacCarthy and Fernandes (2000) in following definitions:

- **Simple products** – complexity of product is easy (e.g. a few parts in product)
- **Multi-level products** – complexity Bill of Material in products is on high level (e.g. assembly numerous parts)

3. 4. 2. Process characterization

Basic purpose of production planning and control is reinforcing of manufacturing function of an enterprise. For that reason, it's very essential, where manufacturing process has to be according to the parameters of the selected production planning and control systems. The production planning and control selection is varying with opinion of each author and is defined by process characterization.

Suggested criteria selection is according to a previous reviewed literature of production planning and control option.

The process pattern: has been determined like most essential element during the production planning and control application. Marco B. et al. (2019) mentioned, that any inconsistency between the production flow and production planning and control can cause of problems during the planning and control phases.

Taking into account the common approach of this research, the proposed systems are put it for the process pattern features that are traditionally be relevant in the OM literature Marco B. et al. (2019).

- **Job shop** – There is unsystematic the routing sequences and multi-directional handling.
- **Batch flow** – There is existing mixed up manufacturing flow, The production flow is while production paths become more clear like a in job shop pattern.
- **Line flow** – It follows fixed sequencing (e.g. station to station, step to step) of product flow.
- **Continuously flow** –Product flow is continuous on the shop floor.

Setup Times: Most of the companies have the problem in operation with the setup times. Due to this reason, production capacity must be considered to evaluate impact of changing priority or releasing the new orders into production in case of dependent sequence. Setup times are split into two groups:

- **Independent sequence setup time** – Capacity of machine is not impacted by sequence of operator.
- **Dependent sequence setup time** – Capacity of machine is impacted essentially by sequence of operator.

Level of Training: Designing and selection of production planning and control methods strongly depend on resource dimension as well (B. MacCarthy, Wilson, & Crawford, 2001). There were two categories defined the intensity of training to shop floor workers:

- **High skilled worker** – Skill and experience of worker is significant.
- **Low skilled worker** – Skill and experience of worker is insufficient.

3. 4. 3. Market characterization

Due date adherence: If the slack time of most committed orders is nearly zero, the environment can be categorised as having due date tightness.

Henrich et al. (2004) wrote, that due date tightness is linked with slack time. It is defined like residual time among finalization of order and confirmed due date towards customer (Jun-Huei Lee et al., 2010). It means, when the slack time of confirmed orders is close to the null value, it can be evaluated like due date tightness. The suggested structure describes two levels of due date tightness of an enterprise:

- **High due date tightness:** All confirmed order is without or minor slack time. Preventing the insertion of orders without influence of DDP.
- **Low due date tightness:** Most committed orders have slack times that allow the insertion of orders without influence of DDP.

Repetitiveness level: MacCarthy and Fernandes (2000) mentioned, that repetitiveness level takes over seven classes with the range of min. and max. repeatability:

- **Purely continuous system:** Refining product.
- **Semi-continuous system:** It’s system with continuous flow and many combinations of routes.
- **Mass-production systems:** Most of the products are repeatable.
- **Repetitive production system:** More than 75% of the products are repeated.
- **Semi-repetitive system:** Class with many of repeated and non-repeated products.
- **Non-repetitive production system:** Minimum 75% of the products aren’t repeated.
- **Large projects:** Unique product.

Volume demand variance: As have been written by Marcos Buestan et al. (2019) volume variance is evaluated with using of the coefficient of variation (CV) on the product demand for time period during the defined year. The coefficient of variation is calculated as formula, which represent a unique product group and minimum 80% of the turnover of unique products. The following categories of volume demand variance has been defined:

- **Low volume demand variance:** Minimum 75% of the products provide a coefficient of variation is less or equal than 0.75.
- **Moderate volume demand variance:** Minimum 75% of the products provide a coefficient of variation in between 0.75 and 1.33 or as a next option of significant value of both low and high variance of products.
- **High volume demand variance:** Minimum 75% of the products provide a coefficient of variation is higher than 1.33.

3. 4. 4. KANBAN

To understand the topic, firstly needs to be explained what does mean Kanban? Kanban is a system that controls inventory with visual management, that base on the demand generating job order with help of card. KANBAN was found by Taiichi Ohno. KAN-BAN means cards – signal. KANBAN was founded after World War II. The KANBAN is divided it into two types of categorization:

1. **Generic KANBAN**
2. **Sequential/operational KANBAN**

Generic Kanban means that the signal (KANBAN) entitle the production stations should be part what is without specification what to produce. KANBAN is the tool suitable to implement in a pull system. The most popular kind of KANBAN is traditional KANBAN. Where the signal (a card) indicates needs a box of unique item. It is suitable in low mix and high-volume manufacturing environment. Let's imagine in vice versa a high mix / low volume manufacturing environment. There will be plenty of items could be manufactured in manufacturing process. It is desirable to use in such manufacturing environment. The identification what to produce is identified thru a manifest or other system. In such situations we use Generic KANBAN cards.

The generic KANBAN isn't linked directly with product describe Bicheno and Holweg (2016). The main intend of a generic Kanban system is limiting to the number of jobs in the system. The work in progress make an effort to change KANBAN into dynamic environments. The generic KANBAN is suitable in a dynamic environment, where manufacturing process received needs. The dynamic environment is MTO. Chang and Yih (1994) described the environment with the low mix and only two various products, the manufacturing line is very easy and direct, and the needs fluctuation is variable. When the quantity of KANBAN cards are fixed, the both systems hold WIP at the same level. The number of cards in the generic KANBAN is defined in each process. Due to the fact that each KANBAN card might be influenced by process, the quantity of KANBAN cards in among each process step is fixed. This rule makes the system stronger and might be processed with higher process time variability.

Sequential/operational means, that the signal (KANBAN) is identifying what must be smoothly manufactured and moved from one workstation to another without any unforeseeable jump written by Bicheno and Holweg (2016). Various sub-assembly workstations are arranged to ensure sequential operations. This process admits to fast respond to the future changes. Sequential KANBAN is accumulating very fast inventory and finally is not suitable for manufacturing environment with plenty of customer products.

The KANBAN set out like a tool for pull manufacturing process in the unfluctuating and repeated industry. To address barriers and ensure applicability to other industry Junior and Godinho Filho (2010) review thirty-two publications on KANBAN. They compared traditional KANBAN and different variation of KANBAN. The difference from traditional KANBAN also advantages reached to be are highlighted.

Gravel and Price (1988) applied the KANBAN in job shop environment. The KANBAN is applied to merge manufacturing flows in industry with fluctuating routing and shared resources.

Also, Gravel and Price (1988) used the KANBAN without an indication from the end process, which release needs upwards. It is placed to set quantity of KANBANs and lot size. They have been reproduced to use three various sequencing rules, in contrast to no workload control and in practice it is first in first out system. It is fundamental job in process of the KANBAN lot-size.

The MTO manufacturing environment, there is higher quantity of various products or plenty of modifications of similar products and as was mentioned in previous sections by Chang and Yih (1994). In such a situation only one variation of Kanban has potential fit to MTO manufacturing environment. It is **generic Kanban**.

Inputs

The general KANBAN runs like two box system. It is using the reorder point (ROP) to obtain the formula to identified KANBAN cards.

$$ROP= D \times LT \times SS$$

Where D means needs within the specified lead time LT, and SS is the safety stock. The Q means box quantity, where the quantity of KANBANs N is computed like below:

$$N= ROP/Q$$

Next procedure how to compute KANBANs N without using of a safety stock, is to include feature of safety lead time (SLT), that is changing the formula in the following way:

$$N= (D \times (LT+SLT))/Q$$

During the changeover in the manufacturing process, the formula must be changed to include changeover like, batch run time (BRT), queue time (QT) and delivery time (DT) in lead time (LT), changing the above formulas. Batch run time (BRT), changeover time (COT) and queue time (QT) is mentioned like Every Product Every (EPE). It is period of cycling a product, which calculated in days. The changeover is included in KANBAN.

$$LT= EPE+DT+SLT$$

The main issue of traditional KANBAN is same as generic KANBAN. It is shown in the formulas: ROP is obtained from the needs and the lead time is determined attribute, which uncover these variance in processing times and rework will do the final quantity of N, quantity of KANBANs, at a high mistake gap.

Products included in a traditional KANBAN should be applied each day, whereas huge and most costly products must be removed from the system. The best environment where KANBAN suits very well is presented by a simple bill of materials, short lead times and of course small order quantities (Darlington, 2015). Darlington also defined that KANBAN is stock based method, which considering the Kanban calculation. It known that there is possibility in traditional KANBAN to connect number of KANBAN cards to shipment time than stock.

Next problem of KANBAN like PPC method in HVLV environment, that must be established between two workstations. That's why the KANBAN control over the whole system is not working, when method is not established between two workstations in directed line.

As Darlington et al. (2015) wrote already, the KANBAN is rejected in high variety and low volume industry, because of necessity of creation supermarket in impossible space and cost results linked with material cost, complexity of BOM (large quantity of parts) and too many design changes.

Summary of Kanban methodology

The KANBAN might be applied as part of large scale of production planning and control system like workload control method. Where can fill up the major manufacturing line with parts called high runners. That's mean pure flow shop environment. KANBAN system requires a buffer of materials on each level of WIP. It means that is not fit for high mix of products. Several studies have been reported as good method for training activities during the Kanban applications process (Silva & Sacomano, 1995).

The main problem what makes KANBAN as handicap for HVLV environment is product information. High product mix is causing high stock, when the unique product in KANBAN is applied. When the multiloop KABAN with high variety of product is applied, it's created very complex system. When the generic KANBAN is applied, process time variance creates needs of control point or cumulating the stock. On top of that KANBAN keeps all info at the workstation, this is control point and on the shop floor is nothing what is balancing the working load.

That's why the KANBAN can't be applied as a system for production planning and control in HVLV manufacturing environment.

KANBAN evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	+6	The KANBAN is well suited in repeatable production with less design changes and a couple products said Abuhilal et al. (2006). The success of KANBAN is in environments, where the customer's needs are precisely forecasted, and product diversity is limited Marco B. et al. (2019).
	Product mix - Many products	-6	Stevenson et al., (2005) mentioned that the KANBAN needs a buffer between each station of process. It makes KANBAN less suited in production with wide variety of products.
	Level of customisation - Mushroom customisation	-3	As was mentioned before customisation is on low level and it indicates less stock needs and move production environment into pull system which is along with value stream (Hopp & Spearman, 2008). Krajewski et al., (1987) described attributes of KANBAN, that makes less liable and has influence on stock increase for item.
Processing Characterisation	Process pattern – batch flow	-3	The KANBAN is pure flow shop process pattern wrote Stevenson et al. (2005). This is ideal production process for order flow from one to another workstation. The less direct job orders in production process influence prediction of customers' needs and shop floor planning (Gargeya & Thompson, 1994).
	Setup time - independent setup times	+6	Marco B. et al. (2019) mentioned, that plenty of literature is focusing on reduction of setup times on machines. The major problem is dependent sequence of setup time in KANBAN. Following problem can happen, when the setup times are impacted by different sequence determination. Independent setup times keep away from for deciding, that setup may be next and what time. Marco B. et al. (2019)
	Level of training - Low operator skill	+6	Level of training of workers, when KANBAN has been applied is very effective. There are no needs to have higher level of education (Silva & Sacomano, 1995). The major pros are simplicity of KANBAN as push production system.
Market Requirements	Due date adherence - Delivery reliability	-6	The KANBAN has poor due date performance, because of many evidences of implemented case studies. The KANBAN miss a few parts, which require make to order

			production firms to reach perfect due date performance rate e.g. job entry and job release is not part of KANBAN (Marco B. et al. 2019).
	Repetitiveness level - Repetitive production system	+6	Production environments with increased level of repeatability fit for KANBAN application wrote Abuhilal et al. (2006).
	Volume demand variability - Moderate volume demand	-3	KANBAN method is not very well suited for volume demand variability due to complex setting of KANBAN cards. Huge variability in customer needs can destroy the whole production flow and threaten the performance of production system.

Table 4: KANBAN evaluation in SME environment (Own work)

3. 4. 5. DBR (Drum Buffer Rope)

Drum Buffer Rope (DBR) has been identified as a bottleneck-oriented idea. The basis comes out from Optimized Production Technology (OPT). DBR is like the Theory of Constraints (TOC) method. DBR organizes manufacturing processes in order to align with rate of the bottleneck(s) in the entire manufacturing system. Goldratt and Cox (2016) wrote, that the core of DBR is the idea of throughput accounting.

Drum buffer rope method is of eliminating constraints in production in order to minimize stock and work in process. Throughput accounting is based on the three parameters:

1. Throughput
2. Inventory
3. Operational expense.

As abbreviation of DBR saying, it is consisting from three main attributes: the “Drum”, the “Buffer” and the “Rope”.

