Universidade do Minho
Escola de Engenharia

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Production Control System for Lean and Agile Processes

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PhD Thesis
Doctoral Degree in Advanced Engineering Systems for Industry

This work was executed under the supervision of
Professora Doutora Anabela Carvalho Alves
and
Professor Doutor Fernando Carlos Cabrita Romero

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I would compare a PhD process with a marathon: we know we will suffer; we know that it will be great, we know that we are going to learn so much, it is a mixture of feelings. At the beginning it looks very enthusiastic because we have many ideas, then a long journey come up with a lot of challenges, questions, and doubts. We get lost many times. And, when the end approaches, an anxiety suddenly appears even seeing the goal. This long journey, sometimes a lonely journey would be much more difficult without important people that motivated, support, and trust me. My appreciation goes to everyone that supported me direct and indirectly during this research work.

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Sistema de Controlo da Produção para Processos Lean e Ágeis

Resumo

O sistema de produção *Lean* é mundialmente famoso na indústria e nos serviços. Embora a sua origem esteja relacionada com a indústria automóvel, atualmente encontra-se totalmente disseminado noutras áreas, sendo a aplicação dos seus princípios, designados como princípios do *Lean Thinking*, considerada universal. Os benefícios associados aos princípios *Lean* leva a que muitas empresas queiram implementar e aplicar os seus conceitos e ferramentas. Um dos princípios *Lean Thinking* é o conceito de produção pull onde se baseia a produção *Just-in-time* (JIT), o sistema de controlo da produção, desenvolvido e implementado pela Toyota.

No entanto, a implementação deste sistema por outras empresas revela-se muito difícil, sendo as barreiras encontradas nesta implementação um alvo de investigação por parte da comunidade científica. Em particular, a autora desta tese encontrou essa mesma dificuldade na empresa onde trabalha, e onde foi desenvolvido o estudo de caso. Adicionalmente, apercebeu-se que ainda não existia uma abordagem para lidar com a dificuldade da implementação dos conceitos *Lean Production* e sistemas *pull* como estratégia de controlo de produção num mundo industrial cada vez mais disruptivo que necessita de uma tomada de decisão ágil. Assim, definiu-se como objetivo desta tese o desenvolvimento de um modelo conceptual que colmatasse as barreiras existentes da implementação *Lean* pela integração holística de quatro dimensões: Liderança, Organização, Operacional e Pessoas (LOOP). Para além destas dimensões, o modelo baseia-se na cultura *Lean* para a sua sustentação.

A investigação iniciou-se com a perceção teórica dos principais conceitos *Lean*, as barreiras para a sua implementação, os novos paradigmas organizacionais e os sistemas de planeamento e controlo da produção. O relacionamento destes conceitos foi relevante para o desenvolvimento do modelo. Os resultados do estudo mostraram a existência de barreiras na implementação de *Lean* e *pull* que superavam as barreiras técnicas, o que reforçou ainda mais a necessidade deste modelo.

Esta tese apresenta uma abordagem diferente à implementação da filosofia *Lean* e dos sistemas de controlo da produção, apresentando um equilíbrio entre as várias dimensões mencionadas que suportam a mudança de cultura organizacional e o nível de maturidade *Lean.* Com esta abordagem espera-se que a implementação destes sistemas integre de uma forma holística estas dimensões e que os resultados permitam a melhoria do desempenho do sistema de controlo e dos processos de produção.

Palavras-chave: Barreiras, *Lean Production*, *Lean Thinking*, *Pull System*, Sistemas de Controlo da Produção

Production Control System for Lean and Agile Processes

Abstract

Lean production system is world famous in industry and services. Although its origin is related to the automobile industry, it is currently fully disseminated in other areas. The application of its principles, namely Lean Thinking principles, is considered universal. The benefits associated with Lean principles lead many companies to implement and apply their concepts and tools. One of the Lean Thinking principles is the pull production concept, in which Just-in-time (JIT) production is based on, the production control system developed and implemented by Toyota.

However, the implementation of this system by other companies reveals to be very difficult, and the barriers found in its implementation have been investigated by the scientific community. In particular, the author of this thesis found the same difficulty in the company where she works, and where the case study was developed. Additionally, it was realized that there was still no approach that would integrate the difficulty of implementing Lean Production concepts and pull systems as a production control strategy in an increasingly disruptive industrial world that requires agile decisions. Thus, the objective of this thesis was to develop a conceptual model that could overcome the existing barriers of Lean implementation through the holistic integration of four dimensions: Leadership, Organization, Operational and People (LOOP). In addition to these dimensions, the model is based on Lean culture.

The conducted research began with the theoretical understanding of the main Lean concepts, the barriers to its implementation, the new organizational paradigms, and the production planning and control systems. The relationship of those concepts was relevant for the model development. The results of the study showed the existence of barriers in the implementation of Lean and pull that overcame technical barriers, which further reinforced the need of the model.

This thesis presents a different approach to the implementation of Lean philosophy and production control systems. It presents a balance between the dimensions mentioned that support the change in organizational culture and the level of Lean maturity. With this approach, it is expected that the implementation of those systems integrates the dimensions holistically. The results will allow the improvement of system performance of the production control and processes.

Keywords: Barriers, Lean Production, Lean Thinking, Production Control System; Pull System

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List of Acronyms

ATO – Assembly-to-Order
BOM – Bill of Materials
CC – Chassis System Control
CiP – Center of industrial Productivity
CM/MFT3 – Centre of Competences
CONWIP – Constant Work-in-process
CPS – Cyber-Physical System
DBR – Drum Buffer Rope
DI – Driver Information
ERP – Enterprise Resources Planning
ETO – Engineer-to-order
IS – Instrumentation Systems
IT – Information Technology
JIT – Just In Time
LOG – Plant Logistics
LOM – Material Flow and Physics
LOP – Planning and Fulfilment
LOS – Interface supplier
LSP – Logistics Service Provider
MCRP – Material and Capacity Requirements Planning
MFE1 – Project Management
MFE1-COS – Sample Build
MFE1-PM1/PMO – Project Management Business unit
MFE1-PM2 – Project Management Business unit 2
MFE1-PM3 – Global & Ratio projects
MFE1-PO – Project Office
MFE1-SC – Series Care
MFE2 – Assembly
MFE2-AS1 – Assembly station Business unit 1
MFE2-AS2 – Assembly station Business unit 2
MFE2-SE – Simultaneous Engineering Assembly
MFE-MTN-A – Assembly Maintenance
MFT5-brg – Manufacturing Technologies
MIT – Massachusetts Institute of Technology
MOE1 – Minifactory 1 SMT
MOE10/11 – SMT Production
MOE12 – SMT Quality
MOE18 – SMT Maintenance

MOE1-EWB – External Workbench
MOE1-P – SMT Projects
MOE2 – Minifactory 2 Assembly
MRP – Material Requirements Planning
MRP II – Manufacturing Resources Planning
MS – Manufacturing Systems
MTD – Make-to-Demand
MTO – Make-to-Order
MTS – Make-to-Stock
OEE – Overall Equipment Effectiveness
OEM – Original Equipment Manufacturer
PC – Managing Director Commercial
PDCA – Plan Do Check Act
POLCA – Paired-cell Overlapping Loops of Cards with Authorization
PPC – Production Planning and Control
PS – Powertrain Solutions
PT – Managing Director Technical
QCC – Quality Control Circles
QRM – Quick Response Manufacturing
SMC – Smart Manufacturing Control
SME – Small and Medium Enterprises
SMED – Single Minute Exchange Die
STS – Socio-Technical systems
SWOT – Strengths, Weaknesses, Opportunities and Threats
TOC – Theory of Constraints
TPM – Total Productive Maintenance
TPS – Toyota Production System
TQM – Total Quality Management
VSDiA – Value Stream design in indirect Areas
VSM – Value Stream Mapping
VSMan – Value streams manager
WIP – Work In Process

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1 Introduction

This chapter presents the thesis contextualization and motivation for its development. Furthermore, it is presented its objectives and an overview of the research methodology's framework. In the last section, it is presented the thesis structure.

1.1 Contextualization

For many years, one of the most important challenge for the companies was to get success in the market with less cost as possible, by trying to achieve high productivity levels. Nowadays, in this current disruptive time, companies are challenged to consider other elements that were not focused before. Climatic changes lead to re-think the strategies of resources use and it will require a transition to circular economy. Furthermore, society is pushed to respect more and more the planet, resources life cycles, and become more sustainable (European Commission, 2021).

The pandemic situation due to Covid-19 brought new work methods paradigm, which also showed some industry fragilities in the value chains to easily react to vulnerable situations. Society is also changing, and industry has to adapt to its needs. A worker is not anymore seen as a cost for a company, a worker should be an investment. In this sense, companies should develop workers in order to have more empowered and more capable ones also prepared for the new technology age. Nature of work will change in the near future and some jobs might become obsolete, mostly affected by automation and other technological transition. Workforce must be re-skilled and continuously trained to follow innovative and technological trends. So, it is important that companies facilitate the up-skilling process, mainly regarding digital skills that will be a win-win deal (European Commission, 2021; Garms et al., 2019; Lund et al., 2019; Schmidt, 2020). The concept of Society 5.0 highlights those needs and brings up the importance of balancing the economic developments, society, and environmental problems (European Commission, 2021).

Historically, the environment, the political and economic situation, and the society needs lead to industrial paradigms' transitions since the second industrial revolution with Craft Production and then American Production, Mass Production, Lean Production, Mass Customization, and currently the Global Manufacturing Networks focused on personalization (Mourtzis & Doukas, 2014). All paradigms are still applicable nowadays depending on the industrial sector. The industrial paradigms mentioned above are based on some characteristics related with volatility of the market demand, the product complexity and variety, and systems' flexibility adaptable to the new requirements (Ivanov et al., 2021; Mourtzis & Doukas, 2014). Nowadays, there is a higher product diversity, the product life cycle is increasingly short, and people are demanding new technological products every day. Those factors affect the industrial world and the way that companies look at the current market. Furthermore, market demand imposes organizations to be more competitive with faster reaction systems. In this sense, the concepts such as agile manufacturing arise answering to this requirements (Vinodh, 2011).

The evaluation of elements that support such paradigms was also possible due to technological advances that culminate in the Industry 4.0 concept after several decades of developments. The applicability of Industry 4.0 technologies (e.g. big data, Cloud computing, Robotics, and many others) contributes strongly to a better organizational performance in different areas such as in the value creation, inventory, resources efficiency, energy consumption, among others. Those technologies will allow the factories to become smarter. New software arises to facilitate data integration and visualization. Moreover, intelligent systems will be able to have abilities such as "self-aware", "self-predict, and "self-maintain" (Nikolic et al., 2017).

That kind of systems will support on decision-making and evaluate alternative solutions, and then select the most suitable one. For that, companies have to implement acceptable strategies to fulfil those objectives (Ivanov et al., 2021; Kamble et al., 2020). Such strategies should be linked with the production system, with the production planning and control systems, with logistic processes, with quality systems among others in order to reduce wastes in the process, inventory, and to achieve high levels of performance.

With this intention, many years ago it was developed a system that is focused on cost reduction by eliminating waste called Toyota Production System (TPS) by Toyota (Monden, 1998). At that time, Toyota was facing new requirements of Japanese market, by requiring high variety of products and low volumes. Toyota managers realized that it was needed a change from the mass production paradigm to small batches of production. Linked with Just-In-Time (JIT) philosophy, some principles were developed by Toyota in order to have an efficient process and to increase customer satisfaction, increase productivity, and reduce costs by eliminating wastes.

Later, this system was named as Lean Production (Krafcik, 1988) and there are many definitions from different authors (Bhamu & Sangwan, 2014). Womack and Jones (1996) have defined Lean as "*The term lean denotes a system that utilizes less, in terms of all inputs, to create the same outputs, as those created by a traditional mass production system while contributing increased varieties for the end customer*". This system involves a management system that supports continuous improvement, waste elimination, and the production focused on customer satisfaction, failure prevention practices implementation, and pull systems implementation as a production control's strategy (Liker, 2004). Pull is the fourth Lean Thinking Principle that requires a clear understanding about customer requirements and is more and more important due to the personalization paradigm. Pull allows to implement a synchronized production systems with the customer orders, by complying with original JIT (Womack & Jones, 1996).

Pull is a strategy for production control systems that aims to control workload by replenishing the stock between processes using customer order signal. In this sense, information flow goes in opposite direction of material flow, which contradicts the traditional push strategy (Hopp & Spearman, 2004; Spearman & Zazanis, 1992). Furthermore, one critical factor for implementation is the link between production pull signal and customer demand, which is a source of variation that implies increased system complexity and decreased predictability.

From the economical point of view, the key point of Lean Production, also nominated as modern production systems by some authors (Sanidas & Shin, 2017), is the inventory management by complying with pull strategy. This system has allowed to decrease the ratio between inventory costs and sales. Furthermore, Lean Production is considered as a way to smooth the production, creating demand stabilization in the value stream, reducing inventories, and allowing economic growth and development of countries (Sanidas & Shin, 2017; Schonberger, 2019; Yadav et al., 2017).

Currently, it is seen in a holistic way, by embracing all the areas involved in manufacturing and the supply chain management, and other support areas. The integration of Industry 4.0 with Lean manufacturing principles has been already proved organizational performance benefits (Bittencourt, Alves, et al., 2019; Kamble et al., 2020). This integration will support Lean Production practices besides some temptation of assuming that Industry 4.0 might replace Lean. In this sense, Liker (2020) highlights the idea of integrating technologies with highly developed people and processes. The processes should be very well defined before the digital transition (Bittencourt, Alves, et al., 2019; Bittencourt, Saldanha, et al., 2019). According to some authors (Bortolotti & Romano, 2012; Leyh et al., 2017; Prinz et al., 2018; Tortorella & Fettermann, 2017), Lean tools work as pillars for Industry 4.0 implementation and it represents a high potential when a continuous improvement culture is already implemented (Liker, 2020).

In the last decades, Lean has demonstrated benefits for industrial world giving good arguments to many companies for Lean Production implementation (Amaro et al., 2019; Cusumano et al., 2021; Hopp & Spearman, 2021; Krafcik, 1988; Schonberger, 2019; Womack et al., 1990). In fact, many studies about Lean have presented benefits that lead operational indicators improvements e.g., productivity or inventory. According to Jasti and Kodali (2015), many authors have proven the improvement of the overall organizational performance when Lean principles are applied. However, in spite of being recognized such advantages, there are also noticed difficulties related to its implementation that leads to unsuccessful implementation and give up in some cases (Amaro et al., 2019, 2021; Bortolotti et al., 2015; Cowger, 2016; Grigg et al., 2020; Lean Frontiers, 2017; Leonard, 2015; Jeffrey K. Liker & Rother, 2010; Pay, 2008; Sangwa & Sangwan, 2018; Secchi & Camuffo, 2019).

Additionally, there are still some doubts regarding the premises to implement a production control system based on the pull strategy. Those difficulties are mainly related with the idea that Lean is only a set of tools, disintegrated of other topics namely people and organizational culture, among others like the organizational structure (Amaro et al., 2020b, 2020a, 2021; Dorval et al., 2019; Hopp & Spearman, 2021; Iuga & Kifor, 2014; Netland, 2016; Secchi & Camuffo, 2019; Soliman & Saurin, 2020). Bhamu and Sangwan (2014), Achanga et al. (2006), and Cowger (2016) have concluded in their study that Lean Production is not widespread due to the costs of implementation and uncertain benefits. The success of the Lean Production also depends on the organizational culture and work practices of the companies (Hopp, 2018; Hopp & Spearman, 2021).

1.2 Motivation

The contextualization described shows a current work environment that includes, by one side, the recent technologies that motivate technological innovation, awareness of social and environmental topics, and the needs of integrating manufacturing systems in the digital transformation as well. On the other side, companies have to overcome challenges of implementing well known systems like Lean and tailor the old ways of organizing work in traditional silo-functional structures. Nevertheless, companies are aware of those demands and develop partnerships projects with universities and doctoral programs to establish win-win relationships that benefit both from innovations advancements.

The project developed in this research was integrated in this context and it was integrated in the PhD for Advanced Engineering Systems for Industry (AESI) that in cooperation with Bosch Car Multimedia Portugal aims to integrate PhD students in an industrial environment answering the industry demands. In this particular case, the researcher is a member of the Bosch company and she has been working in projects related with the pull production implementation needs since 2010.

Bosch Car Multimedia Portugal S.A. is a multinational supplier company of automotive industry (first tier) located in the north of Portugal whose business is related to automotive electronic parts. Currently, the company has around 3508 Employees and 1,1 billion of Euros of sales results. Six main types of products such as navigation systems, instrumentation systems and clusters, professional systems, steering angle sensors, manufacturing systems and two wheelers constitute the product portfolio. There are several customers receiving those products, around 60 automotive brands in many different locations (Bosch, 2019).

In chapter 4, the company is presented in detail. It is going through a period of increasing demand, and consequently the production area has increased in order to fulfil customer needs, and increased capacity. The company is also facing the new paradigm of industry 4.0 by introducing new software that allows connectivity. Furthermore, it has faced many challenges due to the pandemic situation and semiconductors crisis in the last months that requires agile supply chains and robust production planning and control systems. Bosch is a company supported by the Lean Production System, by following principles very similar to the Toyota Production System. It has developed its own system, named Bosch Production System, which includes the following principles: pull principle, fault prevention, process orientation, flexibility, standardization, transparency, continuous improvement, and personal responsibility (Bosch GmbH, 2015).

However, it has been difficult to implement the first principle, i.e., the pull system in spite of some attempts during some years. In the last 15 years, some master students have developed work about this topic in the company. There are several master thesis (Afonso, 2008; Araújo, 2011; Durães, 2012; J. M. O. Fernandes, 2020; Freitas, 2018; Gomes, 2012; Pinhão, 2020; Ribeiro, 2014; Silva, 2014; Soares, 2006; Souza Filho, 2012) published in the University of Minho Repository related to the pull system implementation in the company, but in fact, it has not yet been implemented. Therefore, some projects were developed to achieve that target, but there is no stable implementation period that allows to obtain consistent results and conclusions about it.

The benefits are, theoretically, known and the practical concept is known. Bosch is a multinational company that develops its own guidelines and procedures centrally. However, in Bosch Car Multimedia Portugal S.A., there remains difficulties in the implementation of pull systems, and in general the implementation of a robust production control system. Furthermore, it is not clear which products should follow a pull or push strategy although there are general guidelines as represented in Figure 1. It is also not clear if the pull systems supported by the company are the best approach for this production plant or if there are other more valuable systems. Lean Production principles support the pull principle, but it is really needed to understand if a company can carry out all the principles required to be a Lean company or if it is possible to mix different approaches for different scenarios.

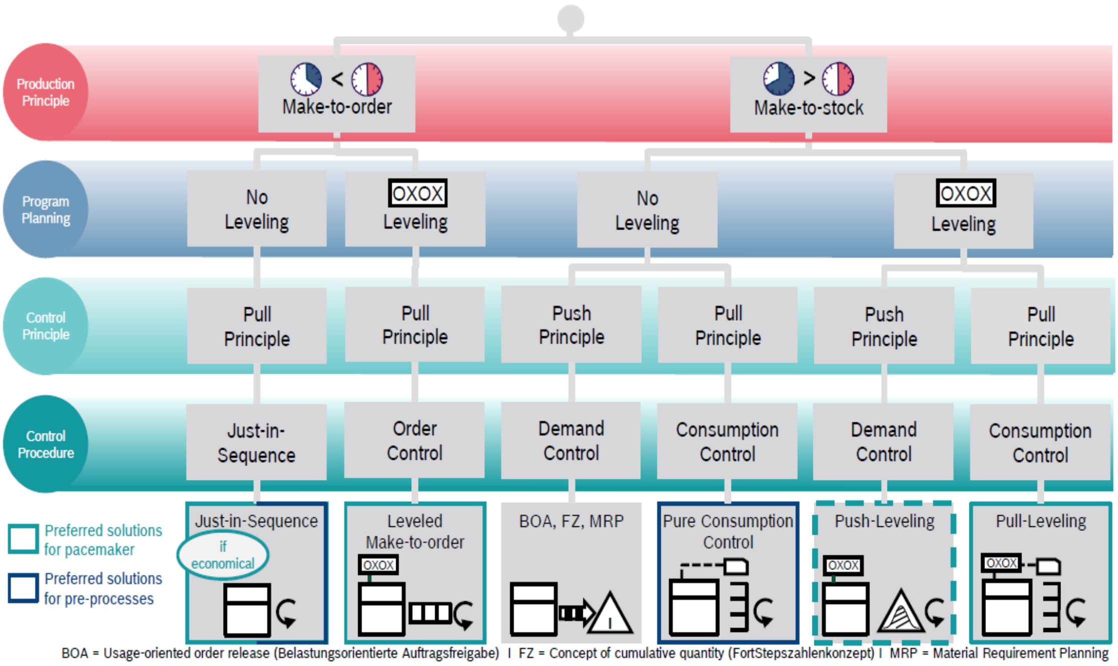


Figure 1 – Combinations of production planning and control recommended in Bosch
(Robert Bosch GmbH C/TEP, 2019)

Additionally, there is still a low confidence level to select production control systems that fulfil production requirements. It is also difficult to measure which system is more suitable for the company. Due to this, the company has some problems like high levels of inventory, costs of expedited freights, production inefficiencies, big effort to fulfil customer orders in the daily business, not fulfilling customer orders, huge daily effort of planning production, and demotivation of people who are involved in the processes among others. However, the challenge it is not only the pull system, but the company also recognises that it is still hard to keep in mind Lean philosophy.

Accordingly, this is the motivation for this project, which are the main factors involved in a successful pull system implementation and understand the premises behind its implementation. It is relevant for this study to understand why the pull system implementation has failed during several years. Furthermore, the difficulties mentioned above, also related with barriers to Lean implementation, motivated the development of the conducted research. As well, it is intended to cover the gap existent in the scientific community about the Lean and pull system implementation barriers. One the hand, this topic represents a relevant contribution for the scientific community to complement research about pull systems in Lean environment, one the other hand it is relevant for companies getting success in Lean and pull system implementation. Many studies have been developed about the success of Lean Production; however, the originality of this thesis is its focus on to understand which limitations block pull system implementation in specific production structures, organizational cultures, or management strategies.

1.3 Objectives and research questions

Considering the main barriers for Lean implementation (Bortolotti et al., 2015; Cowger, 2016; Grigg et al., 2020; Lean Frontiers, 2017; Leonard, 2015; Jeffrey K. Liker & Rother, 2010; Pay, 2008; Sangwa & Sangwan, 2018; Schonberger, 2019), and consequently its elements, namely, pull systems, the main objective of this thesis is to develop a conceptual model that support Lean implementation and the selection of the most suitable production control system as well. The model intends to have a holistic perspective that covers the main gaps found in Lean implementation. Furthermore, the model serves as a guide for Lean practitioners, companies, academics, and other communities that intend to follow Lean philosophy. The development of the model attempts to answer the research questions raised in the beginning of this research that are closely related with the motivation previously presented:

- *Which are the conditions needed for a decision-making process related to the production control systems in Lean Production environment?*
- *Why is the pull systems implementation still challenging for Lean companies?*

The achievement of the general objective and the research questions required a deep research in different knowledge areas and the definition of specific objectives in a lower level. The following specific objectives are:

- Know in a broader way the Lean philosophy and its culture;
- Identify and understand the main constraints that are linked to the Lean Production implementation;
- Define requirements and strategies to implement production control systems in Lean Production environment;
- Identify agility elements in Lean production environment;
- Define criteria for a production control system selection.

These objectives allow to justify and relate important concepts that contributed for the theory development. To accomplish these objectives and the main objective of this thesis, some phases were carried out that are below presented. Those phases were always supported by the literature review.

1) Definition of the research topic and objectives;
2) Definition of the research methodology;
3) Case study presentation and critical analysis;
4) Development of a conceptual model to answer research questions.

1.4 Research methodology framework

This thesis follows a research methodology framework that was divided in two main elements, one related to literature review and other related to the case study development. The framework presented in Figure 2 intends to represent the two main elements and studies developed underneath.

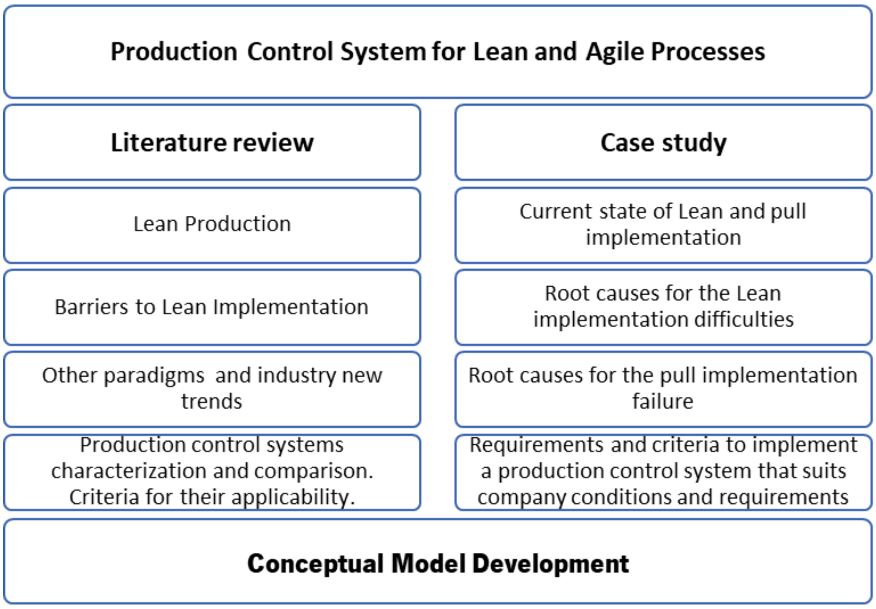


Figure 2 – Research Framework

The literature review intends to support the existent theory and support the case study analysis. For the literature review was mainly used primary and secondary sources. Four main topics were considered in the literature review: the main features that characterize Lean Production, the barriers to its implementation, other organizational paradigms that might impact on Lean and production control systems characterization.

The secondary data's collection was the main data source in the beginning of the case study. As the research evolved, primary data became the main source. Bosch Car Multimedia Portugal S.A. was the company where the case study was conducted to corroborate main barriers of Lean and pull system implementation. For that, it was needed to follow important phases that contribute for the analysis namely:

1) Map the current state of Lean and pull implementation in the company in particular;
2) Identify and analyse the main drivers of continuous improvement;
3) Identify the root causes for the pull implementation failure in the company;
4) Understand the requirements to implement a pull system in the company;
5) Define criteria for a production control system that suits company conditions and requirements.