- Drum – this is constraint. Sets the rate/pace
- Buffer – it is level of stock needed to maintain stable production
- Rope – this is an indication, which is issued from the buffer to allow release of material. It indicates how much amount of stock were consumed.

The Drum is controlling the pace of the system and must be in the right way defined like the bottleneck system, that make throughput as large as possible. The Drum is determined thru the time-based scheduling and associating the resources, which are highly utilized and where is WIP the most detected.

The Buffer is determined in order to ensure, that Drum is utilized as much as possible. It means that processing time, failures and idle time must be considered. The size of Buffer is identified by measurement of time workload for instance hours' worth, days' worth and so on.

The Rope as a result of the Drum meaning, which count with all resources placed upstream of the Drum. It is feature which make warning to release work, when is new job is launched at the Drum. It is giving space in the Buffer stock as well.

Jun-Huei Lee et al. (2010) wrote, that a number of literatures and case studies are describing the practical implementation of DBR method in extremely custom made environments, like make to order or engineering to order said by Wahlers & Cox III, (1994), who described production variants. Concentrating only on internal source makes DBR very easy to applicable in extremely custom-made environments. There will be not easy to guess the estimate process time for each resource (Stevenson et al., 2005).

Darlington et al. (2015) established a time-based capacity scheduling tool in the given MRP framework, which do utilization analysis of all available resources in the given system. There was needs compared with accessible capacity. As drum candidates have been stated like the highest utilized resources.

Specific WIP monitoring tool has been developed in order to determine which candidates has been the current bottleneck. It helped to segregate some drum candidates. At the end coefficient of variation has been measured for the lead time attributes of the system. The drum was found in early stage of the production process and as outcome the rope is short, and the framework is covering workshop as an entire part.

According the statement of Spearman et al., (1990), the DBR is better fit than CONWIP in pure job shop manufacturing. The CONWIP can better control WIP and vice versa DBR better control release rates. Many variations of lead time at bottleneck is allowed by DBR, as the drum releases work according to the processed work at the bottleneck rather than release the jobs entirely. The bottleneck stays same in case of higher routing variableness.

Darlington et al. (2015) prove that the DBR method is predominance of CONWIP method. It corresponds with Stevenson et al. (2005) argumentation, that is saying that DBR is higher level of CONWIP in a general job-shop system as well but Stevenson (2005) also saying that WLC method is better choice all at once. Darlington et al. (2015) decided to select DBR because following three attributes: difficulty of the routings, total quantity of work content and lead time changing.

DBR is coming with a few problems. It is inventory buffer, which is stored in front of the drum to secure that bottleneck is still running. It means that jobs must be released to fill the buffer, when new work go into bottleneck stations. To make sure that rope sequences of job is necessary for an earlier work. The bottleneck of station must be reasonably forecasted. Also, for the workshop must be set up only one buffer, work time for one station. The aim of this activity doesn't have any accumulated work like waiting inventory.

Inputs:

Scheduling with the DBR is performed according to stroke of the bottleneck. Only one source of workload is needed to count the buffer system. There is an assumption, that the bottleneck is fixed. This is the major problem related to the DBR. From point of shop composition, flow shops can be fit rather than job shops. General flow shop composition is more benefit to DBR like general or pure job shop in HVLV manufacturing environment.

As a main argumentation in opposition to DBR, that it doesn't count with enquiry stage and job release stage (Stevenson et al., 2005). In DBR system the rope is not telling the system when to release order. It means that must be defined on top of that.

Summary of DBR methodology:

The DBR appear to be most suitable for general flow shop. The problems can happen, when the system is too complex (routing fluctuation, cycle time variability, bottleneck variance). The DBR is strong in product structure, because is simplify the priority list of job orders in production shop floor and ensure variability to hit specific customer needs. Also, DBR is introduced as well-suited selection for firms with high product mix. A few literatures wrote, that DBR was successfully implemented and suitable in highly custom-made industry like make to order (Guo & Qian, 2006).

The DBR offer achievable due dates according to the fixed volume of the CCR (Cox III & Spencer, 1998). Additionally, DBR applies technique, which release jobs according to processing ability of the CCR (Chakravorty, 2001) and control in advance utilization of buffer management, which offers stable delivery towards the customers (Mabin & Balderstone, 2003).

The DBR is not so strong in high volume order variableness can conclude in a variation of bottleneck, that asks the permanent planning update and has consequence to change resource constraint of workstation (Mark Stevenson & Hendry, 2006). This outcome is affecting the basic hypothesis of any DBR application connected with sustaining the constant bottleneck (Stevenson et al., 2005). It is needed to monitor all machinery load to avoid this event in case of high demands variance.

DBR evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	+6	E. M. Goldratt (1990) wrote, that the DBR has three buffers: 1. The constraint, 2. The shipping, 3. The assembly. The most SME companies don't have assembly buffer because assembly operation is reduced. It has positive impact on priority list of job orders and increase the variability to match customers' needs.
	Product mix - Many products	+3	The DBR is presented like good choice in enterprises with have many products on shop floor said Stevenson et al. (2005). There can be a any restriction for environments, where the product mix essentially have a impact on a shift in the bottleneck (Steele, Philipoom, Malhotra, & Fry, 2005).
	Level of customisation - Mushroom customisation	+6	The DBR is extremely suitable for customised environments like MTO said Jun-Huei Lee et al. (2010) production scenarios. The DBR is uncomplicate to apply in highly customized environment, where is not easy to identify necessary processing time for whole resources has been mentioned by Stevenson et al. (2005).
Processing Characterisation	Process pattern – batch flow	+3	The DBR is suitable for job shop production environments are saying many literatures. Also, in the cases that vary routings have vary

			bottlenecks (Chakravorty, 2001). Most of SMEs use a batch flow production. It means that bottlenecks to be constant (Stevenson et al., 2005).
	Setup time - independent setup times	+6	Ecuadorian SMEs shows sequence-independent setup times. Due to this characteristic the DBR provides very good variability to be ready and reply on customer demands.
	Level of training - Low operator skill	0	During realization has been recognized, that many workers on shop floor must be trained and rearrange to ensure right level of knowledge about DBR (Cox III and Spencer, 1998). Though, many literatures have noted that DBR is considered as simple has been said by Ajoku (2007).
Market Requirements	Due date adherence - Delivery reliability	+6	The DBR can give achievable realistic due date for order. The CCR is basic to determine capacity has been wrote by Cox III and Spencer (1998). Further, the DBR is using system, which release job orders according to the process ability of the CCR with supporting of the buffer management. It offers safe delivery of goods towards customer (Mabin & Balderstone, 2003).
	Repetitiveness level - Repetitive production system	+6	Decreased level of production repeatability have negative effect, due to increased changes on machine, increased constrains and moving bottlenecks (Tseng & Wu, 2006). The product mix repetitiveness has impact on the likelihood of bottleneck changes in production wrote Cox III and Spencer (1998).
	Volume demand variability - Moderate volume demand	-3	Demands variation lead into the moving of bottleneck. This influence planning which must be regularly updated (Mark Stevenson & Hendry, 2006). This has negative impact on fundamental expectation to keep bottleneck unmoving and maintaining (Stevenson* et al., 2005). As a result of case during increased variability of customer needs, it is important to track machine capacity to avoid before mentioned situation.

Table 5: DBR evaluation in SME environment (Own work)

3. 4. 6. S-DBR (Simplified Drum Buffer Rope)

Simplified Drum Buffer Rope (S-DBR) is originating from the Theory of Constraints (ToC) (Figure 9) of production planning and control methodology founded by Eliyahu M. Goldratt in the year 1980. S-DBR has equal concept as basic DBR already reviewed in previous section. To tell the difference between traditional DBR and S-DBR it is expectation that market demand is the main constrain of system, even though an internal capacity constrain is for a short time come out. Traditional ERP and MRP methods might be very easy to support S-DBR method. Exactly said, it is fluctuating market needs.

As has been written by Goldratt and Fox (1986) one of the mostly propagated production planning and control methods is the drum buffer rope in operation management. In spite of many very good implemented applications of the DBR thru the world, the existence of capacity constrained resource (CCR) is took over. Actually, the conditions in which this expectation do not kept. (Lee et al., 2009).

As new option in HVLV production environment has been S-DBR. It is simplified version as has been described by Dettmer, and Patterson (2009). Method is less difficult and more efficient form of traditional DBR which was written by Schragenheim et al., (2009). S-DBR declares a proper choice for MTO environment. S-DBR implementation has been archived in the academic papers and presented by Hwang, Huang, and Li (2011). Hwang and Li reviewed the application of S-DBR in MTO large furniture producer located today in China. S-DBR is basically construct on Theory of Constrains (ToC) principles.

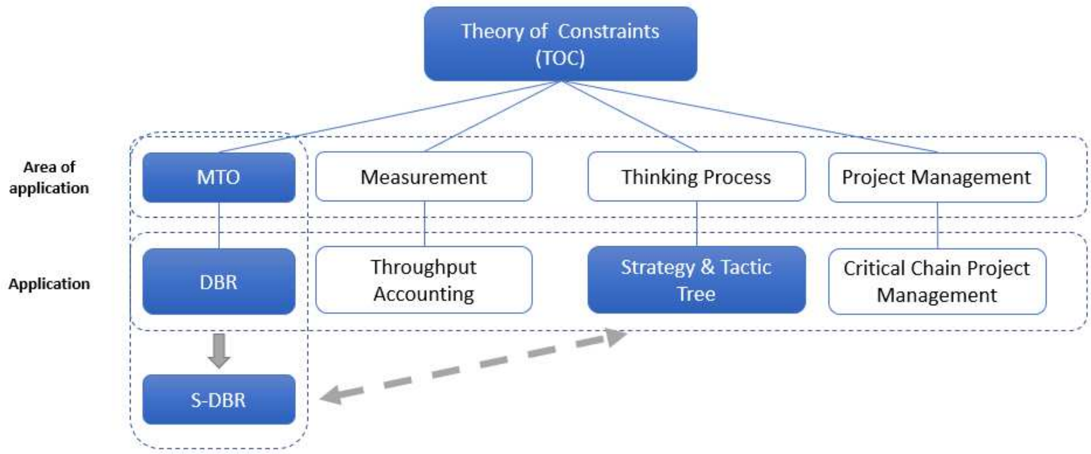


Figure 9: Theory of Constraints (Eliyahu M. Goldratt, 1980)

The ToC was founded by Goldratt in the in year 1980 as stated already before. ToC concept is based on the collecting the maximum usage of the constraint described by Rahman (1998). In the ToC application, capacity measures are judged as initial interest.

The capacity measurement has been categorized before into two ranges:

1. Shop load related
2. Production capacity signal

ToC production executions with a basic importance on giving upper level of solid due date performance (DDP) are DBR and S-DBR. Many practices show a remarkable improvement in service level, for the most part achieving a due date performance over 90% when implementing S-DBR by Hwang et al. (2011) or DBR by Umble, and Murakami (2006). Other measurements, what are mean of tardiness or due date slack time, were presented in some practices by few authors as Chakravorty and Atwater (2005), Gonzalez-R, et al. (2010). Capacity measurements are reflected to be a basic interest in the ToC application literature said Rahman (1998), to obtain maximum usage of the constrain.

A few case studies, resource usage becomes declarative variable than performance measurable. The nice example is investigation of impact CCR usage and specific assignment on operational performance measurement (Kadipasaoglu et al., 2000). Other case studies presented a serious increase in manufacturing capacity without similar enlargement of investment wrote by Hwang et al. (2011) and Murakami (2006). One core attribute of S-DBR must be considered and it is that market must be evaluated as a framework limitation. Accurately, this crucial importance on fulfilling current market needs is provided by S-DBR, which ensure high level of reliable due date adherence for manufactured products as mentioned by Jiun-Huei Lee et al. (2009). With consideration of the today market as sole limitations admit to S-DBR to want to know just one buffer in order to stick to the defined delivery due dates by customer. Mentioned unique buffer, that is named like shipping buffer, might be identified as the average of the time raw materials release during launch of routing to the completed job order. The major aim is to reach the shipping point said Schragenheim and Dettmer (2000). The initial importance in this method is controlling the achievement of the anticipated shipping buffer thru the implementation of different ideas, like the scheduled load or buffer supervision. The method to setups due dates which establish due date commitment towards of customer, according to the current load in CCR is called former. Also, the system for management of job priorities, that defined orders, which need another decision to meet the committed due date.

Though S-DBR is considering the needs like fixed constraints, it doesn't serve as limit the efficiency of this system (Schragenheim, 2006). As matter of reality planned load idea, that is the one of the main columns of methodology mechanism. It was developed to manage the internal CCR workload, that is part of the planning process.