In order to answer the research questions and to develop the proposed model was fundamental to have a research methodology that supports the work plan and the scientific research. In chapter 3, the methodological approach and research instruments are presented in detail.

The strategy applied was a case study, the most appropriate for answering research objectives, and due to the PhD nature, conducted in Bosch Car Multimedia Company. The case study involves several types of data collection techniques such as interviews, observation, documentary analysis and questionnaires (Saunders et al., 2009). In this project it was used some of those techniques in order to understand the phenomena and to develop the model. Independently of the research methodology framework, for Saunders et al. (2009), the most important is to answer the research questions and to fulfil the project scope, and for that it is really essential to clarify and understand the topic.

1.5 Thesis structure

The thesis is organized in seven chapters. It starts with the introduction of the research topic where a contextualization and motivation are explained, the research objectives are presented, and the research methodology applied.

In the second chapter is presented the literature review related to the research domain. This chapter presents the Lean Production concept and the principles of its application, as well the main advantages and contribution for the industrial world. Additionally, it is identified the main barriers for Lean implementation, other paradigms and new trends that might impact in Lean applicability. An important topic is related with production control systems, presented in the last section of the second chapter.

The third chapter describes the research methodological framework, namely, case study research and all methods used to conduct the research, mainly, the interviews that required a specific procedure.

In the fourth chapter is presented a general overview about the manufacturing company where the case study was developed, and special topics that influences the conducted research.

The fifth chapter presents a deep description and analysis of the current company situation that contributed for the main research outcomes. The results of workshops and data collection, analysis of performance indicators and internal processes, as well as interviews results were the main instruments that allowed to diagnose the situation and then corroborated by the literature.

The sixth chapter presents the proposed conceptual model named “Leadership, Organization, People, Operational” (LOOP) to overcome gaps observed in the literature review, in the results analysis, and which fulfil the research objectives. LOOP model consists of four dimensions (Leadership, Organization, People, Operational) embraced by a Lean culture.

The last chapter presents the final thesis conclusions and the main contribution to the field. Additionally, research limitations are point out as well as the ideas for future work.

2 Literature review

This chapter presents the literature review related to Lean Production in order to provide an overview about original concept and further developments related, and the main barriers related to its implementation. In this chapter is also discussed the relation between Lean production and other paradigms and industry new trends that might impact on concept implementation. In addition, it is presented the literature review related to production control systems, focusing on pull systems. Finally, the critical analysis of the main findings is summarized in a final section.

2.1 Lean Production

This section presents Lean definitions since the original concept created by TPS. Then, concepts such as value and waste, Lean Thinking principles, Lean culture and its contribution are presented.

2.1.1 Origins

Lean Production System is the Toyota Production System developed in Japan (Krafcik, 1988) and it became more known after the Second World War. The Toyota Motor company founder was Sakichi Toyoda in 1918. At the time, its activity was spinning and weaving businesses, only in 1937 the automobile business company was formed (Holweg, 2007). A person that contributed for the TPS development was Taiichi Ohno. After analysing the Ford system, he realized that the main problems were related to large production batches that increased inventory, warehouse space and, consequently, capital costs.

Furthermore, product diversity was not enough to fulfil their customer requirements at that time. Taiichi Ohno supported small batches production as a way to reduce production costs by eliminating wastes (Holweg, 2007). So, the system contradicts the old model of Ford's mass production and it involves the waste elimination by increasing production flexibility, continuous improvement and high workers involvement (Erthal & Marques, 2018; Holweg, 2007; Krafcik, 1988).

In 1977, Sugimori et al. (1977) presented the first English paper about TPS concept and its elements, mainly the respect for human system, the importance of JIT for inventory reduction and the kanban system as a method to comply with JIT. Ohno (1988) published the first English book *Toyota Production System* after the first Japanese edition in Japanese. Later on, many literature contributions appeared that led to further concept development. Krafcik (1988) was the Massachusetts Institute of Technology (MIT) researcher that created the "Lean" term to identify the production system used by Toyota. Only in 1990 the "Lean" term became more popular due to the very famous book *The Machine that Changed the*

World, an outcome from a large study conducted by MIT which purpose was to understand the success of Japanese automotive industry (Womack et al., 1990).

The TPS house (Figure 3) is a structured way to present a robust system based on stable base that includes stable and standardized processes, levelled production and two important pillars: JIT and *Jidoka* (in Japanese). In the roof are presented the main organization targets: best quality, lowest cost, shortest lead-time to assure the delivery flexibility, best safety and high morale referring people. These main objectives can be achieved by the Lean tools' implementation through waste reduction, taking advantage of people capabilities and promoting teamwork spirit with a purpose of continuous improvement.

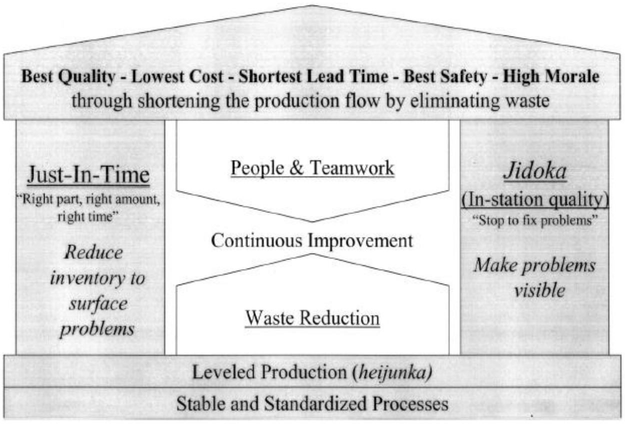


Figure 3 – TPS house
(Liker & Morgan, 2006)

Kim (1985) stated that JIT is a system that produces or stocks "*only the necessary items in necessary quantities at the necessary time*". Due to that, JIT is considered a pull system in relation to material flow system. "*In a Pull system, the succeeding stage orders and withdraws material from the preceding stage, only at the rate and at the time it has consumed the items.*" (Kim, 1985). The main advantage of pull system is to reduce stocks between processes involved and accordingly reduce costs from those stocks (Panneerselvam & Kumar, 2007). JIT complies also with one-piece-flow production that aims having only one piece between processes, producing one by one (Sugimori et al., 1977).

TPS used a *kanban controlled pull system* as an element of JIT that works as an information tool that flows in reverse direction to the material flow (Deleersnyder et al., 1989; T.-M. Kim, 1985; Sugimori et al., 1977). Kanban requires a smoothed production schedule, named levelled production or *Heijunka* (in Japanese) that allows minimizing the variety between consecutive periods, having repetitive pattern in this period (Bohnen et al., 2011; Reichhart & Holweg, 2007).

Levelled production avoids that customer variability is transmitted into the production schedule and also preventing the bullwhip effect in the supply chain (Bohnen et al., 2011). This phenomena is very important for production, because as Reichhart and Holweg (2007) refer, market demand is not smooth. In this framework of thought, Reichhart and Holweg (2007) found that some authors criticize the rigidity and inflexibility of the Lean Production. This concept is explained in detail in section 2.4.2.

Jidoka or autonomation, the second TPS pillar, means that any equipment or production line can be stopped automatically or by workers if an abnormal or defective condition happens. It involves quality control once that if a defect occurs, the line should immediately stop, and the root cause must be investigated. *Jidoka* is very important to prevent extra production and assure quality (Monden, 1998; Sugimori et al., 1977).

2.1.2 Value and waste

In a production system, activities can be classified as value-adding, non-value adding but necessary, and non-value adding. Value-adding are the ones that contribute directly for the product or service creation. Non-value adding but necessary activities are the ones that the production system cannot avoid due to some constraint. Non-value adding activities are those that represent waste for the process, also called *Muda* in Japanese which should be eliminated (Womack & Jones, 2005). In the previous section was referred the importance of waste elimination underlined in Lean production.

The wastes classified by Ohno (1988) were seven:

1) Overproduction: means producing more than customer requires. It is recognized as the worst waste because it leads to overstocks and obsolete products, extra space required, unnecessary capital investment, consume more resources and material than needed;
2) Waiting times: represent worker waiting times for people, material, or machines;
3) Transport: means material transportation due to different process or inventory locations;
4) Over processing: associated to wrong handling or incorrect processing that leads to defects, material and time consuming;
5) Stocks: refers to the raw material, Work in Process (WIP) and finished goods excessive inventory in manufacturing plants that leads to extra floor space, delays, higher lead times and risk of obsolete parts;
6) Defects: associated to quality issues. Defect products represent wasting time and resources and risks to fulfilling customer demand;
7) Unneeded motions: refers to extra worker movements resultants from not suitable line layouts or workstations design and ergonomic issues.

Additionally, authors such as Liker (2004) and Roosen and Pons (2013) presented an eight waste that is related to underutilization of the human potential.

Moreover, *Muda* is not the only obstacle to achieve the best performance. Toyota refers the elimination of three M's: *Muda*, *Muri* and *Mura* (Liker & Morgan, 2006). *Muda* has already been described in detail previously. *Muri* refers to overburdening people or equipment, pushing them beyond natural limits that can result in safety and quality problems, or breakdowns and defects referring equipment. For Hopp (2018), *Muri* can also be interpreted as stress associated to emotional aspect of work. *Mura* means unevenness or variability results from irregular production schedule, internal problems like downtimes, defects or other fluctuations that will cause *Muda* (Liker & Morgan, 2006). While *Muda* was positively recognized in the Western companies, *Muri* and *Mura* have been lost (Hopp, 2018).

2.1.3 Lean Thinking principles and Lean definitions

There are many different references to Lean Production such as Lean Management, Lean Manufacturing, Lean Thinking and others. Nevertheless, it is important to highlight that Lean Thinking provides the philosophy for the organizational management model, as defined by Womack and Jones (1996). The Lean Thinking principles emerged as an answer for companies adopting Lean, after success of "*The Machine that changed the world*" best-seller book (Womack & Jones, 1996). So, these principles are presented like a thinking guide for Lean Production implementation, a reason for calling them a philosophy. So that, according to Womack and Jones (1996) there are five Lean Thinking principles: 1) the value; 2) the product value stream; 3) flow; 4) the pull production; 5) perfection.

1) First principle - Value: to start production, companies must know what the value means for the client, i.e., the value is what he/she is willing to pay for. So, everything that does not generate value for customer should be eliminated or reduced;
2) Second principle - Value Stream: referring all value-added and non-value-added activities to produce the product. This principle shows the importance of analysing the whole value stream. It provides fundamental insights about the value-adding activities and the non-value adding, meaning the waste that should be eliminated as explained previously in section 2.1.2;
3) Third principle – Flow: creating flow means eliminating all non-added activities that provoke bottlenecks and Work In Process (WIP), in order to deliver the required products as quickly as possible producing at the same rate as the customer requires, in order to synchronize customer demand with supply chain (fourth principle). It requires a continuous flow of materials, without intermediate stocks that lead to waiting times and unnecessary movements;

4) Fourth principle – Pull Production: pull means producing only what customer requires. The upstream processes production is pulled by the downstream orders that are synchronized with customer orders. Pull production is described in detail in section 2.4.2;
5) Fifth principle - Perfection: last principle pursuits the system perfection through continuous improvement activities. Continuous improvement also known as *Kaizen* in Japanese (Imai, 1986) is a non-ending process, it should be part of daily business and this mind-set has to be clear for companies adopting Lean.

These interlinked and apparently simple principles demand a company focused on value streams, with all stakeholders aligned to the same purpose: satisfying the client. But companies do not have just a client, they have to deal with many and provide them all the best possible way and at the same time period. This generally means having people working for some and others working for others, normally in a functional and hierarchical organization, each functioning in their own silo which diversifies efforts (Skinner, 1974). This is, frequently, pointed out as a barrier to Lean successful implementation and, consequently, to pull production but it is not the only one as presented in the section 2.2.

Notwithstanding, there are many definitions of Lean Production, for instance, Bhamu and Sangwan (2014) have done a literature review during the period 1988-2012. They presented thirty-three different definitions and most of them stated in different ways that Lean Production is a philosophy focused on reducing wastes. However, there is some ambiguity related to Lean definition, terms like philosophy, model, culture, socio-technical system, paradigm among others are also used to define Lean (Amaro et al., 2020b; Bhamu & Sangwan, 2014; Browning & de Treville, 2021; Cusumano et al., 2021; Hopp & Spearman, 2021). Recently, other studies have shown that Lean is also seen as an organizational culture (Amaro et al., 2020a, 2021; Dorval et al., 2019; Hopp & Spearman, 2021), an important factor for a successful Lean implementation (see more details in sections 2.1.4 and 2.2.3.

Hopp and Spearman (2021) presents four perspectives of defining Lean: 1) *Lean is the pursuit of waste elimination*, 2) *Lean seeks to minimize the cost of excess inventory, capacity or time*, 3) *Lean is a systematic process for reducing the cost of waste*, 4) *Lean is an organizational culture that encourages continual reduction of the cost of waste*; and they mention that none of those are correct but each of them has practical value. Besides, there is no doubt about waste elimination concept as a basis to value creation. To achieve that target, there are several Lean practices and techniques that are widely known in the literature such as 5S, kanban, continuous flow or one-piece-flow, cellular manufacturing, Total Quality Management (TQM), visual management, *Heijunka* or levelled production, Single Minute

Exchange of Die (SMED), Six Sigma, standard work, among others, that contribute for waste free production (Chan et al., 1990; Liker, 2004; Monden, 1983; Sugimori et al., 1977).

Hines, Holweg, and Rich (2004) argue that there are two levels of Lean: the strategic and operational, as shown in Figure 4. They support, from a strategic point of view that it is possible to follow the first principle, that of "value", by integrating other approaches. Hines et al. (2004) argue that "…*any concept that provides customer value can be in line with a lean strategy, even if lean production tools on the shop-floor, such as kanban, level scheduling, or take time, are not used*". At an operational level, other tools can be used, even if they do not belong to the Lean methodology, but support Lean to achieve better results. The important is to understand the Lean methodology as a whole and implement the right tools in order to create customer value. In the operational level, a lot of tools are used, explained in the Appendix 1 (Table 37). The production control systems such as MRP and Kanban will be explained in the section 2.4 of this chapter.

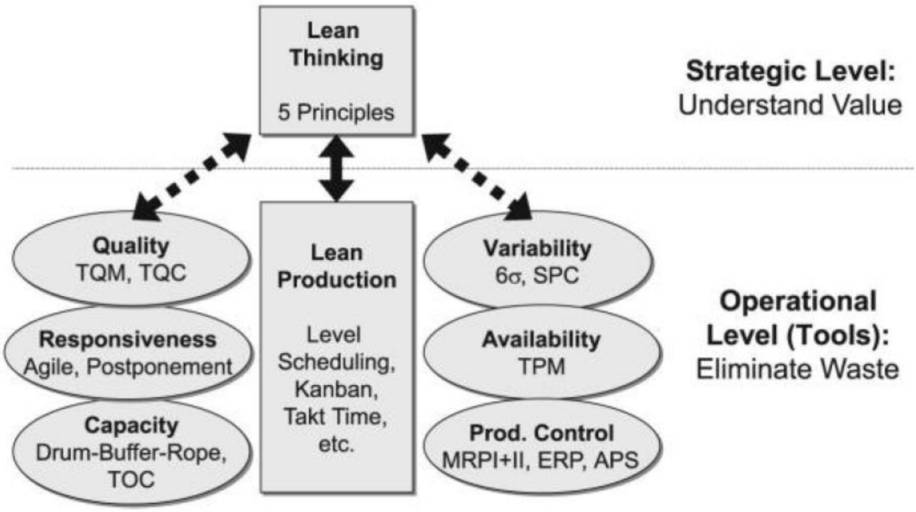


Figure 4 – Lean Principles in the strategic and operational levels
(Hines et al., 2004)

2.1.4 Lean culture

Organizational culture is a concept widely developed and investigated by different authors (Denison & Mishra, 1995; Hardcopf et al., 2021; Hofstede, 2011; Ogbonna & Harris, 2014; Schein, 1984; Yadav et al., 2017). Therefore, there are different organizational culture definitions. Schein (1984) developed his research based on Japanese management style and according to his definition, organizational culture is "*the pattern of basic assumptions that a given group has invented, discovered, or developed in learning to cope with its problems of external adaption and internal integration, and that have worked well enough to be considered valid, and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems*". Accordingly, a culture is inherent to a group defined as a set of people that share same experiences and problems for long time, have the opportunity to perceive the results and have taken in new members (Schein, 1984).

According to Yadav et al. (2017) "*Culture is reflected in how employees behave on the job, their expectations of the organization and each other, and what is considered normal in terms of how employees approach their jobs*".

According to Morgan (1997), culture refers to a pattern of development that exist in a society regarding knowledge, ideology, values, laws and day-to-day ritual. Although modern societies have common characteristics, there are national social individualities, point of views related to national styles and philosophies of management and organization that makes the cultural difference. One example of that is the Japanese concept of work and the relation between employees and their organizations different of Western countries (Morgan, 1997).

Many studies (Achanga et al., 2006; Amaro et al., 2020b, 2021; Erthal & Marques, 2018; Hardcopf et al., 2021; Hofstede, 2011; Iuga & Kifor, 2014; Kosuge, 2014; Lodgaard et al., 2016; Nahm et al., 2004; Netland, 2016; Sakakibara et al., 1997) have demonstrated that organizational culture is a key factor for a successful Lean implementation (section 2.2.3). However, Lean culture still remains very superficial in the current literature review (Amaro et al., 2021; Dorval et al., 2019).

As it was described by Womack et al. (1990), TPS success is mainly related with methods and tools whose pillars are JIT and *Jidoka*. One of the continuous improvement engines defined in TPS is people and teamwork. One example of this mind set was proven by the suggestions boxes and Quality Control Circles (QCC) implemented in Toyota to promote brainstorming between workers and to involve them in the continuous improvement process. The result of this approach would be quality improvement, safety and cost reduction (Monden, 1998).

For Toyota, suggestion system is more than labour and personal management, suggestions goal is to improve quality of products and to reduce company costs in order to company growing continuously (Monden, 1998). At Toyota improvements are not only made by an individual worker also by the Quality Control circle group responsible to provide improvements on their workplace. Monden (1998) shows an increase of number of suggestions from 10,6 suggestions/ person in 1976 to 47,7 suggestions/ person in 1988.

The original TPS identify people and the "respect for people/humanity" as important elements of its system (Monden, 1983). The social elements are in the same levels of technical ones, a reason for some authors (Kosuge, 2014; Shah & Ward, 2007) to define Lean as a socio-technical system (section 2.3.3).

Respect for people means that employees are actively involved in problem solving and improvement activities, aspects such as worker safety are considered by the company, managers respect their employees and provide them greater responsibility and authority in their tasks (de Treville & Antonakis, 2006; Hopp & Spearman, 2000; MacDuffie, 1995; Matsui, 2007; Mehra & Inman, 1992; Monden, 1983; Sakakibara et al., 1997; Sugimori et al., 1977; Womack et al., 1990).

Schein (1984) was the first one to discuss an organizational culture framework based on Japanese style, effective in people motivation and involvement that leads to high levels of loyalty and conformity (Schein, 1981). Schein (1984)' framework is defined by three elements of culture levels, namely, artefacts and creations, values, and basic assumptions. Artifacts and creations concern visible organizational structures and processes, they are visible but often not decipherable e.g., technology, art, language, dress code, public documents, employee orientation materials, stories, sex and age roles, interpersonal relationship. Values refer to the rules, strategies, goals, philosophies, justifications, ideals, norms, standards, moral principles, and other untestable premises - with greater level of awareness. Basic assumptions are related with beliefs, habits of perception, thoughts and feelings, typically unconscious assumptions about the reality (Schein, 1981, 1984).

According to Schein (2004) there are three sources where culture arises from: 1) the beliefs, values, and assumptions of organization founders; 2) the learning experiences of group members; and 3) new beliefs, values, and assumptions coming from new group members and leaders. However, founders have the most important impact on culture as they impose to the group their own assumptions. Schein (1984) is the most citied author in organizational culture topic in the scientific community (Leyva-Duarte et al., 2019) and his culture definition is strongly related with TPS (Amaro et al., 2021). TPS recognize that its mission is based in three forces (Takeuchi et al., 2008):

- Founders' values: respect for people, continuous improvement mind-set, focus on customer satisfaction, the importance of going to *gemba,* which means in Japanese "the actual place", to see the real problems;
- "up-and-in" people management: employ people for "life" and get the opportunity of sharing experiences with younger ones, on-the-job training, learn through experimentation and problem solving;
- Open communication: sharing know-how by implementing best practices sharing ideas, using *obeya* rooms, which means in Japanese "big room", to discuss ideas together, giving to the

employees the opportunity to contribute with their opinion and promoting visual management by exhibit work done in the room walls.

For Parkes (2014) Lean culture characteristics can be defined in Schein organizational culture levels:

- Artefacts and creations: Japanese terminology, rituals, uniforms, visual control management tools;
- Values: Plan, Do, Check and Act (PDCA) process, standardization, visual management, teamwork, paradox, intensity, kaizen and do concept;
- Basic assumptions: particularism, synthesis, collectivism, outer direction, status assigned and synchrony.

Additionally, the open communication enabling know-how and best practice sharing between people using *yokoten,* which means in Japanese "the best practice sharing", and *obeya* rooms might also be considered artefacts (Amaro et al., 2021) as well as lean tools (Ohno, 1988).

Some models related to Operational Excellence, namely, Shingo model that also have a huge focus on people when referring culture. Shingo model pyramid base (Figure 5) is related to cultural enablers that means leaders should create an environment where associates feel respected and energized and give them opportunity to be creative, striving for continuous improvement. Additionally, everyone, including customers, suppliers, the community, and society in general should be respect as humans beings that leads to highly motivated and empowered employees (Shingo Institute, 2020).

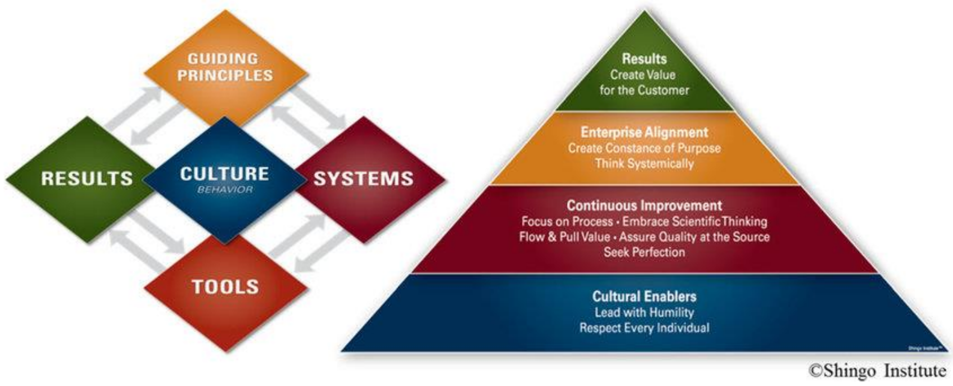


Figure 5 – Shingo Model
(Shingo Institute, 2016)

Recently, Hardcopf et al. (2021) also developed a research that investigated the organizational culture's influence in Lean production and operational performance. This research was based on the model of organizational culture Competing Values Framework (Quinn & Rohrbaugh, 1983). The Competing Values Framework (Quinn & Rohrbaugh, 1983) is the measurement system that has been widely used in operation management research that distinguishes four organizational cultures: hierarchical, group or clan, rational or market, and developmental or adhocracy oriented. This distinction is based in three element values: 1) the focus in internal harmony/stability versus external competitiveness, 2) the structure: stability/control versus flexibility/change, and 3) the outcomes: 'the end' versus the 'means' as an avenue to the end. According to the preferences values of these elements, the organizational culture is defined, summarized in Figure 6.

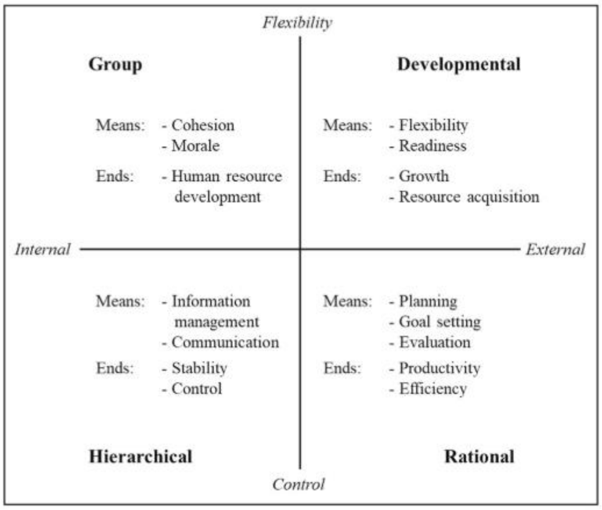


Figure 6 – Competing values framework
(Hardcopf et al., 2021) adapted from (Quinn & Rohrbaugh, 1983)

The hierarchical culture is defined by internal focus and stress control. It prefers information management and communication as means to achieve stability and control. The group culture type is defined by internal focus and values flexibility. It prefers cohesion and morale as means to achieve human resource development. The rational culture type is defined by external focus and control oriented. It prefers planning, goal setting, and evaluation to achieve productivity and efficiency. The developmental culture is focused on external orientation and values flexibility. It prefers flexibility and readiness as means to achieve growth and resource acquisition (Quinn & Rohrbaugh, 1983). Although this is a clear distinction between organizational cultures, more than one could exist in the same organization (Gimenez-Espin et al., 2013; Naor et al., 2014; Quinn & Rohrbaugh, 1983).

The most suitable culture with Lean principles is the developmental culture, according to Hardcopf et al., (2021). Although Lean emphasizes the respect for people and their importance, it works as means to achieve customer satisfaction, the first Lean Thinking principle, so the focus is external. Lean supports flexible workers, gives them the opportunity to participate in problem solving and continuous improvement activities. Furthermore, cellular manufacturing aims flexibility regarding customer requirements. So, a culture that support greater flexibility fits Lean. Due to the focus in the customer that could also result in achieving better organizational performance, having "end" as growth would seem to be a good fit with Lean.

Although the developmental culture fits better with Lean, there are elements of other types of cultures such as individual values in group culture, productivity and resources efficiency concerning waste elimination in rational culture that also fits with Lean (Hardcopf et al., 2021). Hardcopf et al., (2021) recommends creating this type of culture if an organization desires implementing Lean. Authors also demonstrated that the developmental culture will positively moderate the effect of quality, flexibility, and delivery performance (Hardcopf et al., 2021). Curiously, it does not moderate lean's impact on cost reduction (Hardcopf et al., 2021; Narasimhan et al., 2006; Shah & Ward, 2003).

Besides frameworks and models previously described, there were created other underlying Lean models such as the 4P model (Liker, 2004) (Figure 7).

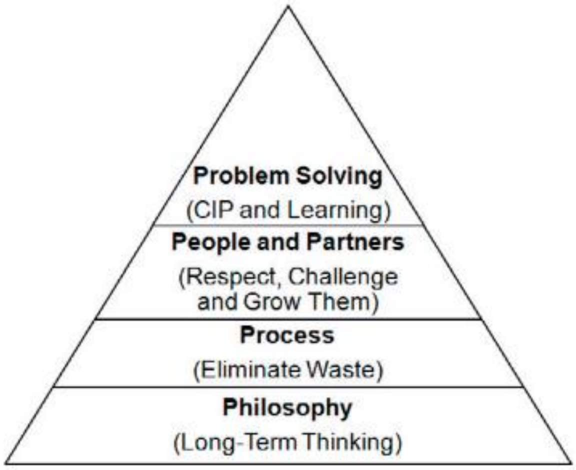


Figure 7 – 4P model
(Liker, 2004)

The 4P model explains the Toyota way of implementing Lean. Additionally, it is used as a reference for the Toyota Kata that is focused on continuous improvement and leadership in Lean companies (Rother, 2010). Despite the different models that have been created by different authors, there is a consensus that Lean is not only a set of tools, but it also requires a culture behind. In addition of such models, several methodologies are described in the literature for Lean implementation by some authors (Bhamu & Sangwan, 2014; Jasti & Kodali, 2015; Maia, 2018). However, TPS (Monden, 1998; Ohno, 1988) is the most well-known over the years.

2.1.5 Lean leadership

According to Dombrowski and Mielke (2013) "*Lean leadership is a methodical system for the sustainable implementation and continuous improvement of Lean Production System*". As already referred in the previous sections, managers have a special role in the employees' development. Lean leaders are the drivers of Lean culture, they are coaches who develop team spirit and the employees' skills (Aij & Rapsaniotis, 2017; Alefari et al., 2017). The importance of leaders in the Lean Production implementation led some authors (Dombrowski & Mielke, 2013) to develop the Lean leadership who identified some principles following described:

1) Improvement culture: which are related with the last Lean Thinking principle which strive for perfection. Leaders should view a problem as an opportunity for improvement;
2) Self-development: Lean leaders must know Lean philosophy, values and tools. They encourage and coach others to develop their skills and knowledge in Lean culture;
3) Qualification: which are related with self-learning organization concept. Leader is committed with continuous learning and development of employees;
4) "*Gemba*": leader goes directly to shop floor to coach and receive feedback from employees;
5) "*Hoshin kanri*": related with the importance of defining goals on all levels, focusing on customer requirements. Furthermore, all hierarchic levels are aligned for the continuous improvements (Dombrowski & Mielke, 2013).

Lean leadership should consider the philosophy referred in the 4P model (described in section 2.1.4) that enables the business sustainability. So, companies have to adapt leadership style to the described model, but there are still some deficits noted in the literature. Although being a focus on operative areas, it can be also applicable to other areas (Dombrowski & Mielke, 2013).

2.1.6 Lean Thinking applicability and multidisciplinary

Many publications have been published about this subject and the concept of Lean Production has been spread out not only in the shop floor but also in other sectors. According to the studies performed by Jasti and Kodali (2015) and, more recently, Amaro et al. (2019, 2021) there was a significant increase of the publications related to Lean Production philosophy during the period between 2006-2020. Those results lead to conclude that there is a positive impact on the organizational performance by implementing these principles.

Additionally, Sanidas and Shin (2017) showed that Lean Production Systems had been contributing for the country's economic development and economic growth through inventories reduction. According to them, many empirical studies evidence the inventories decreasing over a long period of time when companies adopt a Lean Production approach. These results show a positive relation of Lean Production adoption with economic growth and development.

Additionally application of Lean principles is widely spread in different knowledge areas such as Lean Supply Chain and Lean distribution, Lean Product Development, Lean services and Lean Enterprise concepts among others (Figure 8) that show its applicability and benefits in different industries besides original automotive one (Alves et al., 2017; Amaro et al., 2021; Jasti & Kodali, 2015; Reichhart & Holweg, 2007).

Figure 8 – Areas of Lean Thinking application
(Alves et al., 2017)

2.2 Barriers to Lean implementation

In spite of having several advantages to follow Lean Production, the implementation remains difficult to attain (Amaro et al., 2020a; Bortolotti et al., 2015; Cowger, 2016; Grigg et al., 2020; Lean Frontiers, 2017; Leonard, 2015; Liker & Rother, 2010; Pay, 2008; Sangwa & Sangwan, 2018). Several managers have visited Toyota plants to understand the success of this system and to find reasons for the Toyota System's replications have failed in their company. Many of those visitors have assumed that Toyota's success is related to the cultural issues (Spear & Bowen, 1999). Related to their studies, Spear and Bowen (1999) have concluded that what distinguish Toyota from the other companies is related to how the workers and managers are engaged in the system, contributing to the organization improvement.

Important factors such as management commitment and leaders actively supporting continuous improvement, the creation of a Lean culture inside the organization that might require an organizational change management, knowledge and training to develop such expertise in order to perform Lean activities. The correct application of Lean tools, the employees involvement on the Lean culture are some facilitators and successful factors for Lean implementation (Achanga et al., 2006; Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016, 2020; Netland et al., 2020). Attending to the research perspective, these factors were organized in five categories described in the following sections: 1) Leadership and management commitment, 2) Training and continuous improvement, 3) Organizational culture, 4) People involvement, 5) Technical knowledge.

2.2.1 Leadership and management commitment

Leadership is commonly referred as an important and crucial factor driving a Lean implementation process. According to Achanga et al (2006) and Alefari et al.(2017), there are critical factors on the success of Lean implementation such as leadership. These authors referred that strategic initiatives have to be clear by the management. So, the management level involvement on continuous improvement activities should start by strategy definition (Netland et al., 2020).

There is a consensus in other research studies about management commitment and involvement that is fundamental to implement and maintain continuous improvement (Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2020). For a successful implementation, company administrators must believe in Lean fundamentals and support teams on the implementation (Achanga et al., 2006; Amaro et al., 2020a; Cowger, 2016; Lodgaard et al., 2016; Schonberger, 2019).

2.2.2 Training and continuous improvement

Cowger (2016) mentions that Lean is a philosophy of continuous improvement, it does not stop in any point of time. Lean is about creating a continuous improvement mind-set, people-focused leaders and increase Lean knowledge (Schonberger, 2019). Talking about continuous improvement is about process improvements focus on workers involvement, from the shop floor to management levels (Lodgaard et al., 2020).

Managers and workers need training and education in Lean Production, but according to Netland (2016) in the big companies, the managers education is more important than employees. This statement is directly connected with other resulted reported by the author for the success of Lean implementation that is the managerial commitment and involvement. The active participation of managers is a success factor in the Lean implementation.

Companies should look for contradictions as a way of growing and never being satisfied with *status quo* because this mind-set fosters continuous improvement and creativity. As such, developing problem solving methods is needed in order that employees look for contradictions as a challenge and deal with them systematically. For that, the correct application of Lean tools and methods is fundamental. Different research states the importance of knowledge and training to lead and perform Lean activities.

Education and training works as a Lean enabler to select the right tools and practices and to make decisions (Amaro et al., 2020a; Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016). Such training and knowledge is also important at management level to support and manage Lean initiatives (Achanga et al., 2006; Flumerfelt et al., 2016; Lodgaard et al., 2016). In section 2.2.5 is presented different methods of acquiring knowledge.

2.2.3 Organizational culture

Some studies (Achanga et al., 2006; Amaro et al., 2020a, 2021; Erthal & Marques, 2018; Hopp & Spearman, 2021; Lodgaard et al., 2016) refer that organizational culture is a determinant factor and it is also mentioned as a failure cause of Lean implementation. A change management will be needed for Lean implementation and that means resources availability, get workers involved and having people with enough empowerment to implement and sustain the implementation (Lodgaard et al., 2016). This is in line with Yadav et al. (2017) research that mention Lean implementation as a transformational process that involves organizational culture changes from a social-technical systems perspective. In the section 2.1.4 was described the importance of "respect for people" underlined in the Japanese management style.

According with Iuga and Kifor (2014), the management and the organizational culture are the main factors to ensure sustainable development. A company is not only a set of machines, but also a group of people that are a part of the system and they should be included in the innovation and learning process (Alves et al., 2012). Some common practices connected with human resources management and Lean practices like job rotation, job design, job enlargement, formal training programs and cross-training programs enable a flexible and cross-functional work force.

Related to organizational structure, Womack and Jones (1994) argue that a functional organizational structure may create some misalignment between function goals and organizational goals. Soliman and Saurin, (2020) also demonstrated that departmental structure represents an element on complexity for Lean. Additionally, authors (Womack & Jones, 1994) propose a new organizational model: *Lean Enterprise* whose its purpose is value adding creation inside of a value stream.

Later on, Mascitelli (2007) presents *Value-Stream Organization* as an alternative to fully project-based and purely functional organizations, explained in detail in section 2.3.4. This kind of organization structure propose a leader responsible for value stream efficiency and improvements. Continuous improvement activities requires a dedicated person responsible for leading Lean activities, managing value stream resources and coaching teams (Garcia-Sabater & Marin-Garcia, 2011). This role has been already implemented in some companies (Soliman & Saurin, 2020).

2.2.4 People involvement

Related people's involvement, there are some factors such as knowledge, involvement of workers on continuous improvement, and availability for continuous improvement that influence a successful implementation. Creating flow, fast adaption of customer demand, and cellular manufacturing layouts require flexible and multi-skilled workforce. The workforce must be trained to develop this ability, as well as the development of creative thinking and problem-solving skills, are crucial factors (Enkwa & Schvaneveldt, 2001; Ohno, 1988).

According to Lodgaard et al. (2016), clear roles and responsibilities in a Lean implementation process should be defined, otherwise it becomes a barrier. Authors also reported that many workers thought that "*lean was not part of their job*" (Lodgaard et al., 2016) because this kind of tasks are commonly seen as extra effort. Workers must be involved in the process. So, they feel part of the implementation process and contribute with their ideas. This is one reason to get teams motivated. The workers' motivation is also an important factor on continuous improvement process (Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016; Vicente et al., 2015).

Furthermore, employees should have freedom to contradict ideas, give their opinions, and managers should listen them actively in an open environment (Takeuchi et al., 2008). In this process, several types of improvements such as minor improvements that involves a few efforts in the implementation, and big improvements that are also visible into financial indicators, should be included (Garcia-Sabater & Marin-Garcia, 2011; Netland et al., 2020). Netland et al. (2020) presented four levels of value assessment, and it does not necessarily mean that all improvements use financial methods. For instance, some improvements on shop floor only need qualitative methods that encourage workers to participate in continuous improvement, even small ones, and this is also a way of measuring the worker's motivation.

2.2.5 Technical knowledge

Garcia-Sabater and Marin-Garcia (2011) referred that the application of continuous improvement tools, but not only the Lean tools application (e.g. 5S, kanban system, SMED) is required to get the maximum potential of Lean production, however some managers confuse this approach. For instance, related to waste elimination, Liker (2004) refers that it is not possible to eliminate waste (*Muda*) in the manufacturing system without working in other elements such as *Muri* (machines and equipment overburden), and *Mura* (unevenness), the three M's (*Muda, Muri, and Mura*). The lack of understanding about tools, practices, and the need to implement them as whole, leads some practitioners to say that Lean does not work (Liker, 2004).

According to Takeuchi et al. (2008), it is not possible to copy any practice directly from one company to another, referring to Toyota success. Each company should find a way to create its own culture and to adapt the practices. So, human and organizational aspects should be also included and emphasized when spreading Lean principles, and they should not be isolated from the other Lean tools and practices (Lodgaard et al., 2016; Netland, 2016). Nonaka (2007) mentions that tacit knowledge is very important and personal. Author presents four possible modes for acquiring two types of knowledge: tacit and explicit. The four possibilities are: socialization, externalization, internalization, and combination. Their characteristics are explained in Figure 9.

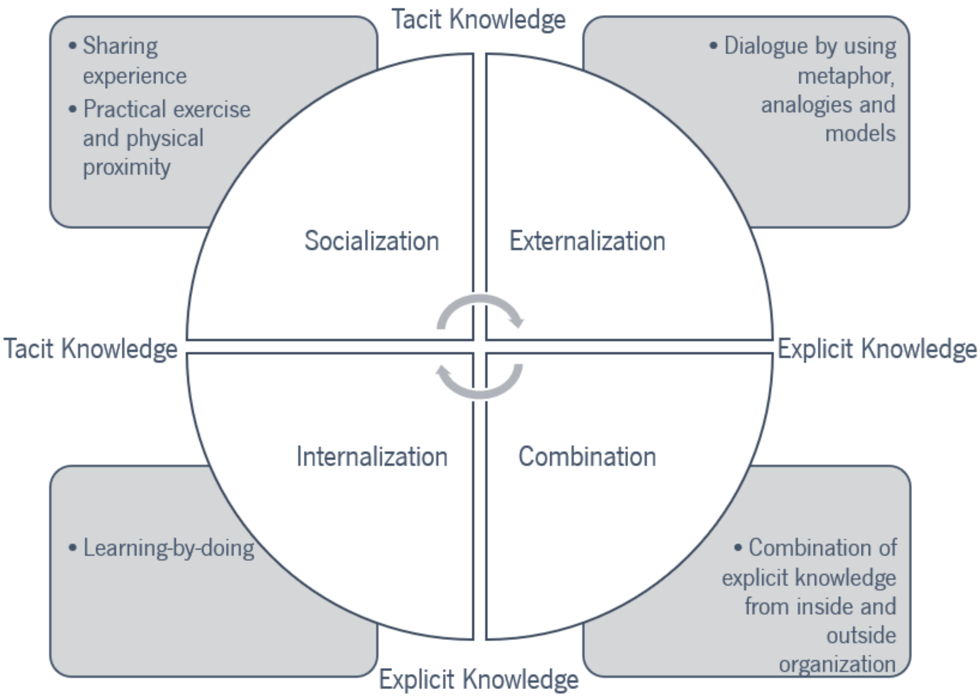


Figure 9 – The four modes of knowledge conversion (adapted from (Nonaka & Takeuchi, 1995))

Teams may learn from each other, using their own knowledge and sharing their experience. The author refers redundancy as an important element to create knowledge because it promotes discussion between members (Nonaka, 2007). Knowledge can be also accessed by using, for instance, a benchmark approach, and external consultants or internal resources in case of high maturity companies (Netland, 2016). Using internal resources can be a way of increasing trust and respect between managers and employees. This kind of teaching can also improve the relationship among employees and managers. Furthermore, leaders can be seen as a coach or adviser, not as a bossy (Spear & Bowen, 1999).

Different methods of acquiring knowledge such as learning factory, presented by National Science Foundation (NSF) in USA in 1994, combine tools of experimental learning and real production site (Abele et al., 2015). The main purpose of learning factories is to teach, train and/ or doing research in a technological and industry related environment. Those methods can be applied in a greenfield and in existent processes as a continuous improvement activity (Abele et al., 2010, 2015; Kreimeier et al., 2014; Steffen et al., 2012).

Process Learning Factory, from Center of industrial Productivity (CiP) in Darmstadt, in Germany, has implemented this concept, specifically for Lean principles where participants can experiment and implement them in a real production environment (Abele et al., 2012, 2015). Learning factory can also be seen as a socialization and internalization mode, explained above.

Some studies (Adam et al., 2019, 2021; Alves et al., 2017; Flumerfelt et al., 2016) have demonstrated the importance of active-based learning approach during the Lean training process. Additionally, train adults effectively and improve their Lean skills became more and more relevant for companies. So, learning factories, simulations, inclusion of didactical methods, and "learning by doing" are examples of appropriated methods to effectively experience Lean tools.

2.3 Other Paradigms and Industry New Trends

This section intends to present some production and organizations paradigms, and industry news trends that has been presented in the literature and influences the organizations.

2.3.1 Agile Manufacturing

In the twenty century has arisen a new manufacturing paradigm that had more importance during the twenty-first century: agile manufacturing (Gunasekaran, 1999; Kidd, 1994; Nagel, 1992; Vinodh, 2011). Agile manufacturing is a term used in US companies that was focused on a competitive environment where customers' requirements changed taking in advantages of the marketplace status (Devor et al., 1997).

For Gunasekaran (1999), agile manufacturing is *a new expression that is used to represent the ability of a producer of goods and services to thrive in the face of continuous change*. This vision suggests smaller scale, modular production facilities, and cooperation between companies. Similar to other methodologies, agile manufacturing principles also has its own principles such as "*continuous change; rapid response; quality improvement; social responsibility; and total focus on client*" (Alves et al., 2012). Practices such as: 1) mass customisation, 2) supply chain networking, 3) manufacturing automation, 4) employee empowerment, and 5) technology utilisation, enable the applicability of agile manufacturing. These are succinctly described:

1) Mass customization: involves a wide range of products and services variety that requires agility, flexibility, and integrated operation from the organization side (Da Silveira et al., 2001; Liu et al., 2012; Salvador et al., 2009). For some authors, mass customizations might represent an advantage for a dynamic market environment (Choi & Guo, 2018; Liu et al., 2012);
2) Supply chain networking: involves the relationship management with the suppliers and the customers in order to increase the customer's value across the entire supply chain. For that, a strong collaboration with supply chain partners is very important (Christopher, 2000; Gunasekaran, et al., 2018; Mentzer et al., 2001; Tsanos et al., 2014). Agile manufacturing also involves supply chain management that has to be also agile (Gunasekaran, et al., 2018);
3) Employee empowerment: many studies (Aravind Raj et al., 2013; Gunasekaran & Yusuf, 2002; Hasani et al., 2012; Jasti & Kodali, 2015; Marodin & Saurin, 2015; Netland, 2016; Sharp et al., 1999), not only agile related, refer the importance of employee's empowerment. One of the recommendations for empowerment enabling is to change from vertical structures to more flat ones (Quinn, 1992). Teamwork culture and simultaneous engineering practices promote the individually and collective empowerment by increasing the available knowledge (Narasimhan et al., 2006; Yang, 2014);
4) Manufacturing automation: refers to the operation that can be performed with minimal human intervention (Pinochet et al., 1996) by using technologies such as automation, robotics and other information, and communication technologies (Caggiano & Teti, 2018; Lau et al., 2002), which allows being more competitive (Edwards, 1996);
5) Technology adoption: refers to the wide range of technologies such as MRP, JIT, TQM, and Optimized Production Technology (OPT) that can be integrated in order to satisfy customer's requirements and achieve more competitiveness (Singletary & Winchester, 1998; Sousa & Voss, 2008). The technologies adoption and their implementation depend on different factors such as industry, size, technology, strategy, location resources capabilities, and goals (Spina et al., 1996).

Being an agile company means that it is capable to operate profitably in the mind-set of unpredictable environment changes. Therefore, the company must have speed of changing. According to Devor et al. (1997) that kind of changes can include, for instance, the customer opportunities, technologies of production, technologies of production engineering, and technologies of information, and data exchange. For that, companies should overcome many challenges, mainly, related with social and environmental aspects (Ciccullo et al., 2017; Angappa Gunasekaran, Yusuf, Adeleye, & Papadopoulos, 2018) to achieve a sustainable manufacturing.

According to Gunasekaran et al. (2018), a sustainable manufacturing is based in three perspectives such as people-oriented, environment-oriented, and technology-oriented innovations. An agile manufacturing requires highly skilled workers and leaders capable to work in different business models and high sense of collaboration and teamwork spirit (Gunasekaran et al., 2018; Kidd, 1994). Additionally, topics such as reuse and recycling, energy, and water consumption should be part of the strategy. Additionally, the introduction of Big data, cloud computing, and internet of things concepts should also be considered (Gunasekaran et al., 2017; Gunasekaran et al., 2018; Kim & Chai, 2017).

The market agility requirements should be visible in all areas. To achieve the agility is crucial to have flexibility and responsiveness in strategies, technologies, people, and systems (Gunasekaran, 1999). This author also compares the two methodologies: Lean Production and Agile Manufacturing. Author referred that "*Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of 'lean manufacturing*". Furthermore, it was referred that Agile Manufacturing is more focused on customer requirements and Lean is more focused on cost cutting (Gunasekaran, 1999).

Lean was originally conceived for environments relatively predictable (Suzaki, 1987) while agile is more applicable in fashion products with unpredictable demands that requires high resources flexibility as well as organization flexibility (Ding et al., 2021; Mason-Jones et al., 2000). Some authors (Haq & Boddu, 2014; Narasimhan et al., 2006) refer the similarities between Lean and Agile, however the focus is different. Therefore, both paradigms and practices can be successfully combined in distinct points (Mason-Jones et al., 2000; Soltan & Mostafa, 2015). The first Lean principle is the customer value as in every organization, the focus should be the customer satisfaction whichever the approach or strategy applied (Alves et al., 2012). According to Alves et al. (2012), being an agile organization requires also taking into account the customer value and waste elimination.

The combination of both approaches was called Leagile. Leagile was presented by Naylor et al. (1997), looking for an integrated supply chain perspective. *"Leagile is the combination of the lean and agile paradigms within a total supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the marketplace"* (Naylor et al., 1997). According to this approach, the decoupling point refers to a strategic buffer between fluctuating customer orders and/or product variety and smooth production output as represented in Figure 10 (C). Lean paradigm can be applied to the upstream of the decoupling point since the demand is smooth. While agile can be applied to the downstream of the decoupling point as the market is more volatile.

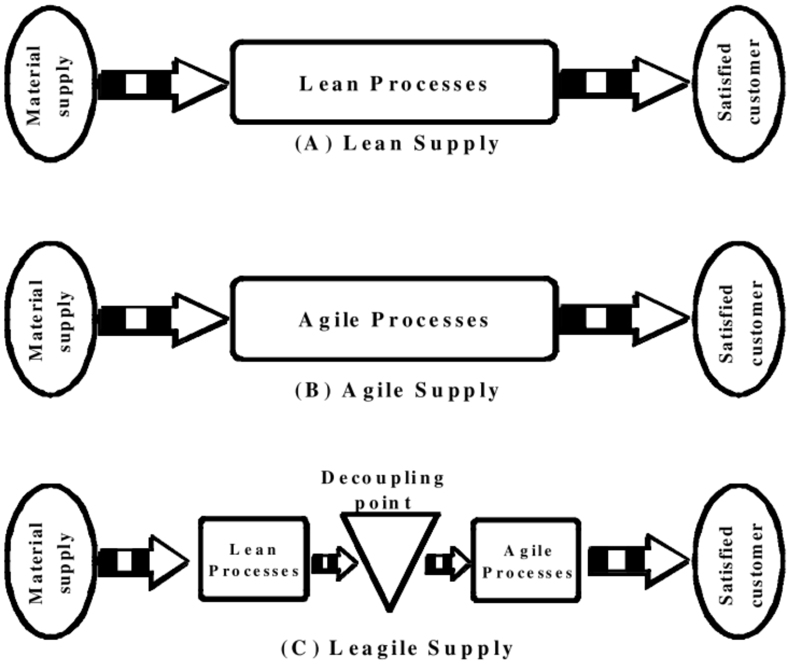


Figure 10 – Lean, Agile, and Leagile supply chain representation
(Mason-Jones et al., 2000)

According to Christopher (2000), Lean was considered more applicable when the demand is predictable, variety of product is low, and volume is high. Those are the characteristics that should determine lean or agile approach. Contrary, in agile approach the market is volatile and unpredictable. These authors (Christopher, 2000; Towill & Christopher, 2002) also supports a hybrid strategy, mainly for supply chain design that should consider the demand characteristics: forecast or demand driven (Fisher, 1997). So, the decoupling point represented in Figure 10 can be defined based also on those characteristics and inventory strategy. In agile supply chain, the inventory should be hold in generic or modular form to be customized as far downstream as possible, which is called postponement concept (Christopher, 2000). The postponement allows greater flexibility at generic level and the forecasting is easier (van Hoek, 1998). However, it requires working in advance during the product design phase in order to use common components and modules.

The decoupling point is not only material related but also information. The last one is an important point that impacts and might reduce demand amplification in the upstream points (Mason-Jones et al., 1997). Additionally, creating close relationships with suppliers, by including them in the process is an important factor that can bring huge advantages, since the suppliers' lead times are a real blocker to respond to customer needs. Improving quality of the suppliers' relationship includes high level of information sharing and connectivity between companies and suppliers (Christopher, 2000).

2.3.2 Learning Organizations

According to Senge (1990), learning organizations are *"...organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning to see the whole together.*"

Creating a learning organization requires five disciplines (Senge, 1990):

1) Personal Mastery: refers to the strength of people to be proactive and keep on learning to continuously achieve results that are important for them. For that, it is important to look at the reality objectively and understand the needs. People who live in a continual learning mode have a high level of personal mastery;
2) Mental Models: consists in turning the mirror inward. People reflect on their own behaviour and beliefs, and are capable of having opened conversations that could influence others. The openness involves transcending power games and internals politics that dominate traditional organizations;
3) Shared Vision: consists of having a shared vision of the organization by all employees. It does not mean that employees are going to play according to the rules of the game defined by the management, but they feel responsible for the game. When there is a genuine vision, people want to be part of that;
4) Team Learning: includes the vision that effective teamwork leads better results. Furthermore, people learn more and faster within a team than in an individual process. For that, the dialogue element is very important, meaning the capacity of a team to create assumptions and develop a genuine thinking together. This element is also related with mental models described in point 2);
5) System Thinking: It integrates the previous four disciplines. The fifth discipline encourage managers to look at problems from a holistic viewpoint rather than small pieces. ''*Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'.*'' (Senge, 1990)

A learning organization helps their workers to continue learning over the time. This mind-set encourage workers to follow the new innovative solutions and adapt the new business environment, which is also a characteristic of TPS that push their workers to think and learn continuously. Transforming a company into a learning organization take some time. It requires a continuous improvement culture and self-reflection. That can be supported using tools such as five-why, PDCA and policy deployment across different levels. The "ability to learn" is essential to sustain this kind of organizations (Liker, 2004).

Additional, a learning organization is capable to anticipate future conditions, adjust internal process, and challenge current business paradigms to meet new strategic and environmental requirements (Morgan, 1997).

Depending on national culture, there are some differences that might influence on learning organizations development. Japanese industrial tradition differs from the German and American. German industrial tradition is typically characterized by deep technical knowledge. Furthermore, business areas are functionally divided that allows to provide products with higher performance compared with others. The weakness of German tradition is regarding the lack of cross-functional cooperation that leads some inefficiencies and higher lead times. The American tradition is specially known by the cult of individual that makes the system very competitive and stressful, which represents a negative point referring production efficiency (Womack & Jones, 1994). Furthermore, Dombrowski and Mielke (2013) also noted that Germany companies have some deficits regarding the application of continuous improvement culture.