Inputs:

Possibility to implement S-DBR begins with the assumption of that the enterprise is not actually limited by any resource coming from inside of enterprise. To be said in another way, the market is often the overarching limitation for many small medium enterprises. If the constraint is the market, the mix of the simplified DBR planning and high control permitted by buffer management results in complete dependence of activity to sales (constraint). Nevertheless, when a CCR start to come out the further very important changes are noticed:

1. The reduced capacity of the internal resource limitation may hold the company's capability to react to the market.
2. More or less job orders can't be stick to the defined dates.
3. To keep this condition from degenerating even further, either some of the market needs must be eliminated, or capacity must somehow be raised. (Schragenheim and H. W. Dettmer, 2000.)
4. The current lead time from raw material release to order realization and final shipment increases essentially.
5. Each part of product must pass thru of two buffers, which are covering different nonconstant operations (assembly and shipment).
6. Buffer management has three buffers and each of them must be organized and controlled.

Summary of S-DBR methodology:

Summary focused on S-DBR in Make-to Order environments, but the approach also covers make-to-stock and hybrid environments. The market needs are the main constraint and capacity controlling of the capacity constrained resource (CCR) is crucial and might be very easily done thru the planned load.

Buffer management is needed condition for successfully application of S-DBR. Next condition, which is needed for sustaining of delivery reliability, is to have sales completely incorporated with operations. Operations come up with realistic safe dates, that are monitored by sales. Managing reliability for urgent orders is possible but needs to have a capacity reservation without losing precious capacity from the CCR.

S-DBR is extremely fit for enterprises, which are focused on reliability of due date performance. The existence of many products is not a roadblock for a methodology.

S-DBR is described like a very variable method, that the comprehension of new products does not bring to confusions.

S-DBR evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	+6	What is described by Schragenheim and Dettmer, (2000b) that approach of S-DBR method is, which release order for all materials at the same time. S-DBR is using simple approach for production planning. If product is folded from more component, we have to maintain more shipping buffer for control at assembly points.
	Product mix - Many products	+6	According to S-DBR there is any problem to work with mix of products. The WIP is replaced by buffer time and it is as protection without maintaining safety stock for each product what is too expensive. This is mentioned by author (Schragenheim & Dettmer, 2000a). The authors Hwang, Huang, and Li (2011) described practical point of view and it means that buffer time is set for more groups of products and due to reason, it doesn't need estimation time for process for each product.
	Level of customisation - Mushroom customisation	+6	S-DBR is flexible system because planning is simple and is based on one buffer and due to mentioned fact there is not chaos, if there are included new products without planning sequence which is typical for CCR. (Schragenheim, Weisenstern, and Schragenheim, 2006a)
Processing Characterisation	Process pattern – batch flow	+6	Complication with implementation of S-DBR can be shop-floor, where CCR location are under frequent changes. This is proposal from Schragenheim (2009c). And due to reason (Stevenson* et al., 2005) recommended to

			use S-DBR for regular shop- floor with batch flow.
	Setup time - independent setup times	+6	Schragenheim et al. (2009c) described S-DBR as method where planning is maintained with less details and is using just on buffer time. Additionally, Schragenheim et al. (2009c) said, that alert that characteristics as is one buffer time or less details can be limited for complex process in production. The one case which is determined for protection of capacity of the CCR is set requiring a sequence.
	Level of training - Low operator skill	+6	Plenty of experiences recommended S-DBR method S-DBR is appropriate for PPC system for job-shop environment, which need and have low skills of operators. This theory is confirmed by Sedano (2011) and Alvarez (2013) according to results in Latin America where is job- environment with low level skills and training of operators.
Market Requirements	Due date adherence - Delivery reliability	+6	Companies which want to achieve reliable due date performance (DDP), where the S-DBR is recommended and suitable. This method is a way for improvement of DDP wrote Lee et al. (2009). Author (Jun-Huei Lee et al., 2010) recommended this method for successful results related with DDP performance.
	Repetitiveness level - Repetitive production system	+6	If company has repetitive group of products and this group consumes production time in large scale so bottlenecks are stationaries what is mentioned by Cox III and Spencer (1998).
	Volume demand variability - Moderate volume demand	-3	Bottlenecks are risk of high-volume demand because resources are not usually CCRs generated for oversized orders. (Schragenheim et al., 2009c) Recommendation in this case is divided order into smaller deliveries and after that is possible to decrease pressure on production and still is keep benefit of a large order. (E. Goldratt, 2006)

Table 6: S-DBR evaluation in SME environment (Own work)

3. 4. 7. CONWIP (Constant Work in Process)

CONWIP is method, which is used for production planning and control. It fits to job-shop manufacturing environment. With CONWIP usually company control the work-in-process stocks said Spearman, Woodruff and Hopp (1990). CONWIP is option to the KANBAN in pull manufacturing. The same time there are benefits to controlling the WIP stocks, it also consists from following pros Spearman et al. (1990):

- Reduction of stock levels and throughput time.
- Offering the adaptability for material flows on the workshop.
- Visualization of manufacturing process effectively.

As listed upwards, it's understandable that CONWIP is focused to improve lead time on the shop floor. CONWIP method is using a set of the cards in order to manage work in process stocks. (Figure 10) (Marek, Elkins and Smith, 2001)

During reception of the order, the raw material will obtain a card, which confirm the reception and identical card will be used to accept motion of the material on the next workshop till the time, when the production of final product is finished. At this time is card released, as a result is allowed to enter new material into the operation process.

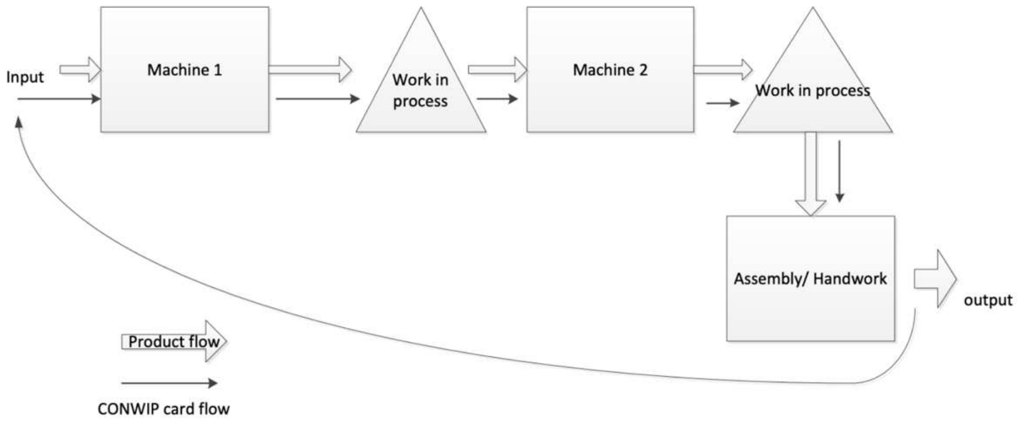


Figure 10: CONWIP method (Modified from Marek et al., 2001)

As being visible in the picture up, the product flow is launched, as the material is entered into the workshop the bottleneck is occurred. The WIP will be built between each workstation. CONWIP method provides very good flexibility from point of mix of numerous items in comparison with KANBAN. It is due to the one global set of the cards (Marek et al., 2001). The main differences are card loop in a CONWIP system, because CONWIP in count with manufacturing shop floor as whole production line.

The containers of items contained a cards at the beginning of the production line and unfasten on at the end of production line in order to be placed to a new job order. Every box passes thru the production line flow, which is part of CONWIP system. System has approximately the balanced number of the work. Entry time is placed on the CONWIP card, when the new order enters into the system. In CONWIP is used first in first served sequencing method.

CONWIP has been described as a mixture to the low variableness of order control (Thurer et.al 2016). Purpose of CONWIP is to make sure balanced workload. Each product involved in the CONWIP system must have roughly the similar workload at the bottleneck, because each product to be appear for CONWIP card. The quantity of cards set level of workload. When the job orders vary in workload, system will have different levels of work mentioned by Stevenson (2005).

Advantages of CONWIP:

As has been mentioned already the CONWIP decreases throughput time, for instance the time needed for a product which must be produced by going thru the all manufacturing process steps. Main benefits of CONQWIP are:

- Reduction of stock levels.
- Offering the flexibility for material flows on the workshop.
- Visualization of manufacturing process effectively.

According the benefits listed previously, it is under stable that CONWIP objectives point out on optimized lead time with support of continuous improvement on the workshop of operations.

Stump and Badurdeen (2012) characterize CONWIP to be used in make to order manufacturing. It fits to standard model of final product, which is customized customer specification out of the standard catalogue products. Stump and Badurdeen (2012) applied CONWIP in company which main product was manufacturing of ships. The firm is producing on stock, but 80% is Make to Order. Production of working groups are divided into three and they are controlled by CONWIP. It is manufacturing, assembly and inspection working groups. The components are supplied to main working group. As a first steps for application of CONWIP in process must be established quatity of CONWIP cards and sets in WIP. For that is used imitation, which is launching with increased number of cards. It is performed due to a few CONWIP cards will freeze up the manufacturing working group. This will cause decreasing of efficiency and increasing of lead time.

Inputs

CONWIP assigns work to a card by obtaining a backlog, or pre-shop queue. As a first work order on the list with raw materials and parts or sub-assemblies is ready to release on workshop layout. The backlog is organized by production and inventory control workers. It's created by master production schedule, and also managed and change around. There are no unique pre-shop release rules in CONWIP. As has been written by Spearman, (1990) is that, any job must be forced on the workshop layout without a card available. To determine the quantity of cards for CONWIP method, Marek et al. (2001) propose a formula already described a couple rows above. To evaluate throughput time and push forward in a CONWIP system.

CONWIP in operation should be controlled by bottleneck resource for instance WIP, finished goods inventory (FGI) and order lateness (service level)

Prakash and Chin (2015) categorized CONWIP resolutions characteristics related to:

- order release procedure
- accumulation of workload measure
- workload control procedure
- workload control method
- establishment of card
- dispatch rule

Internal loop of CONWIP method has three obstacles, which that might obstruct applicability:

1. Work must come and leave the shopwork at designated points to control the CONWIP loop system.
2. Job orders must come at the similar workstations, and flow of the work order had not divided.
3. Workstations quantity covered by a CONWIP loop shouldn't be too long mentioned by Thürer (2016).

As was written in first two bullet points, the load on every station must have stable workload. When the order is splitted, then machine may be overloaded, while another one can have starvation.

Thurer (2016) is saying, that first rule is unneeded, because rule is saying that all job orders must come to the same workstation and in the same sequence. It indicates that entry point and exit point are same for each job order. Every workstation must have at any time minimum at least one job order in order to avoid starvation. Any system, at any time with 10 workstations should use minimum 10 cards and a system with 90 workstations should use 90 jobs. While the system logic in literature is running like pair, but when we look on it closer, might be said differently.

When the system with ten workstations have ten cards, every workstation can have minimum one job. It is valid when every workstation time have same during processing. When the workstation from one up to nine a processing time of one unit, and workstation ten has a processing time of twenty units, just workstation with full utilization of processing time will be workstation with ten units. On top of that, there will be extension of stock in front of the bottleneck. Said with the logic idea where will reach workstation ten in nine units of time, given lead time of workstation one and nine is nine units of time. Can be said, that when workstation ten finish a job, there must be a new job promptly available from workstation nine, or like stock. If the only two cards are applied, there will be stock of one work in front of workstation ten. The needs described by Thurer et al. (2016) and vice versa denied by Prakash and Chin (2015), who showed that CONWIP has positive outcome in semi-conductor industry where is MTO with job shop organization. It's reached due to the better product routing flexibility. Also, Stevenson (2005) present, that CONWIP is best fit solution for general flow shop, where Thurer (2016) has been claimed and argued, that CONWIP relevance is limited only to a pure flow shop.

Summary of CONWIP methodology:

CONWIP method is a production planning and control method, that guarantee a permanent and restricted level of work in process. It's made with obtaining the capacity of bottleneck(s) in the manufacturing and determination of the amount of work needed at the bottleneck for every work order. Work orders with identical work volume needed at whole system belong at the same time in a manufacturing loop, use cards to release a new job order at any time a job is done.

As matter of fact CONWIP is judged as appropriate for a repeated products and minimal changes. Also, CONWIP deal with good flexibility of various mixed products. MTO manufacturing companies have a little bit issue to achieve good due date performance in case of CONWIP.