Japanese organizations are compared to a collective group, where there is a collaborative spirit, interdependencies promoted, shared work experience, concerns, and mutual help. So, Japanese employees see their organization "*as an extension of their family*" (Morgan, 1997). Morgan (1997) refers Murray Sayle that explain the solidarity lived in Japanese organizations, which is related the cultural values of the rice fields in order to serve the samurai. Every farmer expects to perform the best planting to assure a very good collective outcome, so "*there are no individual winners and losers*". These values were transferred to Japanese factories.

2.3.3 Socio-Technical Systems

Socio-Technical systems (STS) are an organizational theory developed by Tavistock Institute in the British coal mining industry during the 50s-70s of the twentieth century. This system is also well known and implemented in Swedish automotive industry, namely Volvo (Pasmore, 1988). STS is based on two factors: the social or human, and the technical one. The combination of these two factors leads to an improved organization performance. In these systems, it is analysed the impact of the technological evolution in the relation between technical and social systems. Furthermore, the success of the systems depends directly how the social system manages technical influences (Trist, 1981).

The socio-technical practices includes participation and union influence; flat hierarchies; informality, open dialogue, consensus among levels and parties; and autonomous workgroups (Åke Sandberg (ed.), 2013). Kosuge (2014) also refers that it will be helpful if the workers see their work in a holistic and organic perspective and control the processes autonomously. There are different models of socio-technical systems based on distinct interaction elements. However, all of them emphasize the importance of people interaction with other system elements and the interaction between other levels of the system (Carayon, 2006).

According to Saurin and Gonzalez (2013) and Soliman and Saurin (2020), a socio-technical system might became complex depending on a set of characteristics like a) a large number of dynamically interacting elements; b) wide diversity of elements; c) Unexpected variability; and d) resilience.

Some authors (Alves et al., 2012; Iuga & Kifor, 2014; Netland, 2016; Spear & Bowen, 1999) referred that learn about the production system and inherent culture is important for its implementation. People should be trained to be the changing drivers. This point is directly related with the people development to allow them to contribute for the organization (Alves et al., 2012; Iuga & Kifor, 2014).

Additionally, practices of self-directed work teams are also commonly referred that required an organization based on work teams and highly involved in problems solving groups (Ichniowski et al., 1997; John Paul MacDuffie, 1995; Osterman, 1994; Shah & Ward, 2003). Dabhilkar and Ahlstrom (2013) developed a hybrid model that converge practices of socio-technical system and Lean Production. This model shows synergies between those factors might provide benefits related to organizational performance, by contributing for variability's reduction in Lean system caused for example by employees' absenteeism. Although most of the Lean Production research has been more focused on technical aspects, authors referred that human factors are not so deeply developed.

Kosuge (2014) has developed a study about the conflict existent in Scandinavian Countries related to Lean practices and the humanization of the work. The conclusions are directly related with continuous improvement process based on TPS. He argues that "respect for people" is an integral aspect of Lean implementation. Its combination with socio-technical practices, which are traditionally used there, is a balancing between process development and people. "*In socio-technical system, an organization or a work unit is a combination of social and technological parts, with the purpose of joint optimization of quality of working life and technological performance"* (Kosuge, 2014).

The implementation of those elements requires a different leadership style compared with traditional one. In a learning organization, leaders are designers, stewards, and teachers that promote a continuous learning process for people expanding their capabilities. Leaders are responsible for learning (Senge, 1990). In section 2.1.5, it was discussed the Lean leadership model that complement the idea of having a different leadership vision.

2.3.4 Value stream organizations

The organizations may adopt different organizational structures depending on the business size, nature of business, values, geographical regions, leadership style, hierarchy, and other factors that can be more or less flat (Rishipal, 2014). A more recent one is the value stream organization that is based on the concept of value adding activities.

Value adding activities require a new organizational model: *Lean Enterprise*, which means a group's mission is to work on value adding creation inside of a value stream (James P. Womack & Jones, 1994). In the last years, organization approach based on the perspective of product development teams has been arisen namely "value-stream organization". Mascitelli (2007) presents *Value-Stream Organization* as an alternative to fully project-based and purely functional organizations. Therefore, an example of Value-Stream Organization proposed by Mascitelli (2007) is presented in Figure 11.

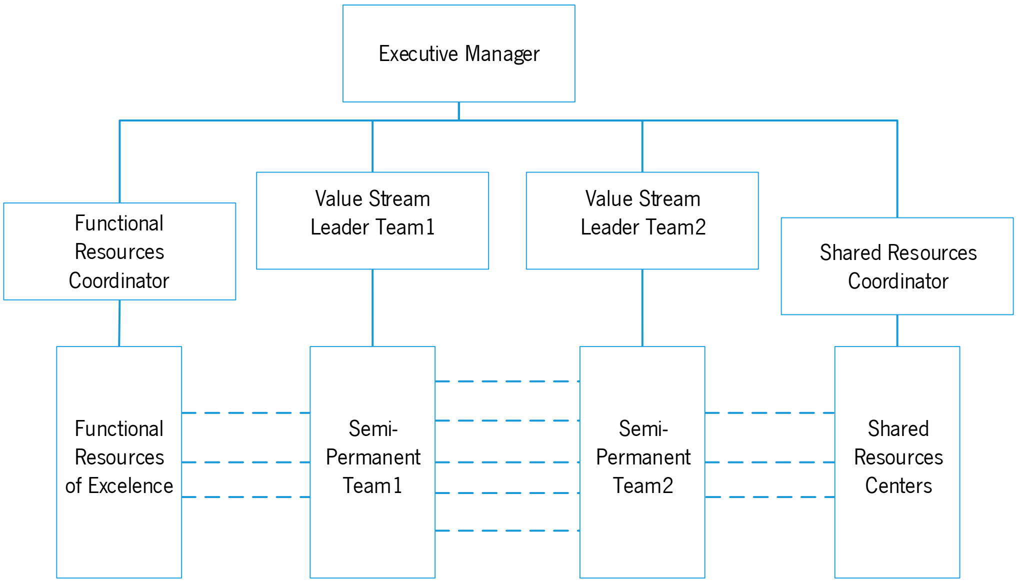


Figure 11 – Value Stream Organization
(adapted from (Mascitelli, 2007)*)*

Value stream organization differs from the traditional ones, namely, the pure functional and the matrix structure that are briefly described next. Pure functional organization also compared to Machine Bureaucracy by Mintzberg (1980). It is characterized by segregating departments into areas of speciality. Therefore, employees have similar skills to perform the same function, giving them enough autonomy to execute a given task. This kind of structure configuration with those characteristics allows a high degree of efficiency but there are many communication problems (Mascitelli, 2007; Mintzberg, 1980, 1983; Rishipal, 2014).

Hence, this kind of structure may create some conflicts between employees because the performance is measured based on their level of skills. This kind of structure fits in complex and stable organizations because everyone knows what should do and which department is responsible for it. This configuration is a top-down structure where decisions are taken on top and then vertically delegated. Departments gain a certain power inside the organization that may struggle inter-departmental communications (Mascitelli, 2007; Mintzberg, 1980, 1983; Rishipal, 2014).

In fully project-based organizations, people are completely allocated to the project which is working on. The mix of fully project-based and purely functional is called matrix organization. Matrix organization relies with Adhocracy configuration proposed by Mintzberg (1980). It is characterized by the employees' assignment to the projects that requires fewer levels of hierarchy compared with functional one. People are very focused in the project. This kind of structure is directly related with project management discipline. A project is assigned to the required people for its development.

Matrix organization breaks the strong functional silos and promote a cross functional work. Project teams are created based on skills required and product characteristics in order to complete assigned tasks for a given project. So, employees move from a project to another one, which demonstrates flexibility of this kind of structure (Mascitelli, 2007; Mintzberg, 1980; Rishipal, 2014).

The matrix structure promotes more flat hierarchies compared with functional one. There are several advantages of having flat structures such as: employees are more motivated because they feel a direct influence on the company, communication is more easier, the decision response is also easier since there are fewer levels of hierarchy and project team share the same goal (Mascitelli, 2007; Rishipal, 2014). The authority should be well defined otherwise it may create conflicts (Mintzberg, 1980).

Value stream organization might be combined with Lean principles using characteristics of a start-up company such as collaborative spirit by working in small teams and efficiency outcome. A value stream may include production lines or cells, other internal resources, logistics, and external suppliers of a product family, which in a Lean environment are focused in value-adding activities (Mascitelli, 2007; Womack & Jones, 1994).

A value stream leader role is created and each one is assigned to a product family. Value stream leader choses the core technical and operational employees that should be include in the team accordingly. Leader push all the team for a common goal, which is focused on value stream efficiency, the opposite of a traditional functional organization that are focused on functional goals (Mascitelli, 2007; Womack & Jones, 1994).

Mascitelli (2007) proposed that some firm areas (e.g., procurement, safety, contracts, and others) might keep in functional structure due to resources' inefficiency. So, those people are not fully working for a value stream. Due to that, a coordinator role, which supports on resources management for those departments not allocated to a value stream is proposed. Additionally, there is also a functional resources coordinator responsible for overseeing centres of excellence of each core function, which promotes job rotation between members and defines the best productivity tools (Mascitelli, 2007).

Womack and Jones (1994) advocate that functions have a role of sustaining the current knowledge and looking for new one such as different technologies and materials, new market trends among others in order to prepare teams working for a given product in a value stream. This systematic method of getting and deploying knowledge is in line with learning organizations approach in section 2.3.2. Furthermore, functions should define guidelines and best practices to be applied in new products or new generations by value stream teams.

In this type of organization, a cross-functional team is implemented, which creates synergies. Teams are totally dedicated to a specific process, so they are more focused and concentrated. Therefore, managers should be aware that optimum resources' utilization will be sacrificed for a better focus on product line and less external distractions (Mascitelli, 2007). According to Womack and Jones (1994), managers will be more concentrated in the enterprise's performance than the individual or functional performance like in old division of labour by departments because that conflicts with value stream.

2.3.5 Industry 4.0 and related concepts

New technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), robotics, big data, cloud manufacturing, and augmented reality are emerged in industries. Those technologies allow the connectivity between machines, human, equipment, and products. The development and implementation of those new technologies will also allow industries to become smarter, allowing them to have more intelligent manufacturing processes (Kagermann et al., 2013). In this sense, many companies developed strategies to implement new tools and technologies following the required digital transformation that leads to better results, increasing market competitiveness.

This phenomenon has been spread in industry world and academic community in the last years (Gallo et al., 2021; Hyun Park et al., 2017; Pereira & Romero, 2017). Some authors refer to this Era as the fourth industrial revolution, also called as Industry 4.0. This concept was presented in Hannover fair in Germany in 2011 (Hyun Park et al., 2017). According to Rüßmann et al., (2015), Industry 4.0 transformation is powered by nine technologies that allow the connection between physical environment and virtual world with internet. Those technologies are the following: 1) autonomous robots, 2) big data analytics, 3) cybersecurity, 4) internet of things, 5) simulation, 6) cloud computing, 7) horizontal and vertical system integration, 8) augmented reality, and 9) additive manufacturing. The technological evolution and the concept of a smart factory is a new paradigm that the industrial world has been challenged with. Following the Industry 4.0 report (Henning Kagermann et al., 2013), smart factories are the key features for industry 4.0 where "*human beings, machines and resources communicate with each other as naturally as in a social network*".

A smart factory will control itself and it would be able to operate autonomously (Tjahjono et al., 2017) in a CPS. It means a fusion between physical and virtual worlds with information exchange between processes, machines, and people. CPS involves an interaction between networks agents like sensors, smart actuators, process controllers, and communication technologies (Jazdi, 2014; Tjahjono et al., 2017).

Wang et al. (2016) describe a layer concept that integrate physical and digital world: 1) Physical layers related to the machines and all the activities that taken in place in the shop-floor; 2) Data layer that means all the information placed in a cloud coming from machines through sensors and vice versa; 3) Cloud and Intelligence layer where data can be analysed based on technologies such as artificial intelligence; 4) Control layer works as a master program that controls the further layers allowing the interaction with employees (Wang et al., 2016).

This interaction between system elements will allow a horizontal integration across the value streams, a digital integration of those elements and processes, and more accurate information sharing with management (vertical integration) (Kagermann et al., 2013). It will also enhances operational execution and decision-making in time and space (Cifone et al., 2021). Additionally, Industry 4.0 will also support the development of sustainable companies, an import manufacturing performance element nowadays, which means sustainability in economic, environmental and social dimensions (Ding et al., 2021).

More and more, customers desire products and services with high level of customization as faster as possible. Companies have to be competitive, gain trust from their customers, work with quality, fulfil their expectations and delighting them. Industry 4.0 will be helpful in this domain because intelligent systems can have abilities like "self-aware", "self-predict, and "self-maintain" (Nikolic et al., 2017) that can improve and speed up internal processes.

Some authors (Hyun Park et al., 2017; Mrugalska & Wyrwicka, 2017) present relations between the industrial revolutions and the production evolution as shown in Table 1.

Table 1 – Production Evolution
(Mrugalska & Wyrwicka, 2017)

	Past	Present	Future
Communication system	analog	Internet and Intranet	Internet of Things Cyber Physics System
Concept	Neo-Taylorism	Lean Production	Smart Factory
Solution	Mechanization and automation	Automation and computerization	Virtualization and integration

Mrugalska and Wyrwicka (2017) presents the smart factory as a production concept for the future – Industry 4.0. However, it still is difficult to define how the future will be. For them, Industry 4.0 will cover a new strategy that allow being more competitive by focusing on smart products and services, with optimized and flexible processes, and controlled production. For Park et al. (2017), the fourth revolution will provide faster processes that allow mass customization. Furthermore, the technology is going to anticipate the human behaviours. Figure 12 presents the different industrial revolutions related with human benefits, production strategy, and quality.

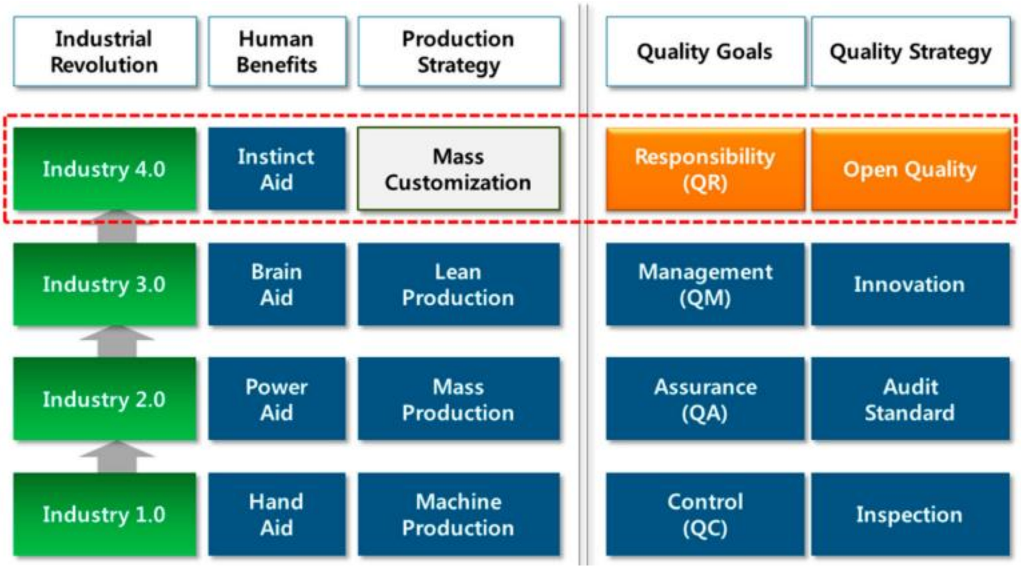


Figure 12 – Industrial revolution relation with human benefits, production strategy and quality
(Hyun Park et al., 2017)

Besides this idea that smart factory or mass customization is the future concept, Bittencourt (2018) refers that Industry 4.0 is not only the implementation of sensors, robotics, and technology. Digitalization will not eliminate the wastes if they exist. The relation between Industry 4.0 and Lean Production has been discussed in the research and industrial communities (Agostinho & Baldo, 2021; Bittencourt, 2018; Cagnetti et al., 2021; Cifone et al., 2021; Ding et al., 2021; Gallo et al., 2021; Langlotz et al., 2021; Schumacher et al., 2020).

Bittencourt (2018) has studied the contribution of Lean Thinking in the implementation of industry 4.0 between 2011 and 2018. The author showed two perspectives: one is that Lean Production is a facilitator of Industry 4.0 implementation, other one is that Industry 4.0 can support Lean implementation. On one hand, industry 4.0 will allow reducing the human effort, facilitating human activities, and increasing production flexibility. On the other hand, Lean Production simplifies processes, eliminates wastes, processes become more transparent, and promote the workers thinking. So, there is a positive integration of both (Bittencourt et al., 2021; Bittencourt, 2018; Bittencourt, Saldanha, et al., 2019). Cagnetti et al. (2021)'s study concluded that "*companies with extensive implementation of Industry 4.0 technologies also have the predisposition to adopt Lean Production in case of success"* and that "*the company that decides to adopt Lean Production technique is very likely to apply Industry 4.0 technologies"*.

Agostinho and Baldo (2021) also identified two similar perspectives of Lean and Industry 4.0: one is that Lean Production is a basis for Industry 4.0, by getting the advantage of having a continuous improvement culture well consolidated. The other one is that Industry 4.0 improves Lean Production effectiveness, allowing greater flexibility and the opportunity of handling with higher complexity. Lean Production and Industry 4.0 have different principles and practices, concepts are not comparable. However, they have similar goals. Due to that reason, good synergies between both approaches might lead to increase flexibility, increase productivity, reduce operating costs, improve quality, and reduce lead-times (Agostinho & Baldo, 2021; Buer et al., 2018).

Like Langlotz et al. (2021) mentioned, Lean methods cannot be replaced but they can be enriched by the technologies. Besides some shared goals, Industry 4.0 supports the increase of complexity to the production environment, and the individualization of products and services. Lean carries out the simplicity standardization and stabilization (Agostinho & Baldo, 2021). Cifone et al., (2021) refer that part of the success of both concepts is to have a clear understanding about Lean strategy and select the technologies that most fit to achieve the objectives.

Industry 4.0 will support industries to increase flexibility and improve cost-efficiency by applying new technologies. Some of them have already mentioned in the beginning of this section, which allow high level of integration (Ding et al., 2021). Flexibility can be achieved using modular simulation for different processes and then connected end-to-end. This allows adaptation to different situations and changes to market's requirements (Koren et al., 1999; Lucke et al., 2008). In this sense, the goal of increasing flexibility is closely aligned with agile manufacturing concept. Ding et al. (2021)' study suggests that industry 4.0 can connect both paradigms Lean and agile manufacturing, and improve cost and flexibility performance competitiveness.

There are no doubts that industry 4.0 will bring huge challenges for the industries and the connection with Lean practices since the main driver for industry 4.0 is technology. Indeed, professionals of Lean have to develop skills related with digital technologies and programming to overcome this gap. Companies play an important role, especially in continuous learning and training programmes that fulfil new technology's requirements (Agostinho & Baldo, 2021).

Human factor is still the key factor for the business success (Gallo et al., 2021). In this sense, a new concept, which was presented by European Commission, called Industry 5.0 came up recently. It answered to Society 5.0 concept, launched in Japan (European Commission, 2021). Industry 5.0 aims to get advantages of industry 4.0 elements for society, industry, and for workers. This becomes extremely important in Era that climate change, resources preservation, and social stability are focus, mainly after a pandemic crisis such as Covid-19.

So, Industry 5.0 requires a balance between industrial development and the resolution of the current social and environmental problems. It is identified by three elements: 1) the human-centric approach that means industry's focus should be the human needs, workers should be more empowered, which also requires up-skilling or re-skilling them; 2) sustainable, meaning industries should develop circular processes, reducing their environmental impact; 3) resilience refers to the ability of reacting to disruptive changes caused by political shifts or natural crisis, in order to keep the business' sustainability (European Commission, 2021).

2.4 Production Control Systems

Production control is part of the general topic related to Production Planning and Control systems in the context of production management. There is wide literature about the subject, and there are many different definitions. Production Planning and Control (PPC) systems are part of the information systems that influence machines, people, material, and suppliers of a production system management, by ensuring market and customer requirements, and an economic production operation accordingly. According to Vollmann et al. (1997), PPC includes three distinct levels:

1) Level 1: Production Planning that includes the company's strategy and the business plan, commonly for the next year timeframe. This planning is an aggregated plan of all products since the specific orders and part number are still not known. During this phase, it is also planned the required capacity of resources (people and machines) and shop floor space for such demand. The production planning is a crucial input for Master Production Scheduling that states the

production plan for each product. Customer's orders are converted into production orders. In parallel, capacity resources are verified to fulfil the planned orders;

2) Level 2: Material Requirements Planning (MRP) refers to a detailed planning of raw material and components, and resources capacity calculation. MRP explodes plans for every raw material and components according to the needs;
3) Level 3: last level refers to the execution system also called production control because it executes the production process planning. It refers to the production scheduling and many times requires real time decisions such as jobs priority management. For that, incoming orders coordination and orders monitoring are relevant tasks concerning production control (Cichos & Aurich, 2016). Depending on the complexity of subparts and repetitive nature of the production, different approaches such as repetitive, JIT, MRP might be applied.

Figure 13 presents the three levels described, representing the macro PPC framework overview. PPC activities include material and resources planning to fulfil customer demand, demand management, capacity planning and scheduling, and sequencing production orders, job priorities management, release material to the shop floor, among others such as quality, and transport (Riezebos, 2010; Stevenson et al., 2005; Vollmann et al., 1997).

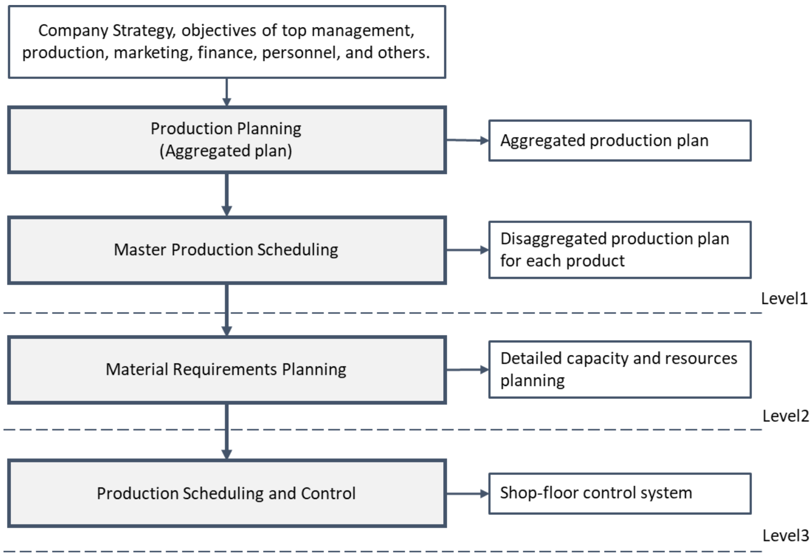


Figure 13 – Production Planning and Control System framework
(adapted from (Vollmann et al., 1997))

Vollmann et al. (1997) described in detail some typical activities related with PPC:

- Resources and capacity planning requirements to fulfil customer demand;
- Raw material arriving planning;
- Production equipment utilization;

- Assure enough raw material storage and control WIP and finished goods stocks;
- Schedule the right production jobs assuring the right people and equipment for that;
- Assure the interface between suppliers and customers;
- Manage customer forecast and its fluctuations;
- Tracking material and process flow;
- Fast reaction to deviations;
- Cross communication between other areas that impact on production activities.

The purpose of such activities is to reduce WIP and overall stocks, which are closely related with costs, production throughput times reduction, responsiveness improvement and flexibility to customer demand fluctuations, and fulfil customer orders in time and quantity (Stevenson et al., 2005).

Beyond Vollmann et al. (1997) framework, there are other definitions and understanding about PPC. Spearman et al. (1990) define as effective production control systems "*those that produce the right parts, at the right time, at a competitive cost*". Salum and Araz (2009) defined Production Control as "*an optimization problem that determines when and how much to produce at each stage to achieve a satisfactory customer service level"*, combining customer satisfaction with company performance indicators like the low inventory levels, and taking into account resource restrictions.

So, for the production control systems there are some elements that should be considered: *materials flow, the operations performed, the resources used, information flow, the decision rules for planning and control and, finally, the performance measures used* (Bonney et al., 1999). Taking into account those elements, production planning and control systems can be classified in three different strategies: push, pull and hybrid systems (Karmarkar, 1991) described in the following sections. Those strategies use different mechanism to control material and information flow through a production system that are also closely related with inventory levels (Puchkova et al., 2016).

Moreover, there are other important element that influences the production planning and control system: the production strategy to manage the demand nature. There are some strategies such as: Make-to-Order (MTO), Make-to-Stock (MTS), Engineer-to-order (ETO), Make-to-Demand (MTD) and Assembly-to-Order (ATO) (Alves, 2007; Carmo-Silva & Alves, 2006; Rocha et al., 2015; Vollmann et al., 1997).

MTO refers to the strategy whose production planning is based on the customer fixed orders, because orders are unpredictable. Orders are fulfilled according to the production capacity and customers are available to wait for the order.

MTS refers to a strategy that adapts inventory levels to meet customer needs. Usually, demand is predictable, and customer is not available to wait for the order, therefore orders are satisfied from the inventory. Meanwhile, inventory should be replaced.

ETO refers to a strategy that includes product development and production of one-of-a-kind products. In this case, products have high level of customization and customer is available to wait for the order.

MTD is applicable in very volatile markets, so activities are synchronized with demand as it shifts because it is very unpredictable and variable. Products are very flexible; therefore, they have a high level of customization. This strategy is variable in different elements.

ATO is related to modular products. Products are produced until a certain point of the production process. As soon as the customer's order is in place, parts are assembled and sent to customer. There is a high variety of products combined with the same modules, reason for stocking modules and then assembling them together according to the customer order (Alves, 2007; Carmo-Silva & Alves, 2006; Rocha et al., 2015; Vollmann et al., 1997).

2.4.1 Push systems

Push is a production control strategy that plans the jobs according to the process lead time to fulfil the material orders date (Spearman and Zazanis 1992). According to Bonney et al. (1999) what distinguish pull and push is the type of information that the system deals with, decision rules, the initial conditions related to stocks, the demand characteristics, and the system itself. While in push methodology, the planning is done based on forecast, in pull it is based on orders consumed. Furthermore, the information flow goes in the same direction as material flow. In push approach, material or parts are released to the next station as soon they are completed to downstream processes do not suffer starvation. That behaviour leads to higher levels of semi-finished or finished products (Puchkova et al., 2016). Additionally, in push system, orders are distributed to fulfil the specific due dates based on given lead times. So, jobs entry in the system, are queued until be processed depending on the schedule priorities rules. Furthermore, jobs are completed when pass through all defined process routes (Lee, 1989).

The most known push system is the Material Requirements Planning (MRP) whose pioneer was Joseph Orlicky (Orlicky, 1974). With MRP, every component and raw material are calculated based on bill of materials (BOM) and inventory for a period of the master production schedule requirements (Deleersnyder et al., 1989; Orlicky, 1974). Furthermore, MRP schedules orders in advance of consumption coming from forecasts (Miclo et al., 2019).

To operate the system, there are two key parameters: lead times and safety stocks. The good combination of those parameters provides the balancing results between inventory costs and costs of shortage. High lead times and high safety stock levels increases inventory costs but the risk of stockout is minimum (Buzacott & Shanthikumar, 1994). Figure 14 is a schema that represents how MRP works in each stage in relation to information and material flows.

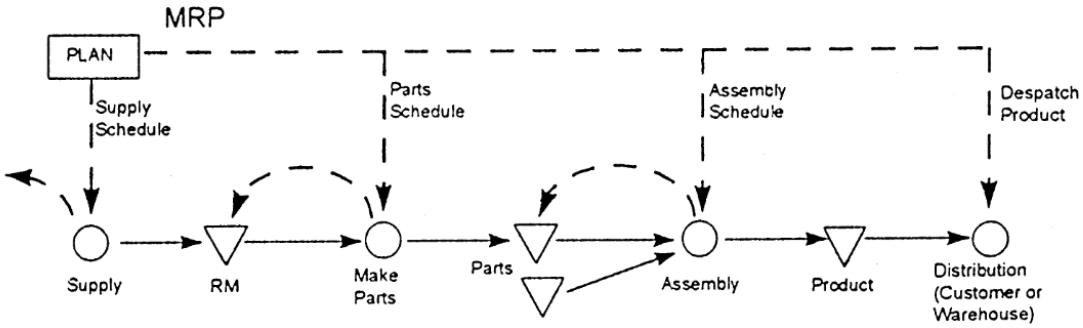


Figure 14 – Material and information flow for push systems (Bonney et al., 1999)

Initially, this system was focused on material planning. However, it suffered some evolutions in order to include capacity planning and management, resources, and supply chain planning. So, systems such as manufacturing resources planning (MRPII), enterprise resources planning (ERP), and material and capacity requirements planning (MCRP) have arisen due to some limitations from the initial version of MRP (Miclo et al., 2019). According to Miclo et al. (2019), those limitations were related to "*integration with formal capacity planning and management, lack of integration into the formal manufacturing planning and control system, lack of feedback and integration with the other areas of the firm*".

MRPII is a method to plan all manufacturing resources of a manufacturing company that involves many areas such as strategic business plan, production planning, master production schedule, MRP, and capacity requirements planning (Miclo et al., 2015). The extension of MRPII is the ERP system that integrate the entire company data such as supply chain, stock control, manufacturing planning, production sales support, and HR with the assistance of an information system. This system avoids duplication of data that could occur in MRP and MRPII because they were not a software alone. ERP systems also provide benefits, for instance, minimize time, cost, errors, and labour data analysis (Shafi et al., 2019).

2.4.2 Pull systems

The pull production is one of the most important principle according to the Lean Thinking principles and is the base for JIT, one of the most important pillars of TPS as described in section 2.1.1. One of the advantages of JIT philosophy is inventory and lead times reduction. It allows to lower production costs and increases flexibility to customer demand, by introducing tools like kanban system and practices such as quality control, set-up reduction, and strongly participation of workers in the continuous improvement system (Spearman et al., 1990).

In general, pull production means: the upstream process only produces when the downstream process requires. To contradict push, the information flow goes in the contrary direction of material flow (Bonney et al., 1999). In pull system, the production is triggered taking in account the customer demand. The signal to produce is given by the downstream to the upstream process. Production is done to cover the replenishment stock between processes (Spearman & Zazanis, 1992). Therefore, it also means that pull system is a method to control the workload in the systems (Powell et al., 2013). Sundar et al. (2014) refer that the success of pull is related to the small batches approaching one piece flow, following the takt time to respect the customer demand, using kanban to signal the replenishment, and level the products in quantity and time. This technical description of pull system explains fourth Lean Thinking principle.

The most known pull system and the one that is presented in Toyota Production System is the kanban system represented in Figure 15 (Powell et al., 2013).

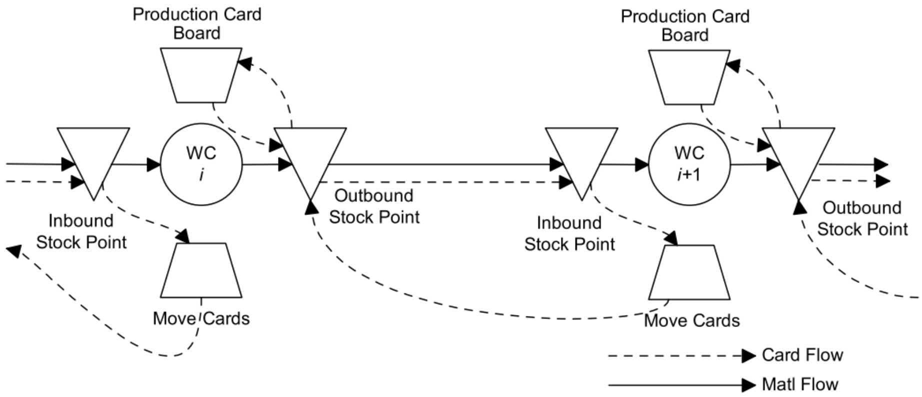


Figure 15 – Example of two kanban system
(Hopp & Spearman, 2004)

The kanban system is also combined with supermarkets that store standard containers of each part number produced. The kanban movement from the downstream process to the upstream process is the signal that customers are consuming parts from the supermarket. it also represents the need to replace parts into the supermarkets. kanban is commonly combined with supermarket technique that represents customer resource. Each time a part is withdrawal from the supermarket, a kanban signal is sent to upstream process to replenish the withdrawal quantity. This is the reason for pull being also called a replenishment strategy (Darlington et al., 2015; Krishnamurthy et al., 2004).

Additionally, kanban also works as an information processing tool since the moment it is removed from a container or a box until the time kanban is processed again, so it facilitates the efficient communication between processes (Huang & Kusiak, 1996). This kind of kanban is also denominated by withdrawal kanban (Kim, 1985) or conveyance kanban (Sugimori et al., 1977) because kanban goes from one process to the preceding one.

The transport between supermarket and downstream is usually linked to a predictable bus route (Darlington et al., 2015). Due to customer demand's fluctuations, supermarkets are needed to smooth the production flow and they should be maintained in order to lower inventory (Sundar et al., 2014). According to Rother and Shook (1999) and Bicheno (2004), in a Lean environment, supermarkets synchronize the workflow across the company processes. Furthermore, supermarkets follow the production rhythm of the "pacemaker" resource, which is the process that steers the whole plant according to production schedule.

Level of WIP within a kanban loop is determined by the number of kanbans (Spearman et al., 1990) that depends upon customer demand. Since customer demand might change across the time, number of kanbans might also change accordingly (Darlington et al., 2015). The calculation of number of kanbans, in each stage of the manufacturing system, represents the main issues of the kanban system implementation (Krishnamurthy et al., 2004). As a starting point for kanban system, the takt time of each operation has to be calculated based on the average of customer demand to smooth the system. Production systems should be designed or even adjusted according to the takt time (Rajan Suri, 2010). According to Sugimori et al. (1977), Toyota calculates number of kanbans based on equation 1 that depends of customer demand (D), lead time that takes a kanban in the system (Tw) and its processing time (Tp), number of pieces per container meaning quantity per Kanban, and an additional factor that allows to be capable to external fluctuations (α).

In a common production system, there are many preceding processes and suppliers involved. Typically, customer's fluctuations are transmitted to the upstream processes in amplified way. That effect is denominated bullwhip effect that causes a lot of instability in the chain and high levels of inventory. In order to avoid this effect, smoothing production quantities by applying levelled production is proposed. Levelled production is one of the principles of kanban implementation (Enkwa & Schvaneveldt, 2001; Hall, 1983; Ohno, 1988; Singh & Falkenburg, 1994).

$$k = \frac{D(Tw + Tp)(1 + \alpha)}{a}$$

K = Number of kanbans,
D = Demand per unit time,
Tw = Waiting for per kanban,
Tp = Processing Time,
a = Number of pieces per container
α = Policy variable.

Equation 1 – Kanban formula
(Sugimori et al., 1977)

Levelling (or *heijunka* already mentioned in section 2.1.1) is a method of doing production schedule in small lots of different models in the same line, adapting monthly demand changes during the year, and daily changes during the month. A production kanban relates to production plan is given to the final stage of production, and then this information flows to the preceding processes (Huang & Kusiak, 1996).

Levelling goal is smoothing the total quantity and quantity of each model by producing same amount of products in the same period. This method is fundamental to eliminate *muda* and *muri* , topics already discussed in section 2.1.2 (Liker & Morgan, 2006). Figure 16 shows an example of how production levelling can be done in a daily basis based on monthly forecast and firm orders, which might have minor adjustments during the weeks (Enkwa & Schvaneveldt, 2001). So, levelling schedule and takt times are essential elements for pull system implementation (Womack & Jones, 1996).

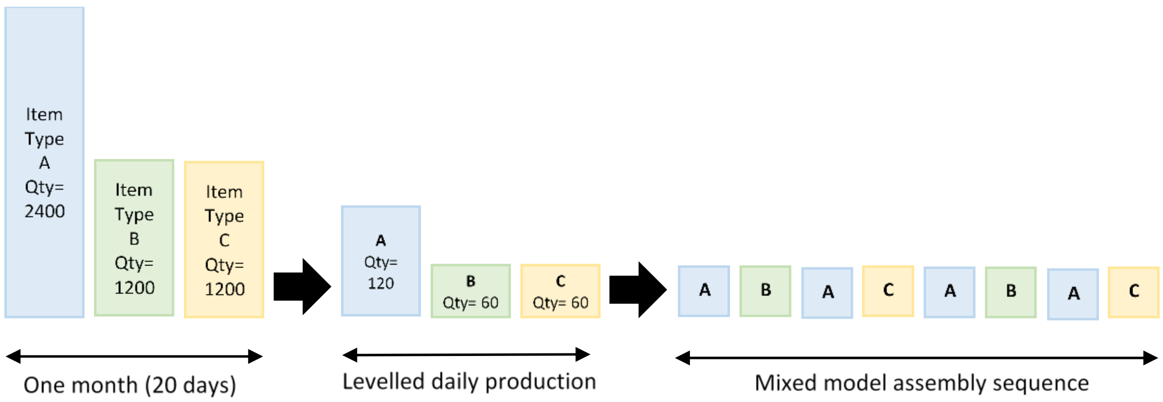


Figure 16 – Example of levelled production
(adapted from (Enkwa & Schvaneveldt, 2001)*)*

Levelling leads to less fluctuations for the upstream processes and for suppliers as well. This requires flexible lines that produce different models including multi-purpose machines and the availability of doing changeover as well (Monden, 1998; Sugimori et al., 1977). Reducing setup times is a requirement for levelling and small batches implementation. The more mixed production sequence is, the closer it gets to the market requirements and one-piece-flow production, like JIT requests. Additionally, it also required multi-skilled workforce able to operate with different products and tasks (Enkwa & Schvaneveldt, 2001).

Over the last years, mainly in automotive industry, the material supplying sequence has been demonstrated a huge importance. So Just-In-Sequence is a supplement of well-known JIT production, which means providing the right parts, at right moment in the right sequence. This principle requires a stable sequence defined and high discipline of suppliers and manufactures (Corell & Edson, 1998; Gujjula & Gunther, 2009; Nof et al., 1997; Werner et al., 2003). For Enkwa and Schvaneveldt (2001), the success of JIT involves the combination of three prerequisites: levelled production, development of flexible and multi-skilled workforce, continuous improvement, and *autonomation* concepts.

2.4.3 Hybrid systems

During the last years, some hybrid systems were developed in order to combine some characteristics of push and pull methodologies such as: Constant Work-in Process (CONWIP), Base stock, Drum Buffer Rope and POLCA (Jaegler et al., 2018; Powell et al., 2013; Salum & Araz, 2009; Spearman & Zazanis, 1992).

Although there are differences between the two methodologies, some authors (Lu et al., 2012; Serrato, 2016) proposed push-pull hybrid systems. Moreover, the authors referred that is possible to combine the use of both approaches in some production areas. They can be even mixed. However, it is still difficult to understand the rules and the decisions when to apply each one (Salum & Araz, 2009). The difficulty is more evident when process complexity and number of processes increase (Lu et al., 2012).

As Salum and Araz (2009) stated it is not so clear when and why it is more effective to apply a pull or a push system. Spearman and Zazanis (1992) concluded that the effectiveness of pull systems is related to the WIP limitation and not by pulling the upstream processes. The WIP is a performance metric that should be taken in consideration when implementing a pull system. Furthermore, a good trade-off between WIP and service level should be achieved (Onyeocha et al., 2015). The WIP purpose is to reduce the impact of production fluctuations such as machine breakdown, different process and transport times, and operators absent. WIP is directly related with input versus output rating and production lead times. The higher the lead times are, the greater WIP will be and higher probability of having delivering defaults (Fernandes, 2007).

2.4.3.1 Constant Work-in Process

According to Spearman et al. (1990), CONWIP combines the benefits of kanban system with the possibility of having a large product variety. It also pulls the upstream process by consumption (Figure 17) constraining the maximum level of Work in Process (WIP) in the line (Spearman et al., 1990). Similar to kanban system, a card represents a signal to the production. While in a kanban system each part number is assigned to a card, in CONWIP the cards are assigned to a production line. In a multi-product manufacturing environment where each product has its own kanban loop, kanban system leads to increase substantially the WIP levels (Hopp & Spearman, 2004; Onyeocha et al., 2015).

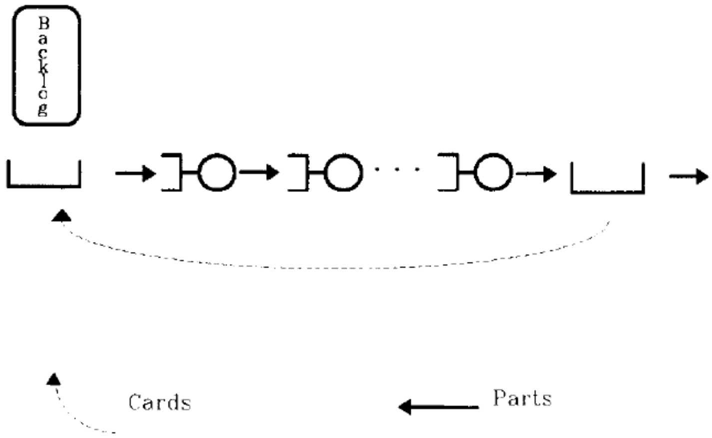


Figure 17 – CONWIP process
(Spearman et al., 1990)

In a certain point, CONWIP comply with theory of constraints (TOC), referred in section 2.4.3.2 (Goldratt & Cox, 1984) that balances the flow instead of the capacity. In a scenario when there is enough demand for the line output, CONWIP assures the enough WIP to not stop the line bottleneck (Spearman et al., 1990). Bottleneck resource determines the operation and the line capacity. Meaning that other resources are often idle and that is the reason why resources utilization might be a contradictory performance measure (Spearman et al., 1990).

According to Slomp et al. (2009), CONWIP requires a mechanism that controls the system workload on releasing orders. This can be done through the production levelling. Combination of CONWIP, takt time control, and FIFO principles provides benefits since that reduces the variability in the production. Takt time represents the ideal production pace to fulfil customer demand and minimize inventory. Order arrives in the process and are released to the next stage according to the takt time and following a FIFO sequence. Some cases reported in Miclo et al. (2019b) show there are positive improvements on inventory levels and lead time after applying this methodology.

2.4.3.2 Drum Buffer Rope

Drum Buffer Rope (DBR) was developed by Goldratt and Cox (1984) as part of theory of constraints (TOC). They introduced the concept of throughput accounting in order to facilitate managers to make decisions. The system throughput is affected by the "drum", the resource that constraint the system capacity (Darlington et al., 2015). Meaning that a given system achieves its higher performance by the bottleneck limitation since the drum represents the bottleneck process (Puche et al., 2019).

TOC implementation consists of applying five steps:

1) Identification of the resource constraint in the system;
2) Exploit the constraint resource;
3) Subordinate the rest of the system to the resource constraint;
4) Elevate the system's constraint by adding capacity;
5) Return to Step 1 if the constraint is broken (Goldratt & Cox, 1984).

In order to avoid the system's stoppages due to a possible failure, a buffer is placed in front of drum to assure it can keep working during a certain period. Buffer is a certain quantity of inventory protects bottleneck from internal fluctuations. Buffer should be calculated based on a probability of failure and the buffer size requires attention because it will impact on success of the technique (Darlington et al., 2015; Ye & Han, 2008).

Rope acts as a control mechanism that release material orders dictated by the drum resource. Rope connects the Drum to the beginning of the production system. Therefore, rope works as a signal to release production orders, and due to that, it controls, indirectly. the inventory in the system (Betterton & Cox, 2009; Darlington et al., 2015; Puche et al., 2019). In Figure 18 is illustrated how the DBR works.

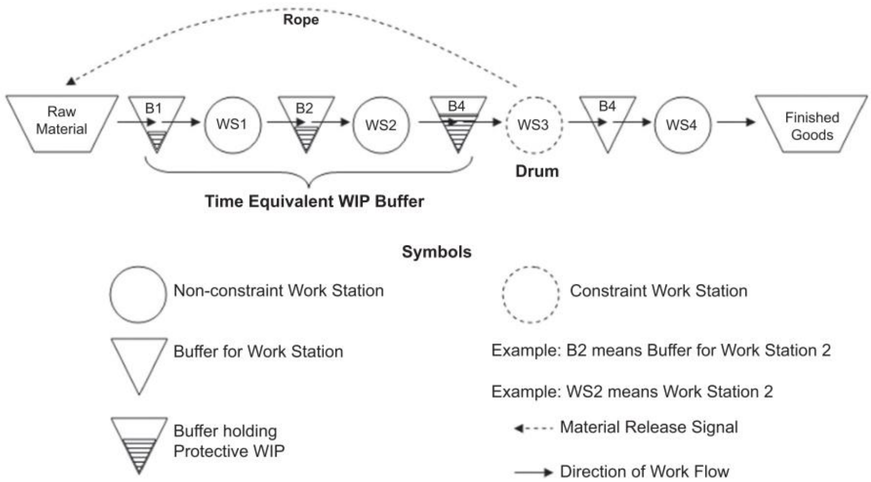


Figure 18 – Drum Buffer Rope
(Betterton & Cox, 2009)

2.4.3.3 Paired-cell Overlapping Loops of Cards with Authorization

Paired-cell Overlapping Loops of Cards with Authorization (POLCA) is a material control system that controls the flow between production cells. This system uses specific cards to control the loop (Figure 19) (Frazee & Standridge, 2016).

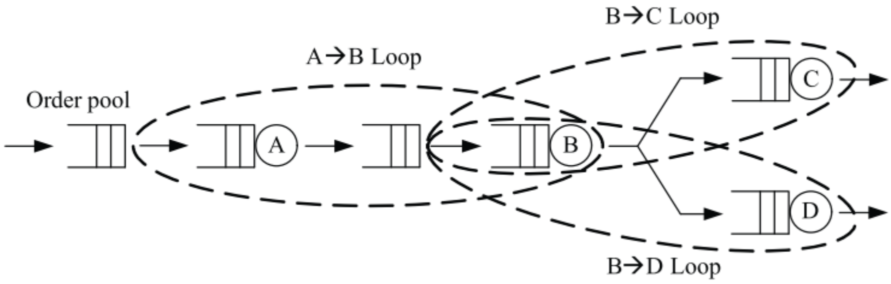


Figure 19 – POLCA system
(Germs & Riezebos, 2010)

According to Suri (2010), this system might be explained using the three key features: Paired-cell Loops of Cards, Authorization and Overlapping Loops:

1) Paired-cell Loops of Cards refers to the cells involved in the loop. For instance, loop B/C in Figure 19 contains an amount of POLCA cards. If a POLCA card is available, cell B will start the job and the card A/B is attached. When the process A completes the job, the job is sent to cell B. When cell B completes the job, the job is sent to the next cell, and POLCA card is sent back to cell A;
2) Authorization refers to the decision about which job starts next. POLCA relates to MRP systems but it also requires additional rules to define job starting;
3) Overlapping Loops implies another loop involved. Looking again at the example in Figure 19, when B cell completes the job, job is sent to C cell. So, it requires a B/C POLCA card as well. Meaning that a job only starts at B when there is a B/C POLCA card available, and when other jobs above it have already been started. Then, the same principles explained before are followed.

Suri (1998) presented POLCA as an alternative of kanban system for the context of Quick Response Manufacturing (QRM). QRM strategy emphasis the lead times reduction across all operations, covering many areas. This strategy gets advantage of tracking faster product deliveries in high product diversity environment (Rajan Suri, 2010).

Some authors (Fernandes & Carmo-Silva, 2006; Krishnamurthy et al., 2004; Rajan Suri, 2010) state that POLCA is used in Make-to-Order (MTO) systems and in higher customization product, with lower production volumes. However, QRM strategy also suit for Engineer-to-Order (ETO) products (Stevenson et al., 2005). Besides lead time reduction, according to Wang et al., (2021), QRM emphasis customization, flexibility, inventory reduction, organization focus, quality, and responsive advantages when compared with other manufacturing paradigms such as TPS, mass customization, Lean, and agile, already discussed.

2.4.3.4 Demand Driven MRP

Recently, it was presented a new approach resulting from improvements that has been demanding from practical world. Those improvements are related to overall performance and effectiveness of the MRP logic. With some developments based on Lean Production and Theory of Constraints, Ptak and Smith (2016) developed a new approach namely Demand Driven MRP, which replaces the static buffer approach from the original MRP by dynamic ones (Miclo et al., 2015, 2019). Demand Driven MRP is based on five approaches: MRPII, Distribution Resources Planning, Theory of Constraints, Lean, 6 sigma, and some innovations, combining the best practices of each one (Miclo et al., 2015). Demand Driven MRP is distinguished by the introduction of buffer definition for critical parts and its adjustment, and the lead time categorization (Miclo et al., 2019).

Demand Driven MRP is characterized by five components (Ihme & Stratton, 2015; Miclo, 2016; Miclo et al., 2015, 2016):

1) Strategic inventory positioning – related to the inventory needed in the supply chain and where inventory/ buffers should be positioned. Those buffers work as a system variability's controlling;
2) Buffer profiles and levels – buffers dimensioning according to the buffer size and different categories to plan parts, e.g., non-buffered parts and lead-time managed parts. Create three buffer levels: green – everything ok, yellow – a replenishment order should be placed, and red - special attention needed. Those levels are calculated based on average daily usage, variability, and lead-time;
3) Dynamic adjustments – adjustments are considered based on average daily usage;
4) Demand-driven planning – introduction of flow in the system by generating supply orders in certain quantity and with appropriate timing;
5) Highly visible and collaborative execution – creation of alerts on the system based on buffer level and supporting on decision-making by establishing clear rules.

2.4.3.5 Base Stock Control System

Base Stock Control System was presented in 1960 by Clark and Scarf (1960) as an inventory control problem. Base stock refers to finished goods inventory, which is the target one. The assumption of this system is: when an order arrives in the end of the system, this information is transferred simultaneously to the upstream processes in order to release a new part like Figure 20 represents (Clark & Scarf, 1960; Hopp & Spearman, 2000). Orders' information can be done using a card-based system like kanban system, and the control system can be similar to kanban if it is only considered one production stage (Bonvik et al., 1997).

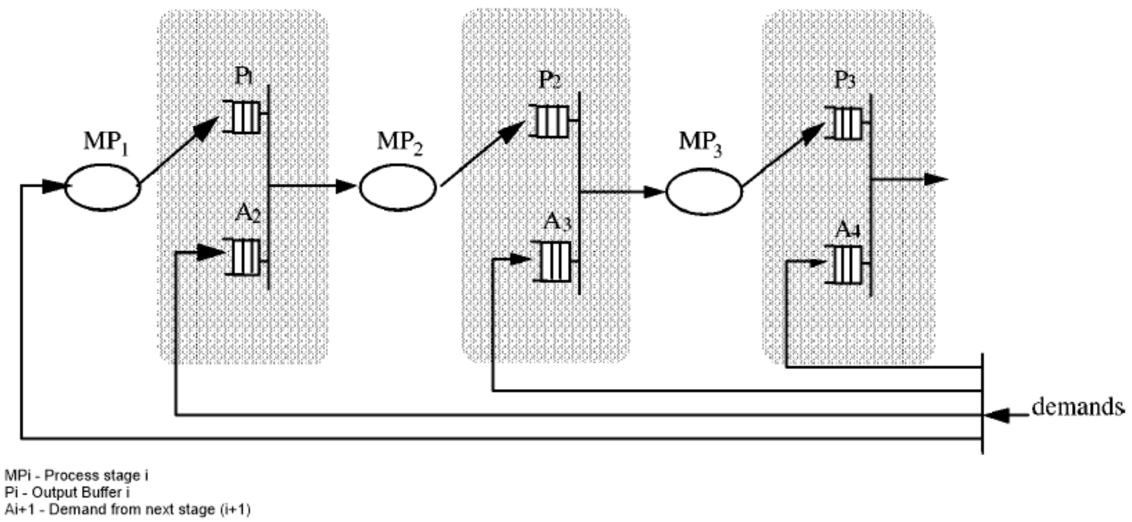


Figure 20 – Base Stock Control System
(adapted from Duri et al. (2000))

Each process stage has an inventory target of finished goods and WIP namely base stock (Clark & Scarf, 1960; Liberopoulos & Dallery, 2002). Usually, MRP systems use a base stock mechanism and the forecast demand for controlling the target stock levels (Veatch et al., 1994). This system is characterized by the constant lead times and the unlimited capacity of the machines stage.