CONWIP evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	+6	In fact, job-shops environment with repetitive and a low number of products and with a limited engineering changes are conditions linked with CONWIP method for this kind job-shop environment.
	Product mix - Many products	+6	The method CONWIP is flexible to process mix of various parts due to existing of one set of cards which are global (Marek et al., 2001).
	Level of customisation - Mushroom customisation	-3	The company makes to stock, but 70 % is MTO. Customer product is according the basic model custom made specification and out of a catalogue range of variations.
Processing Characterisation	Process pattern – batch flow	+3	Stevenson (2005) describes CONWIP like a perfect way in flow shop with batch flow which is as general. Thurer (2016), argue that CONWIP limited to a pure flow shop only.
	Setup time - independent setup times	+6	For CONWIP methodology is important set-up of time by sequence. Problem related with planning can happen, when time which is needed for setting is coming out of sequence decision. (Missbauer, 1997). Krieg and Kuhn (2004) described when we can say about independent sequence and it is to avoid the setup change and decision when and if next setup should be developed.
	Level of training - Low operator skill	+6	As mentioned in subchapter CONWIP, effectiveness of training activities during the CONWIP implementation process, however that employees have a low level of education.
Market Requirements	Due date adherence - Delivery reliability	+3	If companies want to achieve satisfactory performance of due date so CONWIP method are missing elements for MTO manufacturing companies like customer enquiry, order entry, order release are not as standard for CONWIP method (Stevenson* et al., 2005). Exist a few practices and evidences, where is

			used CONWIP method in MTO environment and due date performance is very low.
	Repetitiveness level - Repetitive production system	+6	Organization where are high level repetitive products are appropriate for production planning by CONWIP method (Abuhilal et al., 2006).
	Volume demand variability - Moderate volume demand	-3	Akturk and Erhun (1999) recommend implementation of CONWIP method for production planning in job-shop environments where is group of standard products, that have high volume of products and low variability of demand.

Table 7: CONWIP evaluation in SME environment (Own work)

3. 4. 8. POLCA (Paired-Cell Overlapping Loops of Cards with Authorization)

Paired-Cell Overlapping Loops of Cards with authorization (POLCA), is as a hybrid push-pull system defined for HVLV to achieve a reducing throughput time. With the goal to cope complexity and dynamism of this approach present Shi-chao et al, (2012). POLCA method is created base on card and this card is a representative for signal about availability the capacity.

As Krishnamurthy and Suri (2009) described which pre-condition for implementation POLCA must have. One pre-condition is that, we need to have high level for Material Requirements Planning (HL/MRP).Authors mentioned about second pre-condition and it is some of system which is able to get estimate of lead time, capacity as well and manufacturing based on cells. As is mentioned above POLCA must use High Level Materials Requirements Planning (HL/MRP) and acc.to this is done selection and review of jobs which are approved. HL/MRP is as help as well for planning between cells. POLCA method is used as controller and manage of material movement between cells and HL/MPR has task to control mix. Authors Stump & Badurdeen, (2012) refer to that POLCA is as controls of flow between cells but sometimes is requested different control and from this point of view can be used other method Kanban.

MRP planning system is the main function used for POLCA. MRP is working as calculation when is earliest date of release order and this date is earliest date of expectation that order to be confirmed and materials to be available. Good description how is calculated this system is done by Thürer et al., (2014). One of difference between standard MRP and POLCA system is that POLCA limit the way of the order.

The way for release of order by MRP and by POLCA is different. POLCA release the order just if are capacity available and standard MRP release the order in the time earliest date of release. How is works the POLCA is demonstrated on one example. We have three stations with marking A, B, C. From these stations we can get pairs of stations and that are contained in a product way. Way of product A-C-B are existing two card with combination AC and CB. In case when on station A is earliest date release so product to be realized because we have available card AC. Until to finishing of product on station A and station C is still for this product assigned card AC. Availability of card CB is point for starting production at station C. If card is not available production cannot be started. Without new card can start production at station B earliest release date and it is due to ending of the products way.

Krishnamurthy and Suri, (2009) identified four phases for implementation of POLCA. First is pre-POLCA assessment for using, second is design of POLCA, third is start-up phase of POLCA implementation and last one is evaluation of post-implementation of POLCA. Earlier as we will implement the POLCA so should be sure that cells have enough capacity for ability of required performance. It is needed to do review for confirmation. POLCA as method required design of way identification, workload values, documentation with procedure how to compute quantity of cards. Start with application of POLCA is not so easy. For good implementation is needed training, education and reviews on regular basis.

Implementation must be evaluated by key metrics and metrics must be measured, monitored. Acc.to measurement to be see effect and benefits of implementation.

Parameters as Lead time estimation, order confirmation and confirmation availability of material from MRP system are inputs for POLCA and with these parameters is possible to do combination of two cells. Riezebos et al (2009) In publication published by Riezebos et al (2010) claim that POLCA is using for improvement of throughput time control by three categories of tools. These categories of tools are:

- Routing - Specific routing of cards assigned to jobs
- Release - list of jobs by initial launching times
- Facilities - allow operating the system in factors

From point of view related with comparison Riezebos (2010) state that POLCA can be called as method with certain route. As for comparation Kanban is defined such as exact product an CONWIP is defined as product anonymous. Pure flow shop (PFS) when all products has the same way and General flow shop (GFS) when the all products has several difference but flow is in one direction so acc.to case studies by Krishnamurthy a Suri (2009) point of that in these two case implementation of POLCA is effective.

Inputs:

The POLCA method has been built on three core pillars. First of one is confirmation of orders with second pillar checking of availability of material and it is check by MRP system and last one is confirmation of capacity. For prevention of poor work or the not correct orders must be correct date of release which is defined by MRP as earliest. This can be happened, when the date is defined sooner or too late. Thurer et al, (2016) For determination of capacity we have to know two variables: routing of paired cards and quantity of cards. These two variables are as determination by Riezebos (2010). The values as lead time from stations, waiting time for pair card traveling time from and to receiving station and throughput rate in concrete pair of cards express quantity of cards. The quantity of cards for pair of cells are counted with formula state by Krishnamurthy and Suri (2009).

$$Ni/j = [LTi + LTj\ ] \times NUMi/j/D$$

LT – means ~~is~~ lead time of each cell

NUM – means the sum of jobs that go from cell i to cell j.

D – means the time of the scheduling period. The time are calculated in days.

Delay of production can be influenced by hold-up in front of each cell and Riezebos (2010) point out that waiting times should be included in this formula. The need for average lead times is also mentioned but is theoretically implied by Krishnamurthy and Suri (2009). Traveling time between cells is state also by Riezebos (2010). The formula which are below define that wating and traveling time we can remove and, in this formula, to use estimated safety allowance.

$$Ni/j = [LTi + LT] \times (1 + \alpha) \times \lambda$$

α – means waiting plus travel time and these values are split up by lead time

λ – means thru rate of jobs (Riezebos, 2010)

The way for release of order is specific because is needed to estimate quantity of cards. This is mandatory that release of order must be set earlier then is this order release to the shop-floor.

Summary of POLCA methodology:

POLCA apparently suit well with HVLV manufacturing. Release of order by method POLCA is based on MRP and this MRP system is linked with capacity which are available. What can be one of restraint the setting of way. According to Stevenson et al (2005) using POLCA as method for PPC has two disadvantages. One of is kind of MRP system because MPR is too difficult to use in MTO companies and implementation of this method to be without effect and without benefit for MTO companies. This method used paired-cell nature and way must be with one direction and it is second disadvantage.

POLCA evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	0	The POLCA method is characterized by BOM (Bill of material) but it depends on MRP. MRP is tool to support easy management of products which are composited from many parts (Bertrand and Muntslag, 1993). The simple products don't affect to efficiency of MRP.
	Product mix - Many products	+6	POLCA method is suitable for production with HVLV. The one blocking point is set of routing
	Level of customisation - Mushroom customisation	-6	Execution of POLCA in organization with high level customization of products is demanding challenge. The main challenge is the complexity of adaptation a process to a new product.
Processing Characterisation	Process pattern – batch flow	+6	Stump and Badurdeen, (2012) stated, that POLCA has no effect when variability of routing is too low.
	Setup time - independent setup times	+6	Independent set-up time has positive impact for application POLCA method.
	Level of training - Low operator skill	+6	Suri (2009) stated, that POLCA is very simple and quickly applied and unique

			software is not needed. Expenses for implementation are too low.
Market Requirements	Due date adherence - Delivery reliability	-6	Stevenson et al. (2005) mentioned that POLCA method connected with the MRP. There is poor determination of due date, because the customer enquiry for due date is based on planning of capacity. Except of missing due date, the MRP has gap related to control, entry and release orders which are based on DDP. M. Gupta and Snyder (2009) have stated, that MRP can't achieve high reliability of DDP. For that reason, it's needed to split the flow material from available capacity.
	Repetitiveness level - Repetitive production system	+6	In POLCA system existing demand variability. but the presence of a repetitive production system is beneficial.
	Volume demand variability - Moderate volume demand	+6	Kabadurmus (2009) proposed, that POLCA method has positive impact to the job-shop environments with high variability demand.

Table 8: POLCA evaluation in SME environment (Own work)

3. 4. 9. WLC (Workload Control)

Who was as first researchers with explore of workload control are Land and Gaalaman (1994) and their goal was to find way for optimization the hoarding queues before workstation at shop-floor. They recommend the optimization of waiting times because and it can be effect on manufacturing lead times. How to find right way for implementation of WLC is described by Stevenson et al (2011). Description of this method is defined as very effective tool for production planning control for small enterprise company which are working acc.to MTO. Method WLC is appropriate for small job-shops which are in facing with high customisation and with high variance of demand. Land and Gaalman (2009) state that this method is compatible for these small job-shops. WLC as method is something like optimization of lead times. Focus is on overall lead times. Due to the fact is planning split to categories acc.to planning lead time. Following Land and Gaalman's (1994) theory, Hendry et al. (1998) defined three degrees as possibility for control:

- Dispatching degrees as priority it means as control degree the day-to day on shop-floor
- Degree for order release it means as degree for planning the short-term manufacturing

Degree for order entry it means as degree for planning the medium-term production

Hendry et al (1998) has split of two levels described as important for production. First level is related with entry of order so is process of receiving and processing, confirmation of delivery dates to customer. Second level is focused on sequence of orders which are to be released for machine and which machine to be assigned. As well this level is as information about goal for start of production.

Research done by Stevenson (2006) is described that problem can come if we will have increase orders, sequence which is depend on set-up time. Lack of strategic approach can be reason of these problems. In next publication written by Stevenson (2011) is confirmed base on research that more researchers reached the success by reduction of lead times and inventories by WLC method.

Stevenson (2011) proposed how to be successfully with implementation of WLC method is describe on Figure 11 and we can see three major phases.

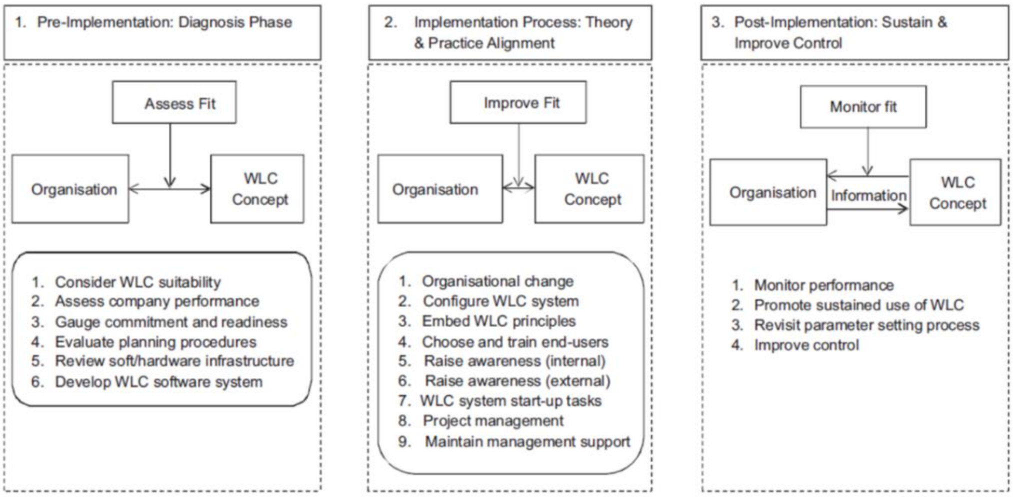


Figure 11: Application approach for WLC (Adopted, Stevenson et al., 2011)

First phase where is done the assessment of compatibility theory of WLC and company and is called as pre-implementation. This assessment is performed acc.to criteria which defined by Henrich et al. (2004). As the second phase is taken to account the implementation process which is state by Stevenson (2011). We can use this phase for definition of solutions for gaps which are between theory of WLC and company. This phase can bring request for reduction or shorter of set-up time. The last phase is post-implementation and in this phase is characterized by monitoring, improvement and focus is on all work-in process.

Two authors and one of them Henrich et al (2004) designed assessment criteria and according to these criteria next author Stevenson (2011) give suggestion to follow these criteria at the first phase.