2.4.4 Comparison between production control system and criteria for selection

The previous sections allowed to identify the main production control systems existent in the literature, and to distinguish the main characteristics and differences between them. For a better comparison, the main advantages and disadvantages of each one, the suitable production environment, and the implementation challenges are represented in the following tables (Table 2, Table 3 and Table 4).

Table 2 represents some relevant features for PCS comparison of push methodology using MRP system (explained in section 2.4.1). It should be noted that MRP system represented a great contribution for the industry at that time, which is the reason for identifying some advantages related to that period.

Table 2 – Features of production control methodology: Push using MRP system

Advantages	Disadvantages	Production environment	Implementation Challenges
•Reduction in inventory •Better capacity planning •Better priority planning •Better customer service •Better management •Improves morale •Better long-range planning (Cox & Clark, 1984) taken into account in 1974 was introduced an approach for material planning (Orlicky, 1974) •Better service level and average of inventory compared with pull strategy for moderate diversity and homogeneous demand (Krishnamurthy et al., 2004)	•Iterative production schedule process (Cox & Clark, 1984) that results in priority changes manually (Ptak & Smith, 2008) •Result in excessive inventories (Hopp & Spearman, 2000) •React nervously to customer fluctuations that cause bullwhip effect (Lee & Billington, 1992) •Misalignment between short-term orders, respective forecasted demand and real orders (Ihme & Stratton, 2015) •Assume that all parts are available on releasing orders time (Ptak & Smith, 2013) •There is no warning alerts concerning safety stock limits (Plenert, 1999) •Ambiguous lead time (Ihme & Stratton, 2015)	•Production initiates based on future demand estimation (Krishnamurthy et al., 2004)	•Technical Issues •Lack of management involvement and commitment •Poor employee attitudes •Resistance to change •Project team assignment (Cox & Clark, 1984; Kneppelt, 1981)

Table 3 represents some features of pull methodology using kanban system (explained in section 2.4.2).

Table 3 - Features of production control methodology: Pull using Kanban system (1/2)

Advantages	Disadvantages	Production environment	Implementation Challenges
•Less congestion and WIP (Hopp & Spearman, 2004; Spearman & Zazanis, 1992) •Lot size reduction (Ohno, 1988) •One-piece-flow production •Smoother production flow since system becomes more predictable (Hopp & Spearman, 2004) •Short quality loops once that short lot sizes and queues reduce time between failure and its detection (Hopp & Spearman, 2004) •Reduce costs because with less inventory, system becomes more transparent, problems will be more visible and solved. So, it becomes a more efficient system (Hopp & Spearman, 2004) •Leads an improvement environment, e.g. improving elements of kanban formula and set up times (Sugimori *et al.*, 1977; Krajewski *et al.*, 1987; Monden, 1983)	•Uncertain environment leads an unsatisfactory performance level (Li, 2013) •It required a rigid control on production schedules (James P. Womack & Jones, 1996) •Allocation of kanban in different manufacturing stages is not easy (Krishnamurthy et al., 2004) •Difficult or even impossible to apply in low runners (Monden, 1983) •Lines that produce many part numbers, WIP levels will be higher as it has maintained by part number (Spearman et al., 1990) •Kanban is not appropriated when set-up time reduction is not economically possible (Hall, 1983) •Requires space and storage costs for supermarkets implementation (Darlington et al., 2015) •Problems with orders control (Thürer et al., 2016) •Production stages may not respond instantly to the demand (Dallery & Liberopoulos, 2000)	•Originally designed for repetitive product and high demand (Enkwa & Schvaneveldt, 2001; Krishnamurthy et al., 2004; Slomp et al., 2009) •No adaptability for huge variations in demand (Monden, 1981;Huang & Kusiak, 1996) •Handicapper for companies that produce different type of products with different demand or processes, MTO or ETO that leads a inefficiencies (Suri, 1998; Riezebos, 2010) •Real consumption triggers production – replenishment strategy combined with supermarket (Ohno, 1988; Krishnamurthy *et al.*, 2004; Huang & Kusiak, 1996) •Kanban card belongs to a part number specific (Hopp & Spearman, 2004) •Connected with levelling production (Sugimori *et al.*, 1977; Monden, 1983; Enkwa & Schvaneveldt, 2001; Ohno, 1988)	•Recommendation: Start with more inventory than recommended and gradually reduce (Spearman et al., 1990) •During 1990s and 2000s, many studies neglected Heijunka technique (Thürer et al., 2016) and it is fundamental for kanban

Advantages	Disadvantages	Production environment	Implementation Challenges
•Controlled throughput (Spearman et al., 1990; Spearman & Zazanis, 1992) •Elimination of over-processing and limitation of surplus capacity of upstream processes (Sugimori et al., 1977) •Limits the inventory in the system by the number of kanbans (Dallery & Liberopoulos, 2000) •Kanban works as communication system between stages (Huang & Kusiak, 1996)		•Do not tolerate production losses (Monden, 1983; Spearman et al., 1990) •Requires standardization of jobs (Monden, 1983) •Requires autonomation (Monden, 1983) •Successful implemented in OEM (R. Suri, 1998) •Requires reliable delivery times and quality of the upstream suppliers (Huang & Kusiak, 1996)	

In Table 4, it is represented the main features of each hybrid system already described in section 2.4.3. Similar to the previous tables, it is collected the main advantages, disadvantages, production environment and implementation challenges of each one.

Table 4 – Features of production control methodology: Hybrid Push Pull (1/3)

System	Advantages	Disadvantages	Production environment	Implementation Challenges
CONWIP	•WIP constraint (Veatch et al., 1994) •Maximizing throughput (Buzacott & Shanthikumar, 1993) •Maximum throughput without exceeding flow time and WIP (Spearman et al., 1990) •Short quality loops since WIP levels are lower (Spearman et al., 1990) •More effective than push systems (Spearman et al., 1990) •Controls the workload on the shop floor level (Germs & Riezebos, 2010)	•No workload balancing capability on workstation level (Germs & Riezebos, 2010) •It is not applicable is decoupled processes/ stations once it control the whole system inventory, not individual stations (Thürer et al., 2016) •Process times and routing should be constant and similar (Hopp & Spearman, 2000)	•First station that receives a card works in a pull system, the others in line work in push (Spearman & Zazanis, 1992) •Card is line specific, not product specific (Hopp & Spearman, 2004) •Number of cards in the shop floor limits number of released orders (Germs & Riezebos, 2010) •More applicability in MTO environment than kanban (Slomp et al., 2009) •Parts are moved in a container with same amount of work (Spearman et al., 1990) •Input-output control (Spearman et al., 1990) •WIP control strategy (Frazee & Standridge, 2016) •Bottleneck resource regulates operation and orders are released according its rate (Spearman et al., 1990) •More general than kanban (Spearman et al., 1990)	•Recommendation: start with more inventory than recommended and gradually reduce (Spearman et al., 1990)
Drum Buffer Rope	•Protect bottleneck process from internal disruptions, inserting buffers in front (Thürer et al., 2016)	•Determines jobs release but not determines which ones and sequence (Thürer et al., 2016)	•More general than CONWIP. Applicable in job-shop environment (Spearman et al., 1990) •Rope works as a control mechanism (Bicheno, 2004)	•Selection of bottleneck position influences the system performance

System	Advantages	Disadvantages	Production environment	Implementation Challenges
	•Optimization of production resources (Telles et al., 2020) •Get maximum bottleneck capacity (Fernandes & Carmo-Silva, 2006) •Bottleneck is the only one resource that limits performance of entire system (Puche et al., 2019) •Works better than kanban in higher uncertainty and complex system (Grunwald et al., 1989) •Buffer calculated based on time rather than in quantity like in kanban (Bicheno, 2004; Darlington *et al.*, 2015)	•Time buffer is considered constant that is not applicable to the majority of the production systems (Georgiadis & Politou, 2013) •There is a few research of DBR applicability in multiproduct environment (Telles et al., 2020)	•*Focus on continuous improvement philosophy by dealing with constraints* (Şimşit et al., 2014) •Bottleneck control mechanism (Fernandes & Carmo-Silva, 2006) •Focus on throughput increase (Moore & Scheinkopf, 1998) •Requires a MRP system (Darlington et al., 2015)	(Thürer et al., 2016) •Manage constraint changing once that requires parametrization; Time buffer might be problematic in Make-to-Stock (MTS) environment. (Schragenheim et al., 2006, 2009; Schragenheim & Dettmer, 2001; Thürer & Stevenson, 2018) •Complex systems (e.g.: routings and lead time variation)(Darlington *et al.*, 2015; Schragenheim & Dettmer, 2001; Schragenheim *et al.*, 2006, 2009; Thürer & Stevenson, 2018)
POLCA	•Mechanism makes part of QRM strategy, reducing lead times, increasing speed response (Suri, 1998) •Get the benefits of combining kanban and CONWIP in MTO (Riezebos, 2010) •Reduce unbalanced processes (Riezebos, 2010) •Introduces safety cards to compensate unforeseen events (Riezebos, 2010) •Balance workload between workstations (Suri & Krishnamurthy, 2003)	•Longer lead times when compared with CONWIP (Germs & Riezebos, 2010; Kabadurmus, 2009) •Authorization element has never been assessed (Thürer et al., 2019) •Not appropriated in high routing variability (Thürer et al., 2016) and different process times (Germs & Riezebos, 2010) •Earliest release date calculated by the MRP may cause starvation in the system (Thürer et al., 2016)	•Designed for MTO and ETO environment that has lower quantities and high customization (Suri, 1998; Suri, 2010; Riezebos, 2010) •WIP control strategy (Frazee & Standridge, 2016) •More applicable in MTO environment than kanban (Slomp et al., 2009) •More applicability than kanban in high demand variability (Kabadurmus, 2009) once it was design to be and alternative of kanban for QRM (Suri, 1998) •Regulates the authorization order of production cells (Suri, 1998) •More applicable in job shop type (Riezebos, 2010) •It is not product specific. It is a route-specific control system (Riezebos, 2010) •Release orders mechanism that involves routing release (Riezebos, 2010) •Card is loop specific, not product specific (Thürer et al., 2019)	•Difficulty on the implementation when there is insufficient synchronization between cells (Riezebos, 2001) •Most of the companies do not have enough reliable data regarding throughput time, mainly wainting times within the cell (Riezebos, 2010) •Impact the system performance remains unknown in the existent literature (Thürer et al., 2019)

System	Advantages	Disadvantages	Production environment	Implementation Challenges
			•Requires a MRP system (Thürer et al., 2016; Orlicky, 1974) •Requires cellular structure (Rajan Suri, 2010)	
Demand Driven MRP	•Take advantages of four systems: MRP, Lean, TOC and Six Sigma (Miclo et al., 2019) •Absolve fluctuations from suppliers and customer by buffers definition (Romain Miclo et al., 2019) •Buffers applied only where they are need (Miclo et al., 2019) •Lead time and inventory reduction, and service improvement (Demand Driven Institute, 2019) •Easier adaption to real demand compared with MRPII (Miclo et al., 2015) •Alert system regarding buffer limits (Ihme & Stratton, 2015)	•Lead time value for buffer calculation remains a critical point (Miclo et al., 2016) •Sensible to huge unforeseen demand (R. Miclo et al., 2016)	•Introduces the concept of critical parts definition and selective inventory positioning (Miclo et al., 2019) •Buffered and non-buffered parts categorization (Ptak & Smith, 2016) •Different Lead times categorization •Different planning approach (MRP between buffers and net flow equation on buffers) (Ptak & Smith, 2016) •Dynamic buffers (Ptak & Smith, 2016) •MTO and MTS environment (Miclo, 2016)	Few researches works in this topic because method is recent (Miclo et al., 2016)
Base Stock Control System	•Provides the inventory need to achieve a certain service level (Hellemans et al., 2019) •Trade-off between two elements: inventory level and lead times (Hellemans et al., 2019) •System responds instantly to the demand (Dallery & Liberopoulos, 2000)	•Base stock calculation based on lead times might lead a huge inventory cost related crossover orders (Robinson et al., 2001) •No limit of number of parts in the system (Dallery & Liberopoulos, 2000) •It does not take into account production capacity of each stage (Dallery & Liberopoulos, 2000) •Possibility of accumulating large inventory due to capacity limitations depending of demand behaviour (Veatch et al., 1994)	•Limitations in the uncertain environment. So, achieving better performance levels become difficult (Li, 2013)	•Base stock policies are never optimal because it can accumulate large amount of WIP due to capacity constraints (Veatch et al., 1994)

The insights of each PCS previously described represents a valuable input for the criteria definition that allows to select the most appropriated one. A deep analysis of these systems and literature review about them allowed to realize that they are released in some distinct factors. Those criteria were identified based on each production control system described previously. Each system has different characteristics. Those characteristics leads to select a given system accordingly. After analysing each one, some criteria were identified as relevant criteria for the system selection. In Table 5, it is identified the criteria such as: demand nature, product diversity, product quantities, process characteristics, main purpose, and production order that impacts the PCS selection.

Table 5 – Criteria to select Production Control System

System	Demand nature	Product diversity	Product quantities	Process characteristics	Main purpose	Production orders
MRP	MTS MTO				• Raw material requirements planning • Capacity and resources planning and management	• Based on future forecast. • Based on BOM and inventory
Kanban	MTS	Low	• High demand. • Sensitive to demand variation.	• Lower Set-up times • Decoupled processes via supermarkets	• Stock control and reduction • Control lead time	• Real consumption • Levelled production plan • Product specific card-based
CONWIP	MTS MTO			• Not applicable in decoupled processes	• Maximizing throughput • WIP control strategy	• Line specific card-based • Bottleneck resource regulates operation and orders
Drum Buffer Rope	MTO	Low (not enough research in multiproduct environment)		• Applicable in job shop. • Requires a MRP system	Better utilization of production resources, mainly bottleneck process	
POLCA	MTO ETO	High	Low	• Not appropriated in high routing variability and different process times • More applicable in job shop type • Applicable in overlapping cell loops	• WIP control strategy • Speed response	• Loop specific card-based • Release orders mechanism
Demand Driven MRP	MTS MTO				• Buffer definition and adjustment for critical parts • Lead time categorization	Based on future forecast
Base Stock Control			System responds instantly to the demand	Target process finished goods and WIP called base stock	Base stock control	

The demand nature is related with strategies to answer customer demand as previously explained. Product diversity concerns the level of diversity in relation to product variants and families. Product quantities refer to the demand volumes. Process characteristics is related with special features of the process that might impact PCS selection. Other criteria are the main purpose of the PCS, which should influence the decision depending on the strategy. Production's orders are related with the interaction between production jobs release and information flow to manage accordingly. Furthermore, those criteria should be complemented with PCS advantages, disadvantages, production environment, and the challenges of its implementation described in Table 2, Table 3, and Table 4.

2.5 Critical analysis

This chapter presented a broad literature review focusing on Lean Production principles and the boundary conditions for its implementation. Over the last decades, many industries have been tried to apply Lean methods and tools. The purpose is achieving the well-known results and the competitiveness coming from Japanese automotive industries. Considering concepts surrounding Lean origins and their relationship with difficulties of its implementation pointed out by several authors, it was essential to develop deeply this topic. This relation is particularly important for the conducted research because barriers of Lean Production implementation is one of the spotlights of this project. Despite Lean has been mainly focused on the technical point of view during several years, other factors have revealed crucial for Lean implementation process. Therefore, it becomes increasingly clear that factors such as leadership commitment, people involvement, the organizational culture among others already described in the chapter should be considered.

Lean organizational philosophy has been developed and widespread during the last century. Although its methods and tools are apparently mature in the literature, the current world is changing considerably, mainly, in the current digital transformation phase. Therefore, understanding the new trends that might affect the industry and might compromise the success of its applicability represents an important point in this research. This risk is due to possible misunderstandings concerning Lean role. In this sense, concepts related with organizational models such as agile manufacturing, learning organizations, value stream organizations, and technological related concepts such as industry 4.0 were described and related with Lean. And the message is now clear: a suitable mind-set cannot be replaced by technologies, although the tools could be improved, enhanced, and augmented by them, which represents an opportunity to achieve better results with such synergies.

The barriers found in the literature are mostly related with organizational philosophy and the mind-set. Literature demonstrates that Lean is an organizational philosophy and very often, Lean is defined as a set of tools, which is a misunderstanding. Lean implementation is based on Lean Thinking principles that all companies should consider. Furthermore, the organizational culture based on respect for people, continuous improvement, and open communication over the hierarchical levels are fundamental for Lean implementation success. All the benefits that Lean has been demonstrated over the years by applying Lean tools only can be successfully achieved when supported by the philosophy coming from the top management.

Companies that want to implement this philosophy should keep this idea in mind. Their main objective is to satisfy the internal and external customer, reduce waste referred in section 2.1.2, and even environmental resources. For that, there are many tools that can be used and adapted to each situation, mainly production control systems. Coming again to the origins, JIT is one of two TPS pillars complying with pull principle, the fourth Lean Thinking principle. Pull is one of the production control system strategies to control inventory and orders' management.

A clear understanding of the existent production control systems and the requirements of its applicability was essential to relate with Lean concepts and to develop a theory from now on. This project would not be completed without understanding the relation between both concepts: Lean and pull since that one of the research objectives was to understand the main difficulties of pull system implementation. This was the gap raised in this research and additionally the experience faced in the company where case study was developed.

Although pull is the fourth Lean Thinking principle, like other Lean tools, each company should analyse and define the most suitable production control system according to its reality. However, having push system in a Lean environment might represent contradictory goals. Pull system implementation requires a levelled production to avoid fluctuations and big production lot sizes, which lead to high levels of inventory. Furthermore, to compensate customer's fluctuations, supermarkets have to be installed to avoid instability in the upstream processes. The consumption from those supermarkets triggers the production, which is one of the most important pull premises: production only starts when downstream process requires. Information flow can be done using the well-known kanban system. Additionally, pull strategy is very sensitive to demand fluctuations and production losses. Therefore, those issues require a special analysis.

The previous explanation refers the technical part. However, it has already observed that Lean philosophy should be present, even in production control systems implementation or other tools. Leadership should be committed to the activities and decisions. People should have the right qualification and be involved in production control systems implementation. Continuous improvement mind-set should be also considered even in this topic.

3 Research methodology and methods

This chapter presents in detail the research methodology and methods used in this thesis. The research philosophy, the techniques and procedures selected for data collection, and the analysis are explained and justified. Additionally, the research strategy, the validity, and the ethics are presented.

3.1 Research philosophy and approach

The research methodology framework approached in this research follows Figure 21. The research philosophy has an important role because it will influence research process. In relation to ontological position that refers to the nature of reality, it will be used the objectivism approach that *"represents the position that social entities exist in reality external to social actors"* (Saunders et al., 2009).

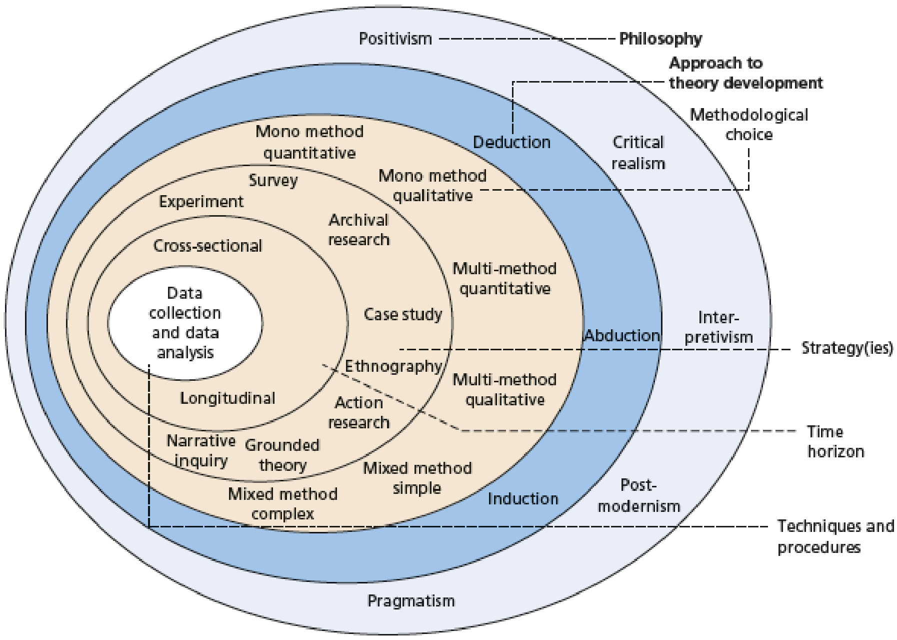


Figure 21 – Research Onion
(Saunders et al., 2016)

Related to the epistemological position concerning the knowledge validity, it will follow the positivism approach, by developing hypothesis connected to the phenomena that will be tested during the research. Positivism is a philosophical current supported by philosophers like Auguste Comte directly connected with industrial revolution when science's development became a huge importance. Positivism supports knowledge based on science facts (Reale & Antiseri, 1991). So, research design followed this approach, started from a theoretical proposition and combining the problem presented by the case study, the facts were analysed and corroborated by the literature.

Related to theory's development, it was mainly considered the deductive approach, meaning that the theory developed will be tested with results from the research strategy (Saunders et al., 2009). However, in some phases of the research, an inductive approach was also used in order to have a completed research that answers the research questions. For Saunders et al. (2016), the combination of two approaches is possible, and in some cases, it could be an advantage.

3.2 Research strategy and questions

The inhibitors and facilitators of Lean implementation have been a focus of several studies. In the conducted research, this topic is also investigated. It is also intended to understand the difficulties of pull system implementation in Lean environment and propose a suitable production control system. In the sense of understanding the phenomenon, this research has some characteristics of an exploratory study. However, it has also explanatory characteristics since the relationship between variables is considered on the analysis. Due to that, mixed methods: quantitative and qualitative were considered on research design. So the analysis of different methods in the same research is applied (Saunders et al., 2016).

The research strategy chosen for this thesis was the case study. Due to the research contextualization and its characteristics, the case study was a "natural" selection. Additionally, the research questions also provided an indication about the strategy to be selected:

- *Which are the conditions needed for a decision-making process related to the production control systems in Lean Production environment?*
- *Why is the pull system implementation still challenging for Lean companies?*

According to Yin (2009) there are three conditions for the research strategy selection: 1) type of research question, 2) if the research requires control of events by the investigator, and 3) if the research is focused on contemporary events. Table 6 shows the main characteristics of each research strategy considering the three conditions referred previously.

Table 6 – Conditions for different research strategies
(Yin, 2009)

Research Strategy	**Type of Research Question**	**Requires control of events?**	**Focused on contemporary events?**
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

According to Yin (2009), there are four types of case studies: single case holistic or single case embedded, and multiple cases holistic or multiple cases embedded. The holistic ones involve only one unit of analysis even in single or multiple cases. In embedded ones involves the analysis of multiple units of analysis in the same case and it is also applicable in single or multiple cases. In this research, a single case holistic was selected due to the research circumstances already mentioned. The research involves a study about a phenomenon in a particular period, so it means the research is a cross-sectional study looking at the time horizon perspective (Saunders et al., 2016). The results of the case study used in this research was focused on year 2019 and part of 2020.

3.2.1 Case study

The case study is an empirical research strategy specially applied to understand, explore, and describe a phenomenon that involves several variables (Yin, 2009). Such variables, and the complexity related to the situation under investigation leads the investigators to make research questions like "how" and "why" as mentioned on Table 6.

Yin (2003) refers that "*case study is used in many situations, to contribute to our knowledge of individual, group, organizational, social, political and related phenomena*" and "*allows investigators to focus on a "case" and retain a holistic and real-world perspective".* In the case study, researcher does not control the case events and commonly research is focused on contemporary events. Case study may refer different situations such as an individual, small groups, organizations, industries, schools, managerial processes, and many others with the objective to get a holistic overview and description of a real-life phenomenon (Saunders et al., 2016; Yin, 2009). Stake (1978) refers that "cases" represents some members of the research target population. Due to that the results' generalization should be done carefully. Instead of generalizing to a population of cases, it might be generalized to a similar case. Developing a case study follow five phases represented in Figure 22 according to Yin (2009).

The phase 1 is described in chapter 1 showing the motivation and the research objectives also the research questions. The unit of analysis is presented in chapter 4 where the single case study is described in detail. The literature review, in chapter 2 supports the conceptual framework by presenting the state of the art, defining some research boarders, and allows the investigator find literature gaps concerning the topic.

Preparing data collection is one of the case study phases that might be complex and difficult (Yin, 2009). In order to increase the data collection's reliability, a protocol should be developed by the researcher. The protocol defined in the conducted research is presented in section 3.2.2.

Collecting evidences is the fourth case study phase presented by (Yin, 2009). For that, every field procedure described in the case study protocol had high importance during the data collection. Data from different sources was considered in this research. Using multiple sources of evidences is a particular positive characteristic of the case study data collection that allows the same phenomena being corroborated by different sources (Yin, 2009). It represents a very hard and iterative process that allowed to describe the current case study situation. Furthermore, it also represents an input for the next phase, the analysis.

Figure 22 – Case study phases
(adapted from (Yin, 2009)*)*

Related to the analysis of evidences, Yin (2009) proposes four strategies: 1) relying on theoretical propositions, 2) developing a case description, 3) using both qualitative and quantitative data, and 4) examining rival explanations. Relying on theoretical propositions strategy means that theoretical orientation is the guide for the case study. Developing a case description is less preferable comparing with previous strategy. Meaning the case study starts without theoretical propositions, so the case study is a descriptive one. Having qualitative and quantitative data is also one analysis strategy of the case study. It makes sense when there is a considerable quantitative data in a case study.

Last strategy is the comparison between the case study outcomes and rival theories. Therefore, Yin (2009) defined five analytics techniques as a part of these strategies: 1) pattern matching, the most preferable in case studies that favour logic patterns, and the more coincident patterns, higher internal validity will be; 2) explanation building that is a special case of pattern matching, commonly applied in explanatory case studies trying to explain a phenomena by building an explanation about it; 3) time-series analysis that follow some patterns over the time; 4) logic models that analyse a set of events during a huge period of time; 5) cross-case synthesis applied in multiple case studies that aggregates the findings across a series of individual studies. These techniques are essential for the internal validity approached in section 3.2.4.

In the conducted research both strategies were used: relying with theoretical prepositions also using qualitative and quantitative data were applied during the analysis. Every interview analysis was corroborated by the literature. The quantitative indicators are a supplement with the qualitative analysis. The techniques adopted for the analysis were pattern matching, which has a huge importance for the interview analysis and explanation building. The analysis of case study evidence results is presented in section 5.2. This thesis represents the last phase of the case study, the reporting.

3.2.2 Case study protocol

The case study protocol should describe the inquiry instrument and procedure guidelines that includes four phases according to Yin (2003):

1) Overview of the case study project, by presenting the project background;
2) Field procedures and planning data collection procedures;
3) Case study questions;
4) A guide for the case study report.

The general overview of the case study is defined in section 1.4. This case study will evidence the development of theory in order to answer the research questions. Furthermore, it is going to support the answering of production control system selection in a Lean environment. It will be provided recommendation for implementation described in chapter 6.

The following phase is the field procedures used for data collection. Gaining access to the organization is an important task to start data collection. Due to purpose of the research already explained in chapter 1, the contact with organization was an easy task because company was involved in the process. Anyway, the research topic was presented in a weekly management meeting for every manager get committed to the conducted research and support during data collection. In this research, several procedures were used such as: individual meetings, observations, internal documents, interviews that are detailed described in section 3.2.3, shop floor visits, workshops, and indicators collection. Since the researcher is also employee of the company where the case study was developed, the information access and close contact with many people facilitates the accomplishment of this phase. So, the researcher has also a role of practitioner-researcher as Saunders et al. (2009) describe. The risk of having any bias due to that was taken into account during the research design and the chosen methods.

The third phase of protocol is the case study questions that are divided in five levels like Table 7 shows (Yin, 2009).

Table 7 – Levels of case study questions
(Yin, 2009)

Level 1	Questions asked of specific interviewees
Level 2	Questions asked of the individual case
Level 3	Questions asked of the pattern of findings across multiple cases
Level 4	Questions asked of an entire study
Level 5	Normative questions about policy recommendations and conclusions, going beyond the narrow scope of the study.

The purpose of case study questions during preparation data collection phase is to keep the researcher on track (Yin, 2009). Levels from 3 to 5 are not applicable in single cases. Level 1 and level 2 were applied in the conducted research. For the interview, a structured and detailed guideline was prepared, Appendix 2. Additionally, for the other procedures, several questions were the research focus like "why is this data important? Is it used for? Which is the contribution for the research?". The research questions of the case study are closely related with general one, however they are more specific:

- *Why is Lean Production implementation challenging?*
- *Why has the pull system implementation been failed?*
- *Which are the most suitable production control system in this case study? Is the pull system?*

In section 3.2.3 is described every interview phase that support the analysis and the report. This thesis represents the case study report required in the phase four.

3.2.3 Interviews

Interviews were one of the nominated methods to achieve and answer the case study questions. This method was chosen because, on the one hand, due to the case study characteristics that would favour a personal discussion, on the other hand, the participant is given the possibility to answer freely each question and reflect the topic.

The type of interview selected was semi-structured interview. Semi-structured interviews are characterized by a list of topics and questions that should be covered and some of those questions may vary depending of participant (Saunders et al., 2009). Based on those premises, it was developed an interview guideline presented in Appendix 2 that connect each question to each topic and research objective. For that, it was important to examine the current situation of the company presented in chapter 5. The current situation analysis allowed doing some connections between different subjects. Furthermore, it allowed to know some approaches experienced by the company and its results, which also allowed to formulate adequate questions by connecting the case study and literature review. All questions were carefully developed in order to avoid any interviewer bias. The conducted semi-structured interview allowed having an overall overview of each participant's point of view. Additionally, it gives the opportunity to explain in detail the problem they were facing. Furthermore, it was important having a free answer in order to not influence the interviewee. So, each participant answered freely about the topic.

Main topics approached in the interviews were the following ones:

- Continuous improvement;
- Lean Production;
- Pull system;
- Training;
- Organizational structure;
- Employees Involvement on Continuous improvement;
- Plant strategy.

The summary of the most important interview questions is presented in Table 8 where questions match with main topics.

The group's selection for the interviews considered the responsibilities they have in production control system and Lean production implementation. Group selection was done based on organizational structure (section 5.2.2.3) and based on Value Stream Design for Indirect Areas (VSDiA) (Appendix 3) performed where roles and responsibilities were presented.

Additionally, some informal dialogues were needed to select the right operational team. Interviewees were split in three different groups of participants:

- Operational teams (O) - involved in pull system implementation and continuous improvement process;
- Value streams manager (VSMan) - responsible and involved in continuous improvement of its value stream and;
- Manager (M) - whose responsibility is related to production control in the company also involved in company strategy. In this group is also included administration managers responsible for company management and strategy.

For those different groups, some questions are common in order to have different perspectives and to answer different thesis objectives. However, there are specific questions for each group of participants

(Appendix 4). Each question has a specific goal clearly defined in order to fulfil the research objectives, as explained in Appendix 2.

Table 8 – Summary of Interview questions and topics approached

Topic	Content/ Question
Continuous Improvement	• What are the main factors that contribute to the projects closure? • Which is the reason to close some projects and others not?
Lean Production	• What are the biggest challenges in having a lean company? • Have you found obstacles in implementing these principles and elements? • In BPS assessment 2018, the factory maturity level is about 1.6 in average for the 3 existing value streams. What do you think about it? • What is different related to TPM success? • In the Balanced Scorecard 2019 there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. What is the strategy to achieve this goal? • Which is the reason to not implement other elements? What should it be done to accomplish?
Pull System	• In your opinion, what are the main factors that block the pull system implementation in the factory? • There are others projects such as the Audi, CC and Renault that were not possible to implement. What do you think about this? • In your opinion, what would it have to change in order to implement pull at the Braga plant?
Pull System And Lean production	• Pull & Leveling project was a high focus project in the company, in the GM/ CTP product family. What do you think about the project? Have you ever participated in this kind of project before? Was it a successful project? Which were the main barriers?
Continuous Improvement And Organizational	• As Value stream manager, do you interfere in all areas? Which is your role in the source and in the delivery? Have you already been a project owner in those areas? Do you think there are any relation between value stream manager role and CIP results? Would it be different with another organizational structure? Which one do you think that would work? • Does Value stream manager interfere with all areas? What do you think of the value stream manager role?
Lean Production And Organizational	• Is there any relationship between the outcome of the BPS Assessment and your annual objectives? • In the Balanced Scorecard 2019, there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. Have you been participating in any activity for the strategy implementation?
Continuous Improvement And Employees involvement	• In 2018, BPS assessor recommended to improve the visualization of employee involvement in CIP. How is it being done?
Training And Organizational	• The employee training level in Lean content is about 30% (April 2019). Does this value seem reasonable to you? Is it enough? Is there any strategy to increase the results once that the company intends to be benchmark? Do you think those results impact on the continuous improvement projects? • Is there any relation between projects and training? Do people, who participate in continuous improvement projects, have training for that?
Pull System Strategy	• What is the factory strategy for pull implementation? • What is the goal for the next BPS assessment? • What is the goal for the pull principle maturity level?

Interviewee characterization is done on Table 9 where is shown gender ratio, hierarchical level on the organization, years of working in the company, and the interviewee group as explained previously.

Table 9 – Interviewee characterization

		Quantity	Percentage (%)
Gender	Female	6	35%
	Male	11	65%
Hierarchical Level	Operational	6	35%
	Head of Section	6	35%
	Head of Department	3	18%
	Administration	2	12%
Years of working in the company	< 5	4	24%
	5 e <10	1	6%
	10 e <15	2	12%
	>=15	10	59%
Interviewee Group	Operational	6	35%
	Value stream Manager	4	24%
	Manager	7	41%
	Total	**17**	

Related to the nature of interaction between the researcher and participant, it was used the common method face-to-face: the researcher and the single participant (Saunders et al., 2009). As Saunders et al. (2009) refer, there is a preference by a personal contact, like a personal interview, than fill in a questionnaire. Mainly, when there is a special interest in the topic. Then, this criterion was important taken into account the case study.

In the next sections is explained the different interview phases.

3.2.3.1 Interview Preparation

Interviews were performed inside the company, in a specific room in order to interviewee feels more comfortable and without pressure during the interview. In the beginning, it was explained once more the confidentiality topics, as well as the interviews context and procedure. The first interview was performed on 22nd October 2019 and last one on 12th December 2019, so for 8 weeks. Seventeen interviews were performed.

The first contact with participants was an email invitation (Appendix 5) to the interviewees requesting for the interview. This email explained the context and the interview goals. A consent to record the interview and confidentiality rules were attached. After the interviewee acceptance, three days before the interview, the researcher provided the questions by email. This procedure was done due to the cultural topics related organization also give the opportunity for better preparation.

To estimate interview duration and train the interview technique, a simulation with a colleague familiar with topic was done. So, in the simulation, the interview tone of voice, the questioning reading, and noting was trained. It was used the longer interview, and the duration of others was extrapolated. This simulation allowed having the perception how much attention was needed and how fast should be done notes written. However, this simulation and this person do not make part of the results.

3.2.3.2 During Interview

During the interview, for each question, the interviewer took notes about the most important topics mentioned by the interviewee. After each answer, the interviewer repeated those topics in order to double-check the answer as well as to summarise the information. In order do not influence, the interviewer did not interrupt the interviewee during the answers and did not make extra questions related to the guideline. When there was some misunderstanding related to the interpretation, it was requested to formulate and explain the topic in another away.

To increase the reliability, the researcher tried to use a neutral tone of voice and corporal expressions. Furthermore, no comments or personal opinions were used during the interview.

3.2.3.3 Interview Analysis

Interview's analysis was divided in three phases: transcription, codification, and analysis, explained in the following sections.

3.2.3.3.1 Transcription

For the interview's analysis, the first step was the fully manual transcription of every interview. This step allowed having a general perception about main categories mentioned and some answers pattern. Afterword, it was used a web software for supporting qualitative analysis: webQDA (*WebQDA*, 2016). This software allows creating categories, codes, filter, control, and search data. In relation to the analysis, it allows searching for the most frequent words, text, and matrix analysing. The last one was the most used in the conducted research.

3.2.3.3.2 Codification

According to the interview guideline (Appendix 2 - Table 38), some questions belong to the same topic. For each topic was created a category tree with sub-categories like Figure 23 shows.

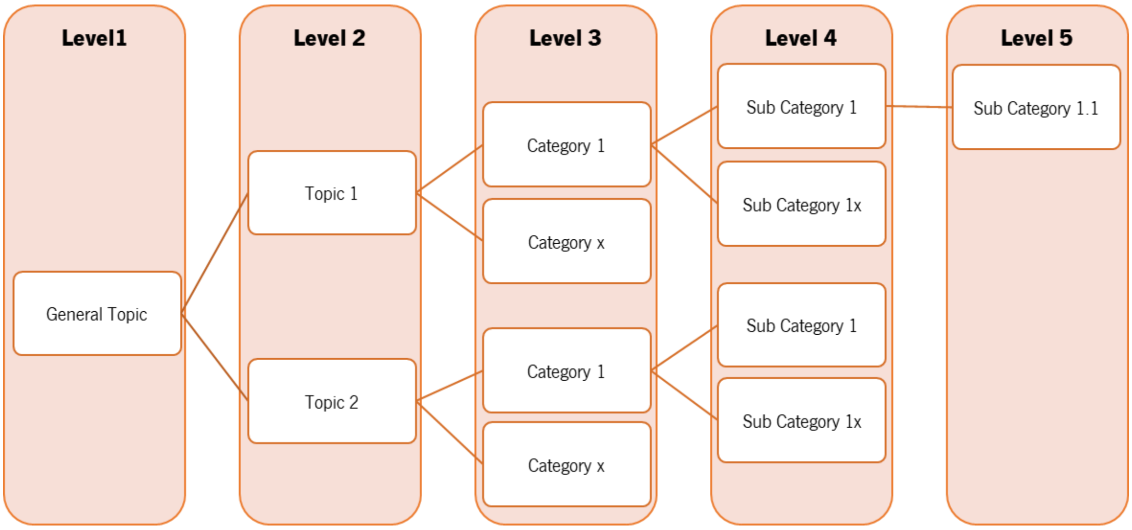


Figure 23 – Category tree explanation

So, different questions belonging to the same topics were organized and combined in the category three. In the beginning of the codification, some categories were created based on literature review. However, during the codification, some codes were created based on the interviewee statements. This was an iterative process: after the first codification, codes were revised and standardized. Some of them were merged with each other due to its meaning and organized in the code tree hierarchy. Therefore, this step represents the codification phase, which allowed structuring the interviews results.

In order to validate the codification that have been done by the researcher, some parts of interviews were codified by other people. Those people were not present during the interviews nether in the analysis. This exercise intends to confirm if there is no research bias during codification also to double check the same understanding on the codification.

The supervisors of this thesis were the two people selected to do this exercise in order to keep the confidentiality rules. Furthermore, the topic is familiar to them. The number of questions and number of answers selection was based on 80/ 20 rule or Pareto principle demonstrated by Vilfredo Pareto published in his first work, *Cours d'Economie Politique* (Pareto, 1964). Therefore, of 19 questions considered in the bigger interview, 20% represents four. The most general questions related to Lean production, pull system, and continuous improvement implementation were the four questions selected for validation. Those questions are also the questions with higher impact on the results.

Then, the criteria to calculate how many people per question to be considered was again 80/ 20 rule related to the 17 interviewees. So, it means three interviewees per question. On total, four questions, each one with three different answers, meaning 12 answers. In order to avoid any bias, for each question it was performed a random to select the interviewee. On Figure 24 is explained the method described.

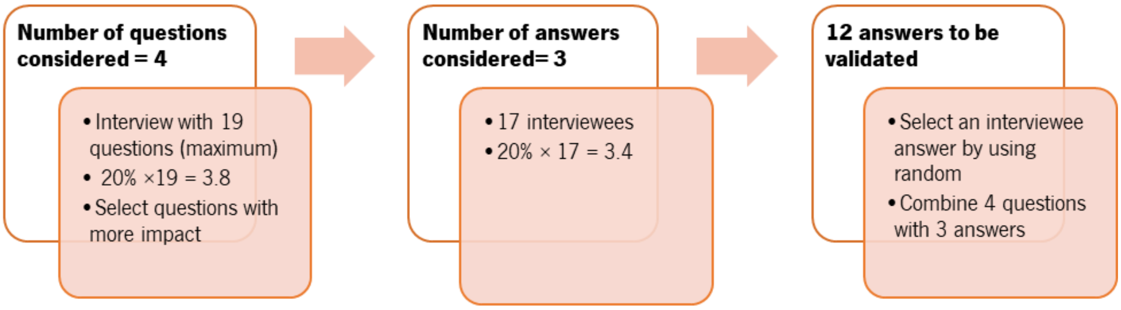


Figure 24 – Scheme explaining validation codification method

Table 10 shows the final structure for the codification validation used in this interviews process.

Table 10 – Codification Validation Method Explanation

Question 1 – interviewee A	Question 1 – interviewee B	Question 1 – interviewee C
Question 2 – interviewee D	Question 2 – interviewee E	Question 2 – interviewee F
Question 3 – interviewee G	Question 3 – interviewee H	Question 3 – interviewee I
Question 4 – interviewee J	Question 4 – interviewee K	Question 4 – interviewee L

The evaluation was done on levels 3 as category, 4 and 5 as sub categories. Table 11 shows the results of this exercise. Category's results (74% of matching in average) are better than sub category (57%) as expected since category is a general topic. Another reason is related to the level of codification knowledge; meaning that researcher knows much better codification and its meaning. Sub categories have a deep level of detail, it is specific and more case study related. In a general overview, results show a positive tendency in terms of codification matching.

Table 11 – Codification validation Results

Question Number	Category Result	Sub Category Result
Q1	68%	46%
Q2	78%	63%
Q3	67%	60%
Q5	83%	59%
Average	**74%**	**57%**

3.2.3.3.3 Analysis

The interview analysis was done based on category tree obtained after codification phase. Analysis was focusing on guideline objectives, by trying to answer them. In each topic, it was evaluated each category and the most citied sub categories taken into account Pareto principle. Additionally, for each topic, it was evaluated the most cited sub categories in order to have a general overview independently of the categories. Furthermore, in some topics, it was relevant to understand the percentage of interviewee mentioning. Analysis of results are presented in chapter 5.

3.2.4 Research Validity

In order to increase the quality of the empirical research, four tests are recommended to do in case studies: construct validity, internal validity, external validity, and reliability (Yin, 2009). In Table 12, it is explained each one.

Table 12 – Criteria for judging the quality of research
(adapted from (Yin, 2009)

Test	**Description**	**Case study tactic**	**Phase of research**
Construct validity	Evidence collection that sustain the theoretical prepositions.	• use multiple sources of evidence • establish chain of evidence • have key informants review draft case study report	• data collection • data collection • composition
Internal validity	Results and conclusions of the case study are valid for the study population, trust of the research avoiding bias.	• do pattern matching • do explanation building • address rival explanations • use logic models	• data analysis • data analysis • data analysis • data analysis
External validity	Possibility of results and conclusions of the case study being generalized for other studies.	• use theory in single-case studies • use replication logic in multiple-case studies	• research design • research design
Reliability	The results will be the same when study is repeated, following the same procedures.	• use case study protocol • develop case study database	• data collection • data collection

Each test was considered during research and tactics were used during the respective phase. The previous sections explained how they were applied in the conducted research.

3.2.5 Research ethics

The personal contact with organization and people is a very important phase of the research, mainly in a case study, which often involves human interactions. So, assuring the ethical conduct is essential to design, plan, collect data from organization and individual, analyse, and report (Saunders et al., 2016). Individuals from organization are a very important source of information, so they have to be protected and respected. The researcher must take it into account. For that, some ethical principles were assured during the research such as the integrity of the researcher, respect for others, avoidance of harm, privacy by ensuring confidentially of data and others (Saunders et al., 2016).

In the beginning of the research, participants were contacted by email (Appendix 5) to participate on the research, explaining the context, confidentially, and anonymity rights. Once the researcher is an internal employee, it was also clarified that the conducted research was not related with internal daily tasks, meaning the conducted research is a separated work. Additionally, an informed consent (Appendix 6) was sent to the participants sign it previously, by accepting participation, interview recording, and confidentially right according to "Regulation (EU) 2016/679 of the European Parliament and of the

Council of 27 April 2016 " (European Parliament, 2016) also the ethics code "Código de Conduta Ética da Universidade do Minho, da Comissão de Ética da Universidade do Minho, de julho de 2012" (University of Minho Code of Ethical Conduct, from the University of Minho Ethics Committee, July 2012) (University of Minho Ethics Committee, 2012).

Just before the interview, it was once again explained personally the importance of their participation on the research, the participants rights, by giving the possibility of withdrawing in any time, saying something without recording, or even not answering some question. Therefore, it was also explained how the data would be analysed and treated. That kind of information was very important in order to assure the participants' trust and avoid any kind of harm due to their involvement.

Furthermore, every data and internal documents provided by the organization were carefully analysed by respecting company confidentially rules. Due to the nature of the topic, which also involved organizational and leadership elements, the access of information and personal contact was always managed carefully, by respecting participants' point of view. Besides the interviews, which involve a deep personal contact, other data collection was used. However, personal explosion and intrusive methods were avoided.

4 Case study presentation

In this section is presented the company where the case study was developed describing company in general, main business area, organizational structure, and the Lean production system implemented.

4.1 Identification and localization

The company Bosch Car Multimedia Portugal S.A. where the case study was developed is a multinational located in Braga, Portugal. Company is one the major exporter and employer in Portugal. Company started as Blaupunkt Auto-Radio Portugal in 1990. In 2009, it was sold to Bosch and included in the reorganization of Bosch Car Multimedia division.

In 2018, its sales were 1,1 billion euros, 1127 million units produced and 3508 employees. The turnover represented 1134 million euros, which was the higher value since 2010 (Figure 25) (BrgP/DBE, 2019).

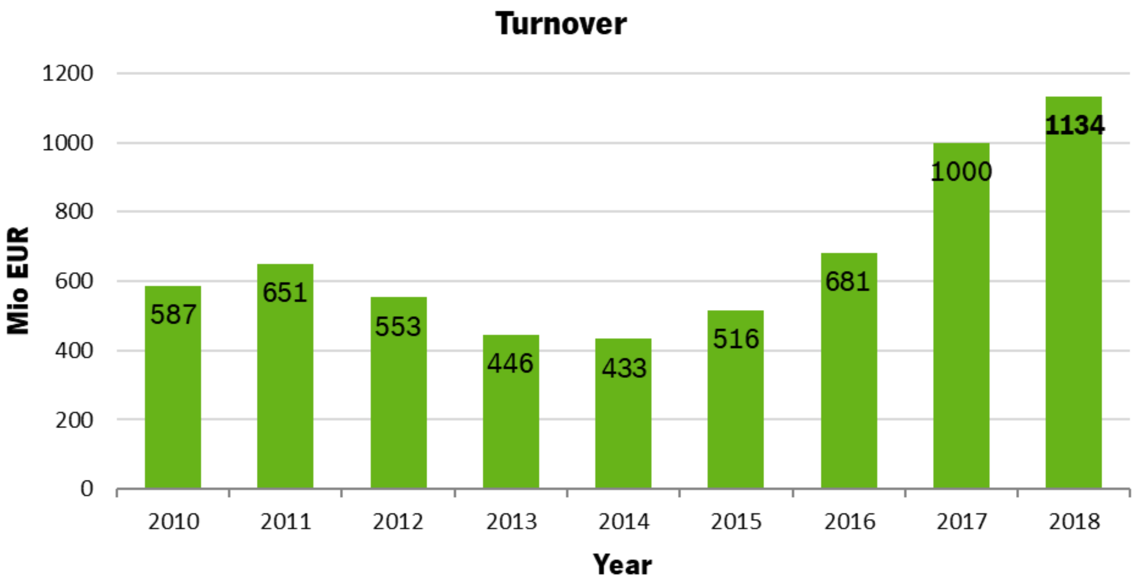


Figure 25 – Turnover Chart
(BrgP/DBE, 2019)

Production area is divided in two main parts: Automatic Insertion of components on Printed Circuit Board (PCB) and Final Assembly. Automatic Insertion represents 11.000m^2 of area with 32 lines installed. This area works in continuous labour model (four shifts) with 696 employees. Furthermore, this area is benchmark in Bosch Group in utilization of Surface-Mount Technology (SMT), Total Productive Maintenance (TPM), and Single Minute Exchange of Die (SMED).

Final Assembly area represents 23.000m^2 of area, with 104 production lines installed. Those lines are more customized to the final products and customers compared with automatic insertion. There are around 1200 active products to manage in this area. Final Assembly lines work on different shift model depending on the line also the customer demand.

The company has several certifications for Quality, Health, Safety, Energy and Environment such as ISO 9001, ISO/TS 16949, ISO 14001, ISO 50001, EMAS III and OHSAS 18001, which allows to reach some awards from quality, customer, and innovation areas.

In the last years, the company has been also focused on development and innovation area, which is the reason to open a new building only for those activities nearby the company. Furthermore, the company has been collaborated with University of Minho and University of Porto in several research areas, and many projects have been developed. This represents an opportunity to approach universities and industrial environments.

4.2 Products

The company is a multinational supplier company of automotive industry (first tier) whose business area is related to car multimedia solutions for automotive industry. Its customers are more than fifty car brands. Currently, product portfolio represented in Figure 26 covers eight main product types:

1) Navigation system (Smart integration solutions for entertainment, Navigation, Telematics, Driver assistance);
2) Next infotainment generation (System integration, Connectivity, TV/Tuner radio, PC HW approach (Intel µP), Integrated CE solutions;
3) Instrumentation Systems (Combiner Head-Up-Displays);
4) Combiner Head-Up-Displays (Innovative free programmable instrument cluster);
5) Steering Angle Sensor (Innovative systems and functions for vehicle safety, dynamics and driver) assistance;
6) House-hold Electronics (Manufacture of complex electronic controllers for a wide variety of different applications);
7) Control Units Systems (Innovative and pioneering solutions for room climate and water boilers);
8) Instrumentation clusters for two-wheelers (Integrated connectivity clusters, Innovative in-vehicle audio/video and Vehicle Intelligence - 2017 CES Innovation award).

This product types belong to Business unit existent in the company: Chassis System Control (CC), Driver Information (DI), Instrumentation Systems (IS), Manufacturing Systems (MS) and Powertrain Solutions (PS).

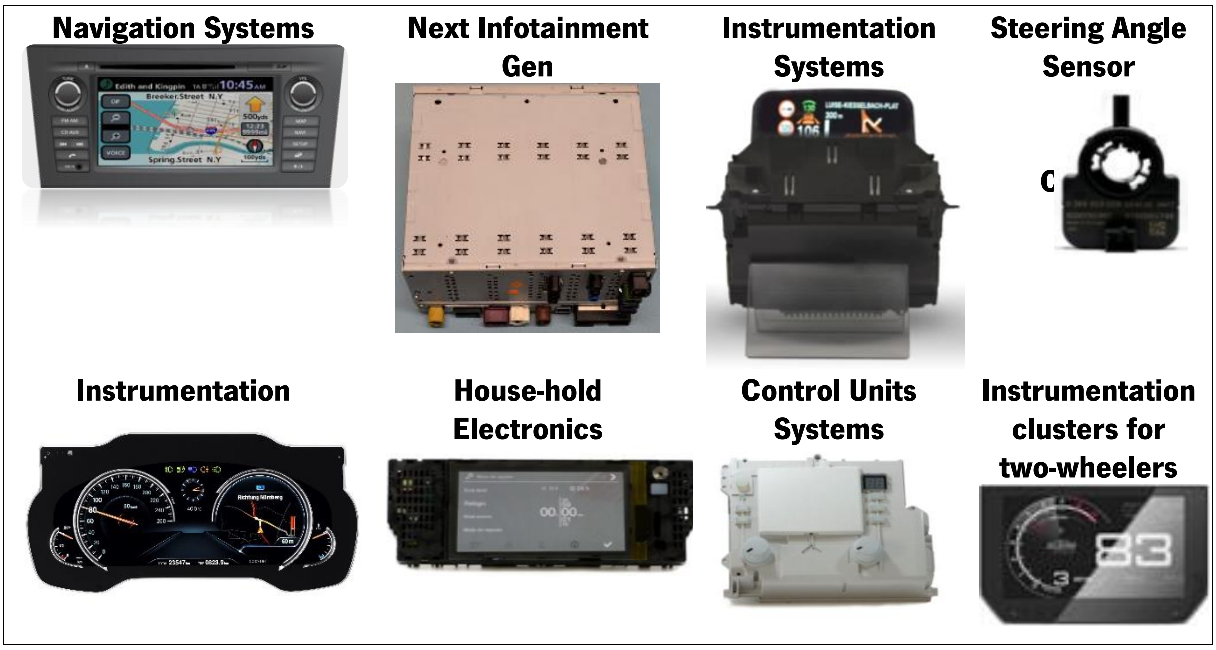


Figure 26 – Bosch Braga Product Portfolio
(BrgP/DBE, 2019)

The presented products have a life cycle that varies depending on the market or nature of the product. However, lifecycle of most of the products are, at least, of five years, and some of them might achieve 10 years. In each family, there are different variants, software of the product changes during the lifecycle, and customer demand is variable over the years. However, it is common that a product family is being produced during some years in the same production line.