One of the reasons is that construction of framework is based on consideration of characteristics which are coming together with coming orders versus shop-floor capacity. The characteristics are (Adopted, Henrich et al., 2004):

- Arrival date (A)
- Due date (B)
- Technological requirements:
  - Operations (C)
  - Routing (D)

The attributes may fluctuate among organisations, especially for SMEs. In the Table 9 are mentioned indicators of variability:

Characteristic	**Indicator**
Order arrival dates	A1 – Arrival intensity
	A2 – Inter-arrival time variability
Due date requirements	B1 – Due date tightness
	B2 – Variability of due date allowances
Operations	C1 – Processing time lumpiness
	C2 – Processing time variability
	C3 – Set up/processing time ratio
Routing	D1 – Routing sequence variability
	D2 – Routing length
	D3 – Routing length variability
	D4 – Routing flexibility
	D5 – Level of convergence

Table 9: Characteristics and indicators (Adopted, Henrich et al., 2004)

Connection of functional correlation among aspects characterized of WLC and characteristic of the firm is demonstrating in matrix. This matrix can be used by researcher for identification of criteria.

- What is typical for job shop is that one of main control point is the release order. Anyway, influences regarding long flow or sequence variety are bring discordance which is impact for release of orders.

- Workload of aggregate values of each individual processing time are regarded as aggregate measures. Simultaneously are as support between throughput processing time and workload.
- High intensity of arrival and with short processing time is good way for organisation and their flow.
- To come into conflict can be in shop-floor buffering due to with due dates which are too tight. We can do correlation of these differences. It will be corrected by waiting times which can be longer and shorter.

If we can achieve load balancing which is perceive as central, so it is needed to reduce mainly in queue of lengths and to take to account variations in arrivals, sequences and processing times. Anyway, we can see some disputes due to requests related with reduction of set-up time. Nevertheless, disagreements arise concerning the conditions of set-up time reduction. It's the best fit for an average MTO organisation.

Order release and also flow of work which is amongst the manufacturing phases is just right method workload control. This method is using control of total WIP throughout a production. As is mentioned right by using this method we can perform control two points Order and flow of work (Mortágua et al., 2014). We can do it if we have transparent situation on shop floor which we can achieve if we will have holding back accepted jobs. This approach allows to provide fast feedback about job status. (Oosterman et al., 2000). Marangoni et al., (2013) present that we can consider three levels of control. First is level related with order entry, second level is acceptance of order and third level is the release of order to production. As a priority of dispatching is selection of job which is in front of a workstation at the shop floor. Lead time in WLC is illustrated in Figure 12 Stevenson (2006) showed that methodology LUMS/LUMS COR which was established at Lancaster University (Lancaster University Management School order release) content third level of control. Method LUMS/LUMS COR is using in system for order release. This level is oriented on customer inquiry phase. Approach of method LUMS/LUMS COR is based on rules. WLC method has more operations steps and for solutions of each steps are exist designation:

1. Station

2. Stage
3. Work center
4. Operation

Thürer et al. (2012) stated that if we can achieve the lean so key element is to use method Workload Control and because there is secured the protection of throughput from variance. Mortágua et al. (2014) as well highlighted that WLC is good solution for proper production planning and control (PPC) using in company which are in HVLV environments and are called as small manufacturing enterprises. Bertolini et al. (2015) are in align in conjunction with definition that WLC is part of pull systems and acc.to these systems are possible to achieve the goals in MTO-HVLV. The main point why is WLC the one of best way is that by this method are covered main segments as are bottlenecks and high variability. One of point what is characterized WLC is explained following as: the WLC work cannot be released if WIP is not on achieved limit which is defined. In this case is difference between CONWIP. Because WLC has value for work content and it is contribution for job. Calculation of job to the complete workload is overall performance time separated by place and it means which production phase is for product in present. Level of controls workload is managed by methodology WLC and controls number of jobs is managed by method CONWIP because these controls amount of jobs are presently has functional status in the system. Level of controls workload is managed by methodology WLC and controls number of jobs is managed by method CONWIP because these controls number of jobs are presently has active status in the system. As (Riezebos,2010) described the convert of production order to workload content is no needs. Workload should be controlled at each phase of production because the point of achievement for WLC is to control immediate load on low level which should be stable as well. This is one of main point for achievement of WLC. As decision element for next release of jobs to the shop floor are the three concepts as is measures immediate load, aggregated load and shop load. These concepts are base for equations and are used for calculation of workload. Measurement of direct load is working in job shop due to fact that achievement of measured phase is see in short time after release. This measurement of direct load is as argument of WLC. The lack of time can come if the flow is directed and for that reason job shop have to pass thorough all phases upstream earlier as is reach the phase where is measurement of immediate load. The immediate load in front of a station measure aggregated load. Except of this measurement is assumed that the load support of all work is released and sits upstream. Aggregated load is measured by shop load and workload is added which be finished downstream. Based on theory of author Wiendahl (1995) are the calculations supported by method the load conversion.

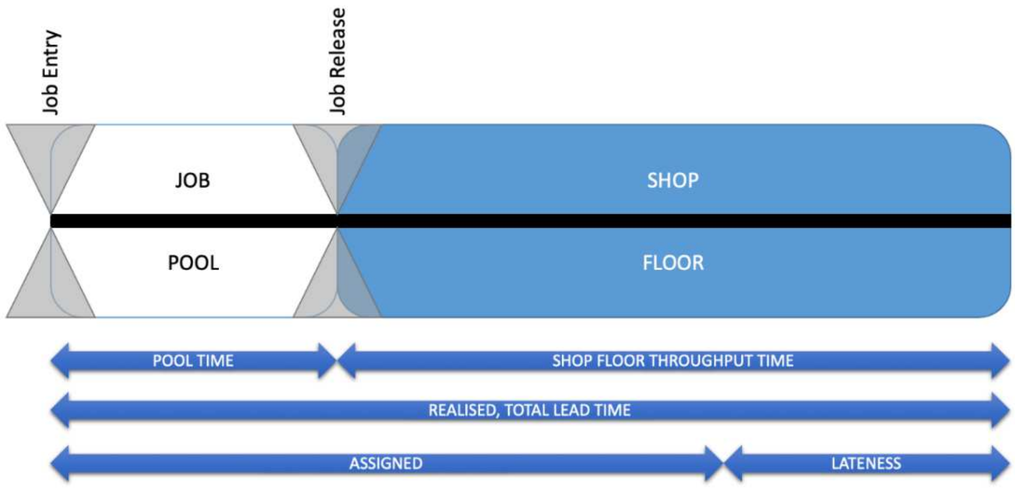


Figure 12: Lead Time WLC (Oosterman et al., 2000)

Thürer et al. (2012) is did research about release methods which are suitable for WLC and one of them is method CONWIP which is included to these release methods. Author did comparison continuous methods and combined continuous and periodic release method. Conclusion of this research is statement that all methods defined as continuous release method exceed all methods defined as periodic release methods. Benefit from research is done by Oosterman et al. (2000), their investigation found, that release method CONWIP is more exceeded with other release procedures. The major focus of of Thürer et al is to investigate and compare using with other methods how is used this release method “Lancaster University Management School Corrected Order Release” (LUMS COR) and a hybrid periodic/continuous release method. LUMS COR is method for release work from pre-shop pool to the shop floor and using comparison the workload and contribution of job to work centres in direction which are set limits for workload. (Thürer et al., 2014). The methods which are called as continuous are “Superfluous load avoidance release” (SLAR) and “Work centre workload trigger planned release date” (WCPRD). SLAR is system working on based release jobs if any work centre is not fully used and it is means that jobs is not any urgent in front of the work centre. When we have direct load and this load is in front of work centre so WCPRD release a job and for that reason direct load in front of work centre will be under lower bound designated border. We can say that WLC has impact on improvement of performance as Planned Operation Starting Time (PST). Next investigation is done by Thürer et al. (2014) is oriented on more increase of WLC performance. They investigate influence of Customer Enquiry Management (CEM) and their effects of WLC.

CEM has focus on setting more precise due dates and it is impact on increasing of accuracy of pool selection rules and shop-floor shipping rules. These two rules are including due dates in job choice as PRT and pre-shop pool choice defined by (Mortágua et al., 2014) or PST, shop-floor dispatching defined by (Thürer et al., 2012).

Mortágua et al. (2014) simulated diversely function of methods for release in flow shops which has one direction of flow. Selection for simulation is in two approaches which are related with workload bounding and workload balancing. Release of job from the pre-shop pool is defined for workload bounding. This can be valid if levels of production are within un upper limit through all phases of process.

Second approach is release of work which is defined as workload balancing. This approach is as improve balance of work which is thru the manufacturing process and as well permits for levels which are over selected with limit up to 50% of production phases.

Defined instructions for picking jobs from the pre-shop pool has been tested by Mortágua et al. (2014). For this testing are chosen three rules:

1. Rule: Earliest scheduled release time
2. Rule: Shortest processing time
3. Rule: Largest total work content

Mortagua et al (2014) simulated one of scenario where is presented hypothesis that MTO production has six phase system in two shop configurations and flow has two definitions as pure flow shop (PFS) and second flow is defined as general flow shop (GFS). Oosterman et al. (2000) describes the differences between PFS and GFS. Differences between PFS and GFS is that ways in PFS has all stages and GFS has variable number of stages. But we can say that if always is in an ascending order it is means that flow has just one direction. Sequence of job on each machine or station is performed acc.to priority to the job. It means which job is urgent is done with priority and with this approach we can avoid variance in lateness between defined jobs. We can achieve result with focus in due date and capacity production time and remaining way for the product. According data what we have is see if we use the pool selection rule, so this rule has small impact on performance of WLC and GFS. The better results of workload balancing are seen in the case standard variation of lateness on jobs and in case of delay on jobs. The much higher impact on results in a PFS has pool selection rule. If the release method is workload bounding so the impact is a visible. Workload balancing as result should be defined as method of release in PFS. Due to the fact that this release method is more robust.

Inputs

From all PPC´ methods which are described in this thesis, so Workload Control has the most inputs for my case. When complete advantage of WLC is required measurement of workload, then this measurement must be done continuously or periodically, and must be used based on rule of release and after that we can do control of workload on shop-floor.

Measure workload might be using rule of release for release work on the shop-floor. All rules for release and dispatching are described in the table 10.

Description of method	Categorization	Short explanation
Constant Work in Process (CONWIP)	Continuous order release method	Releases works when the amount of jobs on the workshop falls under a specified level.
Lancaster University Management School Corrected Order Release (LUMS COR)	Periodic and continuous order release method	It mixes regular with continuous release. Works are pulled to the workshop in amongst regular review, when a work centre is starving.
Corrected aggregate load (PERIODIC)	Periodic and continuous order release method	Releases works sporadically up to the workload norm.
Superfluous load avoidance release (SLAR)	Continuous order release method	Releases jibs when a work centre is starving or there are no important jobs line up before work centre.
Work center workload trigger planned release date (WCPRD)	Continuous order release method	Releases works when the direct load of any work centre drops under a established level.

First come-first served (FCFS)	Shop floor dispatching rule	The work that appeared at the work centre in the beginning to be selected from the queue line.
Planned operation start time (PST)	Shop floor dispatching rule	The work with the earliest scheduled start time at a specific work centre is selected from the queue line.

Table 10: Release and shipping rules (Thürer et al., 2012b)

Except of complex rules for release as is in case for other PPC´s is this overview required for rules in shop-floor.

Summary of WLC methodology

For summary of Workload Control methodology is defined as a good solution as optimal for PPC´s in environment where are designed different products and different customers. Methodology WLC has requires more requirements and information as others PPC´s. This split is in table 11. CONWIP is still one of valid rule release in WLC.

WLC evaluation in SME environment			
Scope	**Criteria for evaluation of PPC**	**Outcome**	**Arguments of outcome**
Product Characterisation	Product structure - Simple products	+6	The WLC method is basically with released for pre-production and after release of material from incoming phase and it's proved that they are accessible. By reason of this can be seen, that when a few components exist, complexity of products might be reduced. Stevenson and Silva (2008) gave an evidence, that execution of WLC method in job-shop organization with product difficulty have impact on calculation of due dates.
	Product mix - Many products	+6	Some articles recommended the WLC method as appropriate for job-shop environments which are characterised with product mix and their high variety. Eivazy, Rabbani and Ebadian (2009) saying, that WLC method is important for companies which have high variety of products.
	Level of customisation - Mushroom customisation	+6	Henrich et al. (2004) presented about level of customization, that the WLC method is appropriate for MTO and job-shop manufacturing because these environments have plenty of various customers with different design and requirements of product.

			Author Hoeck (2008) described, that WLC method is appropriate method for companies with high level variety of products and Mark Stevenson and Hendry (2006) emphasized that implementation of WLC in MTO with variety of product is needed due to fulfil customer requirements and expectations in order to be successful on markets.
Processing Characterisation	Process pattern – batch flow	+6	M. Land and Gaalman (1996) presented, that WLC is suitable for job-shops environment which is dynamic. Methodology WLC is very flexible and appropriate for solving of situations which are more complex. These complex situations are coming from real cases.
	Setup time - independent setup times	+6	Base of all elements of WLC i control point for release phase. After release of orders should be valid simple rule that these orders have to be as priority and has to be controlled. This rule may be infeasible for sequencing-dependent setups, which may require joint progress control of the orders released on the workshop.
	Level of training - Low operator skill	-6	Plenty of accurate data is needed for feedback if job has progress is similar as for MRP. Proposal for WLC is to have a procedure for sequence. This procedure requested all information in continuous flow about buffer contents. To the attention must be given, that when training or education of people on shop floor will be done by staff from shop floor, it can happen that unskilled staff gives not correct training. That can be a big blocking point for application WLC with success.
Market Requirements	Due date adherence - Delivery reliability	+6	The mandatory rule for implementation and keeping of WLC method is monitoring of lead times by controlling of workloads (Wiendahl, 1995). This rule is significant for MTO companies and can make easier handling of due date of orders (Henrich et al., 2004). Stevenson et al. (2005) mentioned that the original base of WLC is designed for achievement of high DDP by integrated of customer enquiry with focus on backlog of shop, when DD is determined.
	Repetitiveness level - Repetitive production system	+6	Hoeck (2008) presented, that the WLC method supports job-shop environments where is required high flexibility and production has low-volume level of products.

	Volume demand variability - Moderate volume demand	0	The WLC method according to Henrich (2004) is well suited for approach with short processing time and workload with plenty tasks. When mentioned characteristics are applied, then it supports to generating foreseeable lead time.

Table 11: WLC evaluation in SME environment (Own work)

3. 5. General summary of methods

With general summary list of PPC methods overview, it has been feasible to highlight pros and cons of evaluated production planning and control method. It was done with support of defined evaluation criteria. Summarized data is reviewed and introduced in the Table 12, where S-DBR has been evaluated as the best method with comparison of the others PPC methods.

General summary of PPC methods							
Scope	**Criteria for evaluation of PPC**	**KANBAN**	**DBR**	**CONWIP**	**S-DBR**	**POLCA**	**WLC**
Product Characterisation	Product structure - Simple products	+6	+6	+6	+6	0	+6
	Product mix - Many products	-6	+3	+6	+6	-6	+6
	Level of customisation - Mushroom customisation	-3	+6	-3	+6	+6	+6
Processing Characterisation	Process pattern – batch flow	-3	+3	+3	+6	+6	+6
	Setup time - independent setup times	+6	+6	+6	+6	+6	+6
	Level of training - Low operator skill	+6	0	+6	+6	+6	-6
Market Requirements	Due date adherence - Delivery reliability	-6	+6	+3	+6	-6	+6
	Repetitiveness level - Repetitive production system	+6	+6	+6	+6	+6	+6

	Volume demand variability - Moderate volume demand	-3	-3	-3	-3	6	0
	Total score:	**+3**	**+33**	**+30**	**+45**	**+24**	**+36**

Table 12: General summary of PPC methods (Own work)

The lowest evaluation score has KANBAN method. KANBAN has not been positively evaluated for MTO environments. One of the major arguments have been low due date performance in a customer enquiry, job entry and release stages said Stevenson (2005). It is supported by arguments, that KANBAN method has lack of elements to reach high rate of DDP. It was also confirmed in several case studies, that poor due date performance has been reached (Huq, 1999).

As have been written in reviewed literature the KANBAN production planning method was linked mainly with repeated production environments with a small number of products and a few developments changes (Abuhilal et al., 2006). It can be said also, that from point of the product categorization, the KANBAN is supporting simple products. It influences stock inventory in positive way. The KANBAN is most of the time applied in the pure flow shop manufacturing scenario. (Rodríguez et al., 1998) (Stevenson* et al., 2005). The problems can appear, when direct job orders in shop floor will missing. It will cause troubles demands prediction and scheduling of work in shop floor (Gargeya & Thompson, 1994). Finally, with the comparison to the other PPC methods, KANBAN is not well suited in MTO manufacturing.

Among the evaluated methods, the WLC method is matching very good into the MTO environment, that is on the third place. It is caused mainly, due to the serious information flow, that is needed to keep system running. The WLC needs good IT hardware and software and very good trained persons who maintain and manage production information thru IT.

Companies with MTO environment has key indicator is due date so WLC system is solution but should be more investigate another influence. WLC method is suitable and implementation is possible in environment where is dynamism. It means many variable ways from point of lead time. This is described as internal dynamism.

In the fact, the increased due date tightness in the SME environments can cause disputes with available system parameters with keeping rows before defined resources. During review of collected literature, it was recognized that WLC pool waiting time is not well matched with restricted due date allowance in SME environments.

When comparison to be focused only on WLC and DBR method, the WLC method is better appropriate option as can be seen in table 12. The score is better. On another point of view reduced needs regarding to the information distribution, volume and precision, the DBR method is well suited for enterprises, where higher IT level is not needed.

One of the pros of the DBR method is controlling of job orders. It's essentially simpler and needs smaller portion of information like WLC. That is supported by buffer management (BM). It can be applied like visual management control. This is improving due date performance of company. Such results are in line with delivery dependability. On opposite side WLC method, demand variables have a little impact on scheduling of production. In the end can be summarized that the DBR seems to be more feasible solution to apply in SME environments, but it has limits until now.

For predictable production we can say that WLC is the best solution. This methodology with steps which that are a good solution for management of demand because for environment of MTO is demand unpredictable and unstable. With this methodology is possible to achieve levelling in MTO and base on this it is appropriately for type of environment as is MTO.

WLC system is unique for reason is a very good managing of variability and it seems that WLC is one of the best PPC solution for MTO. WLC is methodology which analysed all ways for release of work. Due to that are orders released to the shop floor with the biggest possibility of using. This way is as well prevention how to forestall of bottlenecks which can be occurred.

The S-DBR has the best result coming from the Table 12. It is mainly due to the simplicity of S-DBR method. The method has only one buffer and minor of detailed CCR planning. This makes method very flexible solutions in environments where are new products launched wrote Schragenheim et al. (2006a). One of other pros of the S-DBR method is option to apply very simple products. There isn't need many assembly stages, which may generate obstacles for S-DBR method in case of real application (Schragenheim & Dettmer, 2000b).

The S-DBR is most of the time found in general flow shop environment. The mentioned process pattern is suitable for specific system like S-DBR. It is caused mainly due to CCR, which is kept stable. As next pros the S-DBR requires a few information with the comparison of rest PPC methods. Control method in the S-DBR system is performed thru the visual management. There is not needed special training of workers (Hwang et al., 2011). The job order sequencing is limited by market, due to the existence of independent sequence of setup times (Schragenheim et al., 2009c). This make the reason for S-DBR application and creates good background for SME environment.

The S-DBR attempts to simplified planning complexity from point of process variance. The main target of S-DBR method is have low processing time variableness. It is reached by size of time buffer, set up for each specific product family (E. Goldratt, 2006). The arrival time most of the time in the S-DBR system is managed by mechanism, which is working that job orders are released half of a buffer time before an job order is dedicated to be processed in the CCR wrote (Schragenheim, 2006). The mechanism is called a pre-shop pool, where job orders wait and there are released by the availability of the CCR.

The S-DBR is considered appropriately variable in case of volume and demand variance. Schragenheim et al. (2009c) wrote, that unforeseen demand of manufactured products tends into detection of bottlenecks. Also, S-DBR is well-suited in MTO environments wrote Hwang et al. (2011).

The S-DBR is extremely suitable for enterprises where is important DDP rate. This is supported by CCR's capacity, where is set due dates thru planned load and the buffer consumption monitoring of available orders.

In the end can be concluded, that the major positive degree of S-DBR execution in SME environments is very constant due date performance. It's showed with eliminated slack time variance.

CONWIP system of PPC for which is not blocking point of the variability and can be managed, but to be sure that it is depends on existing of lead time which has stability.

CONWIP and DBR can be transformed to WLC systems if in both systems CONWIP and DBR are visible some "fixes" which are needed. It is clear, that system has stability during taking of time so we can see any implemented WLC in practice is changed to CONWIP and DBR.

We can say that WLC method is more difficult as is S-DBR. For that reason, S-DBR are implemented as first because on beginning of implementation in the system are plenty unknows and implementation of S-DBR as first is a little bit easier.

4. Case study

The section presents heuristic issues related to S-DBR application in SME thru a case study. As a first step is introduced suitable company. Later there will be explanation of the application S-DBR method and resulting of experiences with this application.

4. 1. Company description

The case study, which is following methodology discussed previously, small medium enterprise MECASYS as my case has been selected.

MECASYS is small manufacturing enterprise with interesting portfolio of products. Main raw material for their production consist of aluminium, stainless steel, hard steel and steel, which they are machined. They are offering to customer various services and products mainly for automotive industry.

1. Measuring and assembly jigs – here company provide services for customers from engineering up to manufacturing of finished products.
2. Automatic and Semi-automatic station - this product portfolio provides services from the engineering, up to manufacturing and final assembly of workstation.
3. CNC machined parts
4. Manufacturing and repairing of injection tools

The turnover of company is 1,4 mil EUR per year with 30 employees. Production strategy is currently 10% MTS and 90% MTO. Repetitiveness of product is maximum 15% of total production. Company has functional layout with general flow shop. Design of product most is 50% given by customer and rest is standard combined components. The management of the company is working according to customer´s requirements and they are offering to employees' opportunity for personal development, create good work environment and to be responsible for good job within the manufacturing process. The executive board of company is consisting of 4 members. Their positions are high management positions of the company. This management of company is accountable for establishing demands, management of staff, material, machines, production planning, production, delivery to customer.

The managing director has the overall responsibility for the whole company while also taking communication with customers, because company is considered as small manufacturing enterprise.

When an purchase order was received from customer, the acceptance is done by logistics supervisor after discussion with production manager and later is starting production scheduling, creation of technology and everything is depending on manual planning in software called CITO, where is created technology (routing) with time of operation. Production manager takes every time a conclusion, when to start production, that machines are associated, and which available manufacturing time is acceptable to book and consume. Production manager pay attentions also for any issues with machines, that point out on less organized preventive maintenance.

Company MECASYS is a producer of different goods as are gauges and fixtures which are used for measurement, components which are used for assembly of finished goods for several industries as is automotive, commercial and residential industries.

During the discussion with production manager, has been recognized that production and delivery of each product extremely depend on customer request. To be comply with customer demands and meet his requirements, the whole management must have ambition to delivery right product with the best quality and with on time delivery. Of course, with competitive price as well. Satisfying this market company must focus on the reliability in the delivery of products with priority.

MECASYS has two buildings.

First Building – production hall with machines and laboratory:

- 2x - 5 Axes CNC Milling machine
- 1x - 4 Axes CNC Milling machine
- 2x - 3 Axes CNC Milling machine
- 3x – CNC Turning machine
- 1x – CNC Bending machine
- Laser engraving JPT MOPA
- 3D CMM DEA PIONEER

- Raw material warehouse
- Scrap storage

Second Building – tool shop and assembly shop

- 1x Die Sinking Eroding Machine
- 1x Wire cut machine
- 1x Grinding machine (flat)
- Area for finishing assembly and injection tooling

Second key element which is blocking point for on time delivery has been identify during discussion with managing director. It's waiting time. It takes place at any level of production process for instance: during ensuring material, not running machines park or not available workers.

MECASYS is working according to make to order so changeover is critical factor for planning because it's connected with 3M – material, machines and man. If it is changeover occur frequently it is one point for not good planning.

MECASYS has plenty of various products and all of them manufactured are manufactured in a make to order production system. The call off difference from customers are extremely big for all parts and products during the year, which creates production planning and control more serious, because there are plenty of changeovers.

After identification of main potential root cause for problem with production planning. S-DBR method has been applied into working system as a new method how to manage production planning and control within company environment. Activities connected with this PPC method were applied according to theoretical background and theories.

Company MECASYS	
Product	Measuring and assembly jigs Automatic and Semi-automatic station CNC machined parts Manufacturing and repairing of injection tools
Sales	1,4 million EUR
Number of employees	30
Production strategy	90% MTO and 10% MTS
Repetitiveness level	At least 75% of the items are not repetitive
Level of customization	Standard components combined
Types layout	Functional layout
Types flow	Pure flow shop

Table 13: General information about company MECASYS (Own work)

The following results (Table 13) provide evidence that the selected company is appropriate for application of S-DBR, company is categorized like SME in MTO environment. It is in line with S-DBR method (Table 12).

4. 2. Performance measurement of PPC method

Since the PPC method into the SME environment of MTO manufacturing is going to be implemented. The appropriate performance indicators must be defined. Due to this reason, academic literature has been reviewed, related to how to measure performance of PPC method. Previously studies defined following performance measures, which are classified into four areas:

- time-related (Mean lead time, Standard deviation of lead time, Shop floor queue Time)
- dependability (Mean earliness, Due date performance, Mean tardiness, Maximum tardiness)
- shop load related (Utilization CCR, Resource utilisation, Location of the CCR, CCR production rate, Production capacity)
- finance-related (Throughput, Operating expenses, Sales volume, Profitability, Inventory cost)

The lead time is very often included in the ToC production execution literature said Georgiadis and Politou (2013). The lead time is period of time among reception of job order at the starting point and reaching end of process.

Many of literatures and studies are saying, that ToC production systems have significant lead time reduction (Hwang et al., 2011). The lead time in many practices has been defined as major key performance indicator of the productiveness of S-DBR procedures in various manufacturing environments.

With the S-DBR method applications can be emphasised, that due date performance indicator is very reliable. Another key performance indicator has been selected service level by many authors. It's basic for assessment of on time delivery performance. Many executed case studies report an essential progress in service level, that have positive impact on DDP which overrun 90% (Hwang et al., 2011). Last but not least due date slack time, average tardiness or average lateness are extra key performance indicators which has been measured and part of case studies said Gonzalez-R, Framinan, and Ruiz-Usano (2010).

Turnover indicates generated money thru the company. It's total sales. The stock (inventory) means money booked in raw material, in WIP and in finish goods stock. It consists of many numerous principal goods like buildings, features and machines. In the end operating expenses ensure, that whole money consumed in each company are converting money into company turnover.

Also a few studies took over financial performance indicators like due date according to currency value of products (Y.-C. Chang and Huang, 2011). It's named throughput currency per day.

All mentioned key performance indicators were applied in various cases and practices to see results of S-DBR or ToC in manufacturing environment from point of financial and operational performance. A few indicators are used in this case study to assess outcome of applied the S-DBR method, where is considered specific features of company.

The following performance indicators have been followed in case study:

- Due Date Performance
- Tardiness

- Turnover
- Cost of non-quality

4. 3. Implementation of S-DBR in SME environment

The case study provided information. What kind of difficulties have small medium enterprise in MTO environment? Such collected data has been analysed to identify correlations and differences in the S-DBR execution processes. The analysis has been performed by matching the data of company related to principles of the S-DBR implementation (Goldratt 2006). The right implementation process of the S-DBR on the operational level were supported by other cases review in the available literature.

As was mentioned in theoretical background the S-DBR method has five elements.

4. 3. 1. Element 1: Mechanism of order release

The significant influence on operating performance of enterprises has order release. Practical evidence in this case study indicate, that other methods monitor order release according to sustaining of unchanged WIP. It had positive effect.

The S-DBR method is simpler than rest of the available systems said E. Goldratt (2006). Also, it was recognized in case studies, that any troubles were found during S-DBR execution.

Before application of S-DBR company didn't express any obstacles for releasing the job orders. With the simple rule the production manager decided the release date. To reach the due date of customer, the job order must be released as soon as possible. Nevertheless, due date performance didn't reach anticipated outcomes. The increased rows in front of machines have negative impact on the lead times and essentially influence the key indicator of company, what is service level.

Generally, to priorities job orders in manufacturing shop floor are done thru the enlargement of productivity. Most of the time workers were motivated thru realization of extra bonuses, when performance indicators have been reached or overran the targets. As a consequence, markets requirements have been not taken into account because workers choose easy products without difficult setup times or higher series of job orders.

Most of the job orders were finished a few days in advance, where the rest of the job orders are in the middle of WIP. Usually, the enterprise processed orders that customers did not need and did not request to be delivered earlier than anticipated due date, while the rest have been not dispatched on time. The due date performance has never overrun 54%, it was caused by bad performance of on time delivery within of company.

During the implementation of the S-DBR was desired to achieve elimination of productivity. It was restored by the system to achieve highly reliable due dates.

Setting the production buffer of the S-DBR, have positive affect on the key company performance. First step of the S-DBR implementation is that orders must be released as a part of the original lead times. It was noticed with positive increase of service level. In MECASYS company orders have been released according to 33% of the original lead time. An impressive improvement in the due date performance of company was observed (Figure 14) at the end of year. This improved service level is a part of the positive impact of implemented S-DBR method. The main reason of reported improvements are decreased numbers of orders which meet its due date. Mentioned conclusions are described and it is also identical with prior research (Corsten, Gössinger, and Wolf 2005; Lu, Huang, and Yang 2011), which have positive impact on the due date performance. Additionally, constrained the number of jobs on the workshop is leading, in all cases, to a decrease of work in process and decrease usage of application in the period of the first year. The company has taken cons of further capacity.

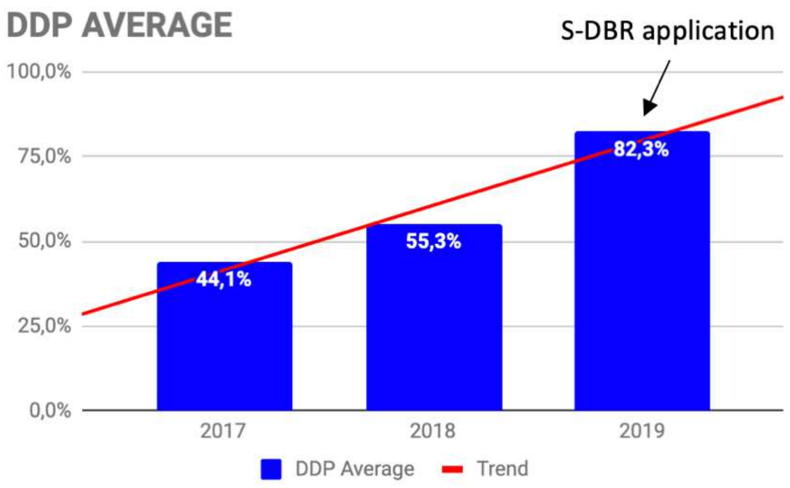


Figure 13: Due Date Performance in MECASYS company (Own work)

4. 3. 2. Element 2: Management of priorities

S-DBR method has decision-taking given by the buffer management system developed to set up priorities on the workshop of company (Schragenheim, Dettmer, and Patterson 2009). S-DBR is obtaining less specific planning of items than DBR, S-DBR creates the conclusion through the realization (Schragenheim, Weisenstern, and Schragenheim 2006). Both frameworks are constructed according to Theory of Constrain principles for instance planned load (PL) or buffer management (BM), which is monitor delivery date performance and reinforce delivery date confirmation towards customer. The shop floor information like order release or ending of orders time is presented in friendly software environment. As soon as the information is gathered, the information is providing through reports or different charts concentrating basically on current status of the orders with the support of buffer consumption and the load of customer constrained of resources. Furthermore, both frameworks offer pareto charts which give rise to the often causes of breaks in buffer consuming. On top of that it is providing support for the time of planning and realization of the manufacturing, both characteristic system modules which give support in areas of retailing, distribution or obtaining of goods. With help of another priority rules was planned to provide early due dates performance to bring exact benefit for customer with request of a high-priority order. Nevertheless, if the delay time of the residual jobs is nearly zero, any change in the sequencing will impacting the company's cycle time or due date performance (Lee et al. 2010).

In case study where the company provides workers and departments with all needed information about status of all orders. It was easy to implement visual management to manage and control buffer management. This simple tool was nice support element for decision making during execution on shop floor. The colour management has been instinctive and can be very simple reproduced. For instance, in these direction like, implementation of tag to WIP, build a central board to summarize the buffer consumption. The system has been not built to manage only order priority in shop floor in this case study, but it follows and avoids situations which are generating conflicts between local performance and reaching of high DDP rate. It was caused mainly with situation among sequencing of products and the time spent on preparation. Increased level of usage has minimised slack time of the job order and made system more sensitive to really minor change.

4. 3. 3. Element 3: Deal with capacity and visibility

There is not needed to have detailed planning for CCR. With S-DBR method the CCR sequence is not scheduled said Schragenheim et al. (2006b). There is uncomplicated mechanism implemented to avoid offering of due dates, that aren't matching with actual load of the CCER, as an alternative sequence. Although positive due date is not lead to accuracy.

The strategy and tactic tree present the necessary steps to avoid an occurring capacity constrained resource from obviously influencing the due date performance the DDP (Hwang and Li, 2011). Following steps need to be completely applicable in case study, which is properly settled system of monitoring the workload of resources. These resources are the most sensitive to be a CCR on a weekly review. Incorrect management of priorities lead to serious and permanent tardiness.

In the MECASYS company is currently existing responsive approach, because improvements are launched only, when causes of issues seriously impacted company performance. The official process description to address created problems not existing, that is influencing buffer using for job order during the running week. This responsive behavior of company has serious limitation on the capacity. Finally, it is influencing to reach robust system with defined operation key performance indicators. Following key performance indicators are written for instance, such us the service level and the tardiness (Figure 15). These indicators have been optimized directly after execution of S-DBR.

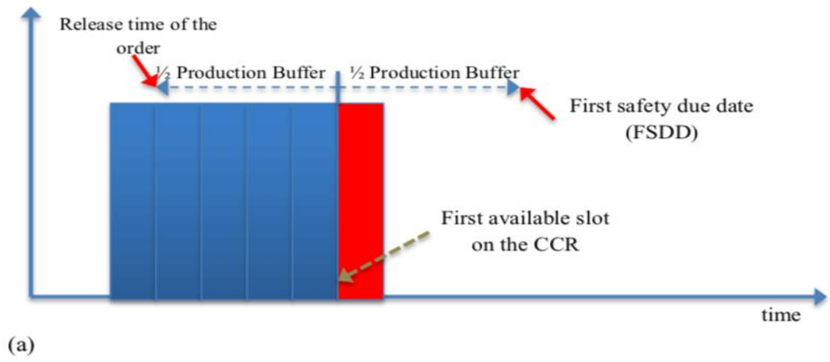


Figure 14: Mechanism for due date estimation (Schragenheim et al., 2006)

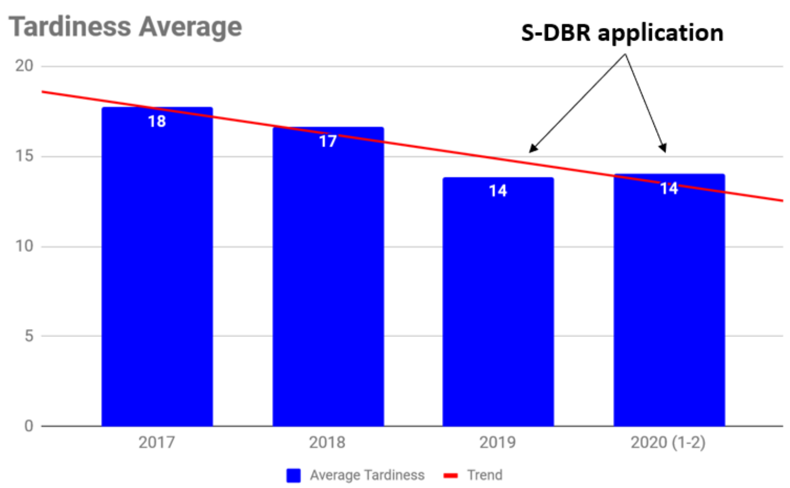


Figure 15: Tardiness average in MECASYS company (Own work)

To simply say, right capacity control and administration reaching positive trend of operational performance like turnover of MECASYS company (Figure 16), even though in conditions, that there is instability of workload. The usage of CCR is changing essentially, with dependency on season period. Finally, company MECASYS trying to continuously search any improvement to increase capacity, when demand period is.

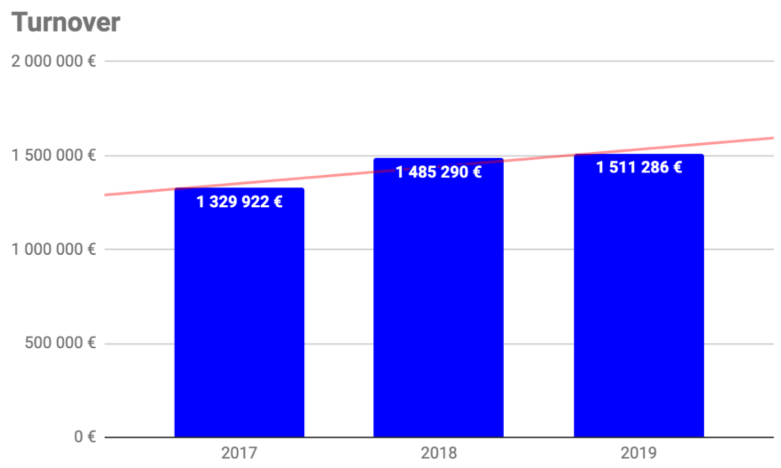
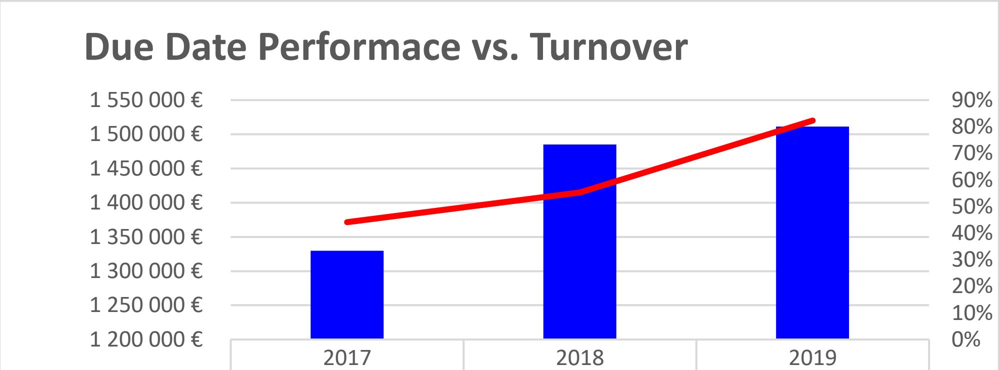


Figure 16: Turnover of MECASYS company (Own work)

4. 3. 4. Element 4: Management of load control

Aggregated amount of hours demanded to fulfil of whole work copied from the CCR in a period of time range (Schragenheim, Dettmer, and Patterson 2009). Goldratt (2006) wrote, that workload monitoring process identify critical resources, but he planned load is not a close organized. Leading planned load is the period of the time when the CCR can work with a new job order from customer. Usually, CCR is placed in the middle of the routing in S-DBR method. The initial due date of work is determined by additional one and half shipping buffer, which is given into the front of the planned load. Eventually, each suitable production planning system, that is setting due dates isn't useful, when enterprise ignore the defined rules. The manufacturing process can be obviously jeopardising the productiveness of the S-DBR execution, when the lead time is committed less than usual lead time or sales is not coordinated properly. However, a slight correction to the common system of mechanisms determined by Lee et al. (2010) which is saying, that S-DBR well-suited in this situation. Addition problem was given at the same time of planned load estimation in case study, where increased fluctuation of the products for each product family obviously impacted their own workload assumption. Implementation of specific customer constrained request is processing time for whole of the products portfolio and parts positively changed the precision of accuracy in the workload estimation. In that options the workload seems to be underrated and offered, that due dates weren't feasible. Such problem has been fixed by dividing of products family, which showed an enormous divergence to the processing time. Previously mentioned problem became more visible during the first couple days of execution. It didn't remarkably impact the operational performance within the long time period. The market determined the sequence of work in the planned load. This assumption was not confirmed in case study with company MECASYS, because particular sequences is affecting the CCR capacity. In following demonstration, extra reflection for sequencing job orders have been put into practice, e.g. a rule that put forward the best mixture of orders to eliminate the time for preparation. Previously mentioned expectation is not finally precise in other cases. The special reflections have been done by trained workers and subordinated into available market that gave thru the buffer management precedence. The implementation of load control resulted in a sustainable increase in service-level (DDP) and company performance (Figure 17).



	2017	2018	2019
Turnover	1 329 922 €	1 485 290 €	1 511 286 €
DDP Average	44%	55%	82%

Figure 17: Due Date Performance vs. Turnover in MECASYS company (Own work)

4. 3. 5. Element 5: Ongoing improvements

Ongoing improvement is the step by step or all at once improvements performed over the time on the services, products or processes. The TOC proposes Process of On-Going Improvement (POOGI) also known Five Focusing Steps. It's the guideline for developing continuous improvement. To start any project where is applied continuous improvement, it's obligatory to point out the causes of problems. It is not possible to develop right prioritization, when the enterprise does not sustain system, which doesn't follow reason of customer delays. Most of the systems are constructed in PC environment. There is database of cause where workers or foremen choose cause of problems for every order, when buffer utilization has been overrun the default value.

The Pareto chart is dealing with the main issues, which are in order. Pareto chart is part has relation with the POOGI.

Company MECASYS doesn't have any procedure implemented for recording the causes of disruptions, as was previously explained. Company has a reactive approach when customer claimed low level of service level from point of due date performance (DDP), which has never exceeded 55% since S-DBR implementation. That's why was important to set up system of recording causes of disruptions. As a first was issued list of causes of disruption with code. As a next step the causes were recorded and collected into the table weekly. The collected causes of disruptions have been then given into the Pareto chart (Figure 19). With support of Pareto chart causes were analysed and actions have been placed to make improvements as well (e.g. Figure 18: Cost of non-quality in MECASYS company). Owner of this activities has been production manager, he follows disruptions and analyzed root cause of main contributors. Most of the suggested actions were very simple solutions to improve process and eliminated constrains such as 5S, visual management, quality process control, SMED and application of lean principles. This part of master thesis presents the negative effects of company, which has not implemented and has not focused to have continuous process improvement. With help of this master thesis company changed thinking and allow to work with the POOGI.

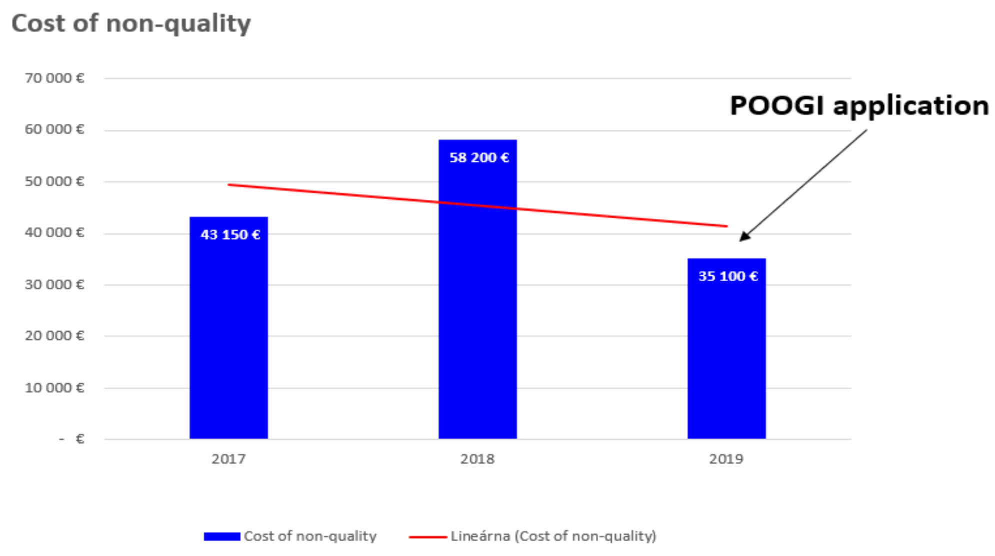


Figure 18: Cost of non-quality in MECASYS company (Own work)

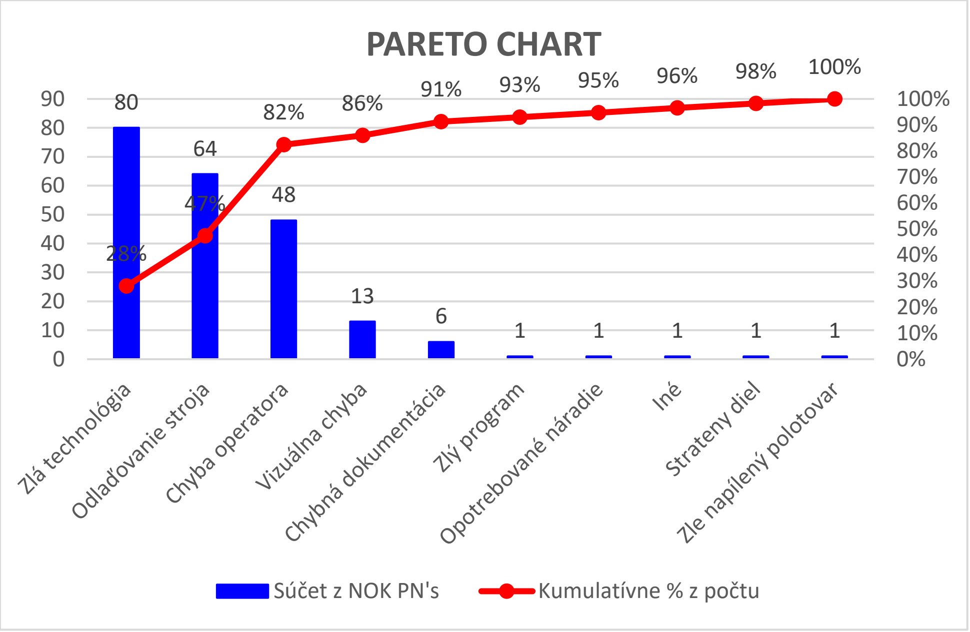


Figure 19: Pareto chart in MECASYS company (Own work)

5. Conclusion and further work

In this chapter are reviewed conclusions of master thesis, both the academic and the case conclusions. Those conclusions follow master thesis quality. Also, question of further work is discussed

5. 1. Conclusion of findings PPC

Based on findings, is concluded that an unsuitable choice of a PPC can have a serious outcome on the performance of small manufacturing enterprises. This master thesis focuses on this specific group of industry, because most of the SME have problem to manage PPC. It is mainly due to the missing financial resources and knowledge of existing PPC solutions, what are giving them answers how to properly manage production planning and control in their own environment.

Due to this problem, it was mandatory to create criteria and make relationship between three scopes product characterisation, process characterisation and market requirements. With definition of those criteria, that there was possibility to tell that S-DBR is the well suited PPC method in the SME environment.

As result of master thesis, the findings of three research questions are shown and explained hereunder in the next part of master thesis.

RQ1: Which Production Planning and Control (PPC) methods are applicable for MTO manufacturing and job shop manufacturing?

In the chapter 3 presents and review the literature regarding the PPC methods applicable for MTO manufacturing and job shop manufacturing. There are many PPC methods recognized. To get this result basic criteria were defined to identify and select right PPC methods for MTO and job shop manufacturing environment. Criteria were selected based on pull-push and hybrid environment, applicability in MTO industry, ability to manage highly customized products and last one applicability to small manufacturing enterprises. With theoretical background following production planning and control methods were identified, what are relevant in MTO and job shop manufacturing. They are KANBAN, CONWIP, S-DBR, POLCA, DBR and WLC.

RQ2: Which Production Planning and Control (PPC) method is well suited for a SMEs environment with MTO manufacturing?

Based on the selected criteria and comparison of applicable PPC methods for MTO manufacturing in SME environment, it was possible to select S-DBR as well-suited method for SME environment with MTO manufacturing. The result is justified mainly very well relevance to product variability, MTO environment and due date reliability. Next very good factor was simplicity of products produced in SME environment, which is not require plenty of assembly points, which can influence of realization of the S-DBR method. As was remarked in theoretical background S-DBR is variable possibility for conditions, where newly products are very often brough into manufacturing process. In the end can be concluded, that S-DBR is recommended for companies where any IT system and highly skilled are not available.

RQ3: How should the selected method be applied within SMEs environments for MTO manufacturing?

The primary contribution of this master thesis has been the application of an appropriate PPC method for SME environments in MTO manufacturing. It was reviewed in chapter 4.3. Implementation of S-DBR in SME environment. As well, this master thesis is a practical tool to see weakness and strengths of each PPC method with respect of main characteristics of a company.

The results of master thesis also provide contribution, what can be applied into other companies with similar characteristics of SME. With help of case study, it was possible to explore practical problems during application of S-DBR in selected company. The case analysis found out the of outcomes of the S-DBR method application with selected performance measurements. Results of selected performance measurements showed to company new outlooks into the S-DBR execution process in the SME environment for MTO manufacturing. Furthermore, can be concluded, that the application of a S-DBR is a not short process. It requires a lot of internal will and support. Finally, this master thesis and case study gave me overview how long time available PPC method can change performance in today modern company, when is known and right implemented.

5. 2. Further work

The master thesis has been writing as a practical case to evaluate the well suited PPC's for SME environments in MTO manufacturing. A future research could confirm applicability of S-DBR in other companies well suited in such production environment. Even though master thesis brings the pros and cons of production planning and control for every of the judged area, but judgement of mentioned tool from the perspective of the improvement process of PPC according to a company's characteristics was not performed.

On top of that, future research could directly point out to evaluate extension of proposed S-DBR methodology. Finally, with the help of practical case study, I introduce specific subjects of matter, where can be conducted an investigation in near future as well e.g. different release techniques, visual management. Finally, evaluation of the application alternative mechanisms like visual tools can support and provide real time knowledge and information.

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