4.3 Organizational structure

The company organization is divided in two main areas: the commercial and technical, and both of them has its own Plant Manager (Figure 27) (BRGP/HRL, 2019). The company is organized in functional departments, with multiple hierarchical levels (e.g., four levels depending on the department). First level represents administration, second level represents head of department, third level represents section head, and forth level represents team leaders. Some central departments only report within their specific areas because their manager is not located in the plant. Meaning that those departments follow central guidelines, which are deployed by their managers (outside the plant), however local issues such as holiday period should be reported to the area manager. Each plant manager reports to different entities from the executive management board, located in Germany, according to the area. Hierarchical levels of organizational structure are presented in detail in Appendix 7.

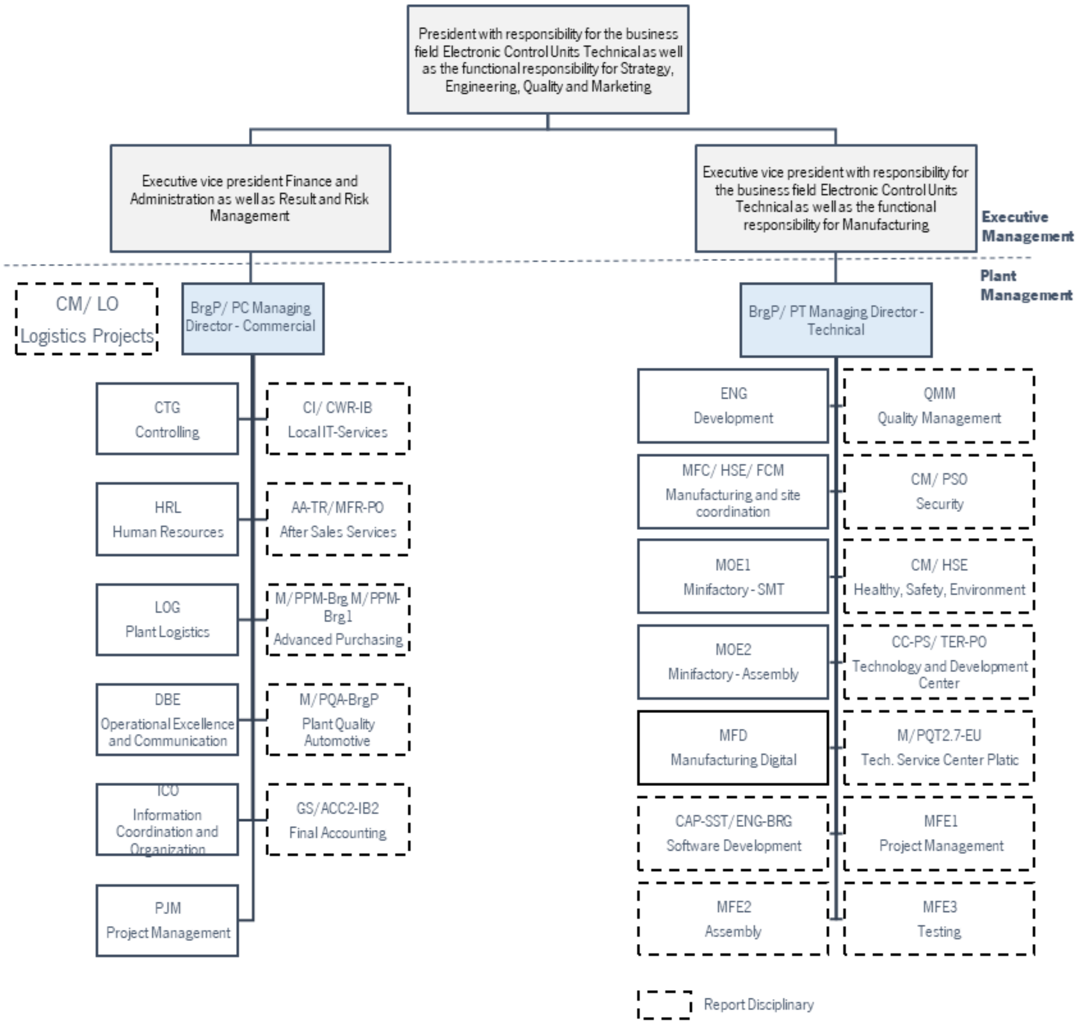


Figure 27 – Organizational Chart

4.4 Bosch Production System (BPS)

Bosch Production System is a sub-system of the Bosch Business System. This term "Production System" refers to a systematic approach that ensure an optimized fulfilment process. Its target is to deliver products on time, on cost, and on quality customer's desires. With BPS, it is possible to design Lean value streams in accordance with SQCD (Safety, Quality, Costs, Delivery performance) objectives. For that, principles, processes, methods, and rules are defined, and they serve as a guide for the implementation. Furthermore, employees and managers' tasks are identified (Bosch GmbH, 2015).

4.4.1 BPS Vision

BPS vision represented in Figure 28 is linked with current Bosch mission statement "We are Bosch" that provides guidance and influences to create sustainable waste-free and agile value streams. For BPS, this statement also promotes cross-functional value stream teams in order to achieve an ideal global value stream and work together to develop and spread-out BPS principles.

Furthermore, the Bosch motivation is to inspire people with its products and to provide sustainable improvements to their quality of life. That is the reason of motivation statement "Invented for life". Additionally, it is important to think on sustainability and to use resources sparingly (Bosch GmbH, 2015).

Figure 28 – BPS Vision and its approach
(Bosch GmbH, 2015)

BPS vision defines where company want to go, which means the target. As a reference point, BPS names "True North" that refers to an ideal state of a waste-free order fulfilment process (Figure 29). This point of reference is achieved with a combination of four elements: 100% added value, 100% delivery performance, zero defects, and one-piece flow (Bosch GmbH, 2015).

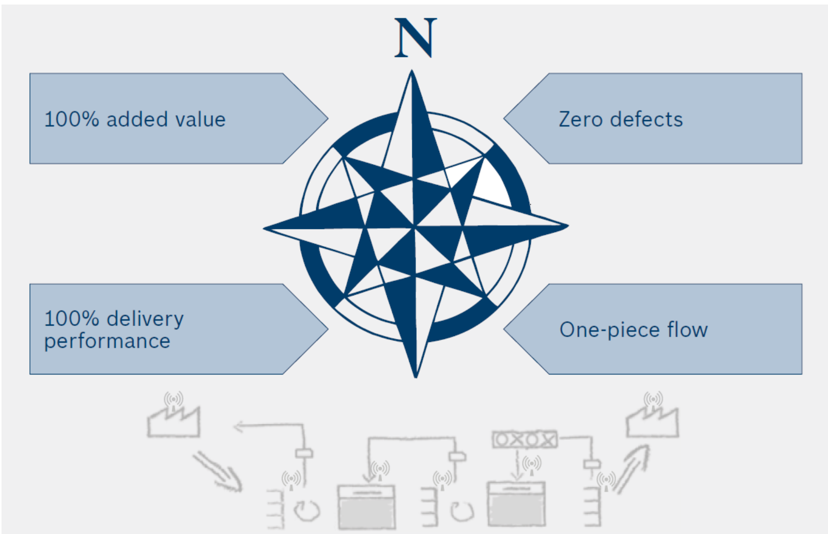


Figure 29 – BPS True North
(Bosch GmbH, 2015)

100% added value means that all activities should be added value and optimized in order to increase value in product. 100% delivery performance means that company aims to deliver the right product, in the right quantity and at the right time to the customer. Zero defects mean that defects have to be avoided working on prevention, and detection systems, as much as possible in an earlier phase. Additionally, defects should be an opportunity to learn and understand. One-piece-flow means that parts should flow straight from one value-adding process to the next value-adding process, until customer avoiding batch processes or waiting times that create intermediate stock (Bosch GmbH, 2015).

4.4.2 BPS Principles

BPS principles are eight and they frame a methodology across different functions that design a sustainably waste-free and agile order fulfilment process. These principles are represented in Figure 30.

Pull principle	• We produce and supply only what the customer wants.
Fault prevention	• We avoid errors by means of preventive measures in order to deliver flawless products to the customer.
Process orientation	• We develop and optimize our processes holistically.
Flexibility	• We adapt our products and services quickly and effectively to current customer requirements.
Standardization	• We standardize our processes and implement best-in-class solutions.
Transparency	• Our procedures are self-explanatory and straightforward; deviations from the target situation are immediately apparent.
Continuous improvement	• We are developing continually and in a targeted way.
Personal responsibility	• We know our tasks, competencies and responsibilities and carry them out actively and independently.

Figure 30 – BPS Principles
(adapted from (Bosch GmbH, 2015)*)*

4.4.3 BPS Elements

BPS elements are tools and methods to implement BPS principles and they are crucial to have successful results. Furthermore, it is essential to understand the relation they have among them in order to implement systematically. The BPS elements are fourteen (Bosch GmbH, 2015):

1) Value Stream Planning;
2) Standardized Work;
3) Levelling;
4) Consumption Control;
5) Critical Chain Project Management;
6) 5S – Order and cleanliness;

7) Poka Yoke;
8) Lean Line Design;
9) Flow-oriented Layout;
10) Quick Changeover;
11) Ship-to-Line;
12) Cyclical Material Supply;
13) Total Productive Maintenance;
14) Shop-floor Management Cycle.

For the BPS implementation, Robert Bosch Gmb (2004) proposed three phases represented in Figure 31: preparation, stabilization and reduction.

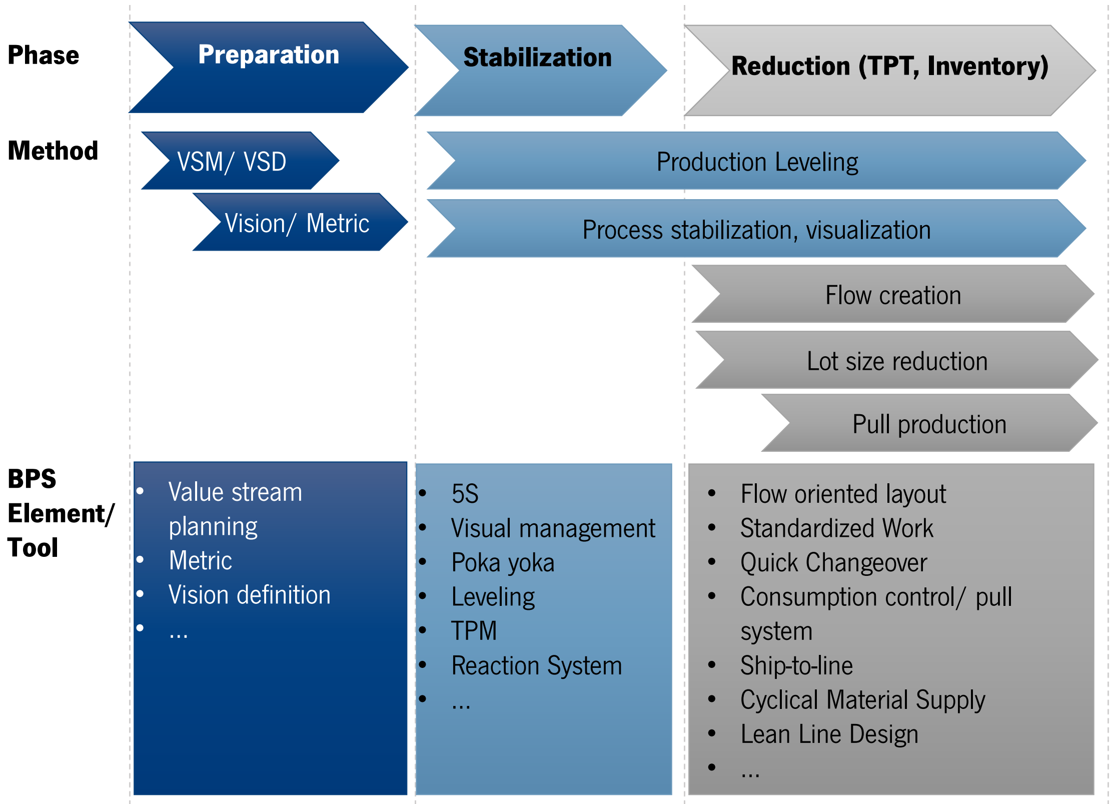


Figure 31 – Proposal of BPS implementation
(adapted from (Robert Bosch Gmb, 2004)

The first phase is the preparation, which involves planning production lines, production areas or plants that should be in accordance with BPS principles. In this phase, existent value stream should be analysed and waste elimination planned. For that, some metrics should be defined in order to control the implementation by following a PDCA cycle. Furtheremore, holistic value streams and long-term planning should be part of the vision. Second phase is the stabilization whose goal is to create pre-conditions for switching to continual flow and pull production. For that, there is the need to apply elements that brings transparency to the system by visualizating waste activities. Additionally, an important aspect is the stabilization of production planning by applying levelling, which creates constant and short replenishment lead times. During the reduction phase, the goal is the reduction of throughput times by generating flow and pull.

Depending of phase purpose, each one includes the application of specific elements as Figure 31 shows. Elements such as Ship-to-line, Cyclical Material Supply and Lean Line Design were introduced later since its own system is also continuously improving. The element Critical Chain Project Management is a method for planning and controlling projects to estimate the required time for the individual work packages. Method is applicable in Engineer-to-order (ETO) environment.

4.4.4 BPS Assessment

In order to assess the BPS principles' maturity of the plant, there is a standard procedure to assess if those principles are being followed. The procedure is followed during the BPS assessment days and it can be used to compare and rank different plants. However, the most important is the opportunity of being with qualified assessors that are available to coach and share experience.

BPS Assessment occurs once a year for each value stream by an auditor outside of the plant. The core team that should participate in all days of the assessment is the Value Stream Leader, one manager from production, logistics, and procurement. The BPS plant coordinator or the value stream coordinator also participates as observer and support on the activities. In addition, the commercial and technical plant managers participate and act in the System CIP questions, and in the final presentation. For specific questions, experts from that area should also participate explaining the topic and giving inputs.

The assessment evaluates the entire value stream, from the customer to the supplier. The assessment structure is divided in three main parts: 1) deliver that is related to the customer orders, 2) make that is related to the production areas, and 3) source related to the suppliers. Furthermore, a higher-level section evaluates the target derivation and methods used in the overall value stream. It considers 20 questions, and it covers the main BPS elements. The developed concept that is developed and the execution level is evaluated in each question. The maturity result is given by BPS element. Additionally, a global score is provided based on each element. The maturity levels are four and they are characterized as follows:

- Level **1: "BPS Essentials" (Implementation)** – Meaning the Basic elements are introduced in the plant;
- Level **2: "Improvable organization"** – Specific improvement activities are identified on the basis of existing standards;
- Level **3: "Self learning organization"** – Closed Plan Do Check Act (PDCA) cycles are completed at system level;

- Level **4: "Lean Company" (True North)** – Very mature company related to BPS principles.

Furthermore, at the end of the assessment, it is provided a SWOT sheet where the assessor identifies the main strengths, weaknesses, opportunities, and threats (SWOT). Those are a summary of main points that should be reported and recommendations for the plant, in order to improve and achieve a better result in the future. The results are presented in a chart mode, which evaluates each element from level one to level four (example Figure 37 in section 5.1.1). The evaluation is performed for the concept also for the execution. The purpose is to discuss and evaluate the developed theoretical concept and the created standards, and the real concept to identify the gap between both.

4.5 BPS System Approach

The continuous improvement process is a systematic called BPS System Approach defined and implemented in the Bosch. "*The BPS System Approach is a systematic procedure that aims to improve existing value streams in a comprehensive, targeted and sustainable way. It serves as a guideline and provides a framework for ensuring a structured approach to the continuous improvement process"* (Robert Bosch GmbH, 2018a). BPS System Approach includes three phases: System CIP – Continuous Improvement Process, Point CIP, and Daily Management. The interaction of both and improvement process are represented in Figure 32. Figure 32 also shows the inputs for stating a continuous improvement project, which is described in detail in section 4.5.1.

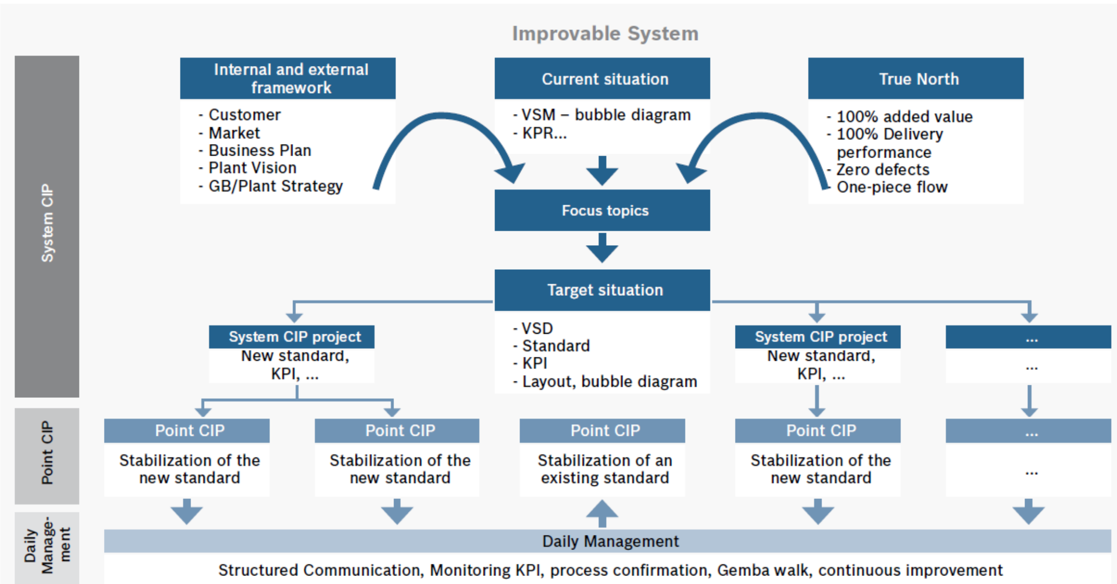


Figure 32 – Continuous improvement process representation
(Bosch GmbH, 2015)

4.5.1 System CIP

System CIP derives the focus topics that should be worked in the value stream, defines the target future condition of those topics, and identify the required projects to achieve the target. The following elements describe the System CIP elements that also are steps to perform this phase:

- **Internal and External Requirements** in terms of quality, cost, and delivery of the value stream are the input data. "*The internal requirements include the strategy of the division and plant, the plant's vision, the business plan KPI such as the planned production cost (PPC), total coverage time (TCT), productivity, budget allocations and defect costs, as well as results from the BPS maturity assessment. External requirements are those of the market and of customers (quantity, variance, quality, delivery service etc.)"* (Robert Bosch GmbH, 2018a).
- **Analysis of the current situation** by using the Value Stream Mapping (VSM) tool.
- **True North** that is a reference point that characterize the ideal condition. Bosch True North has four elements: 100 % value added, 100 % delivery performance, Zero failures, and one-piece flow.
- **Identification of focus topics** that results from the comparison between the current situation and the value stream requirements. That comparison reveals potential areas of improvement and the true north is the reference. For each focus point, Value Stream Key Performance Indicator Results (VS KPR) are defined.
- **Definition of target conditions** is defined for each focus point. A target condition consists of a clear definition of the new standard and responsibilities. It is also defined the monitoring KPI and its stability criteria. Meaning the acceptable fluctuations within the defined limits.
- **Definition of the Target Value Stream** considering the defined targets.
- **Execution of System CIP projects**. In this step, it is time to develop, implement and validate standards. The target condition is the starting point to establish a Monitoring KPI, the stability criterion, and defined standard. Furthermore, the monitoring KPI influences another factor called improvement KPI. Example: Monitoring KPI is the Overall Equipment Effectiveness (OEE) losses due to change over time. Improvement KPI is change over sequence related to manual work. System CIP project ends when it has demonstrated that new standard can be implemented. To achieve the stabilization level, project pass through the Point CIP Level.
- **Transfer ("handshake") to Point CIP**. This step happens when a new standard is created and introduced.

4.5.2 Point CIP

Point CIP is the second step of the BPS system approach. It is a method to stabilize a standard, focused on the improvement KPI and stability criteria (Figure 33). When a deviation happens, it should have a kick reaction system to analyse and define actions. In Point CIP, it is also confirmed if the work is according with the standard. Team Leader from the implementation area should led the Point CIP meeting. This meeting should happen in a daily basis. Project information should be visible for all team members in a board.

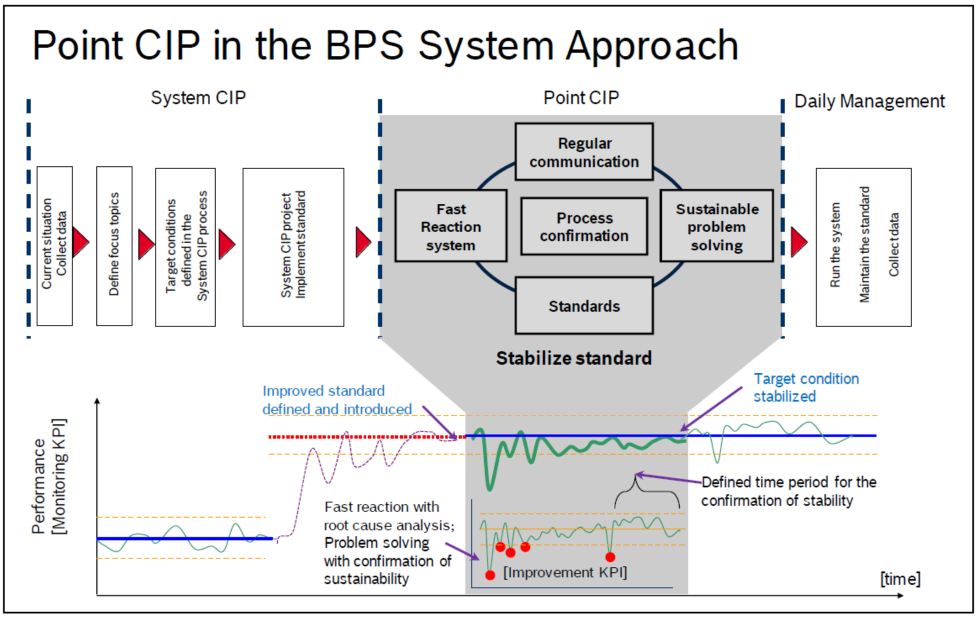


Figure 33 – Point CIP as part of the BPS System Approach
(Robert Bosch GmbH, 2018a)

Similar to System CIP, Point CIP follows some elements:

- **Standard (with KPI and stability criteria)**. A standard includes the KPI and stability criteria, and they are the base for Point CIP. Improvement KPI must be tracked, and it is recommended to track the monitoring KPI that will affect the improvement.
- **Process confirmation**. This is a very important step to find deviations from the standard, also opportunities for improvement to achieve the target condition. In the process confirmation, it should be involved leaders and employees with different roles. Employees have to report the deviations and to interfere directly. Meanwhile leaders should monitor the working, assuring the one is according with standard, identifying deviations, and search for improvements jointly with employees.
- **Fast Reaction System**. The fast reaction is the procedure that assures the deviation from the standard are documented. Furthermore, the action to re-establish the standard should be also documented. The process has to return to the planned condition.

- **Regular communication**. This element assures the exchange of information between parts involved. For that, a daily meeting is required. The Point CIP meeting has a standard that follows mainly tree phases: data collection and preparation the rough root causes analysis by the team leader, deviations' presentation, the action plan and actions follow up during the meeting. After the meeting, it is time to work on improvements. Furthermore, there is a standard agenda for the meeting in order to follow the right sequence and to approach the relevant topics.
- **Sustainable Problem Solving**. This phase has the purpose to create transparency of deviations, became them visible, and action limits should be clear. For the problem-solving method, different tools should be used according to different scenarios:

Table 13 – Different scenarios and tools to apply in problem solving

Scenario	**Tool**
problem known measure clear	Tracking with OPL by responsible person and date
problem known measure unclear	PDCA card
problem unknown measure unclear	problem solving sheet

Point CIP finishes when the stability criterion is achieved.

4.5.3 Daily Management

Daily Management is the last level. In this level, the scope is keeping the standards running and preserve the current performance. For that, team leader's routine includes data collection, deviations identification, and reaction. So, leadership functions have to assure the fulfilment of the method. In this level, improvement KPI is not anymore monitored, only the monitoring KPI.

Daily Management elements are the following ones:

- **One Pager "Daily Management"** describes the content and the approach for problem solving: the "why" refers to the needs, "what" KPI should be monitored, "how" to do it in order to create transparency, "where" that should be in the shop floor, and "who" is responsible for this task.
- **One Pager "Daily leadership routine''** describes the standard daily routine for team leader in relation to the problem solving.
- **Data collection and Monitoring KPI (Data Basis)** related with Monitoring KPI that must be collected in production areas: Work accidents, external claims, internal quality issues,

productivity, overall equipment effectiveness (OEE), delivery or levelling performance (if applicable).

- **Fast reaction and definition of reaction limits (Routine level 1)**. To easily visualize the deviations, clear reactions limits should be defined. When those limits are achieved, they trigger for a fast reaction or improvement actions (e.g., Andon system).
- **Daily regular communication and problem solving (Routine level 2).** In order to not waste time in the meeting, the Daily Management Meeting has to be prepared and it should follow a standard. This meeting should focus on the actual status of security, quality, delivery, productivity, and line performance KPI. The current deviations coming from process confirmation and the action plan with responsible in order to restore the standard should also be part. For that, after the Daily Management Meeting, during a time window defined, problem solving team should be on site to work on the specific tasks coming from the meeting.

4.6 Training in Lean concepts

Training process is centrally defined and then deployed in different Bosch divisions, and then at the existent locations in the world. Company offers several training sessions in different topics related to Lean fundamentals. Every available training of several areas is visible in a training portal. Furthermore, being a BPS trainer requires certification and authorization by the central department. Central departments, commonly located in Germany, are responsible to define standards, guidelines, and deploy in the plant locations worldwide.

Certification process is a standard procedure and centrally defined. Divisions and locations are responsible to determine and plan requirements for trainer certification. Central department defines training guidelines, procedures, and update. They are also responsible to coach and train new trainers, and trainer the trainers to ensure the standards procedures. Each location should follow the standards.

Table 14 shows the current offer in Bosch Car Multimedia Portugal S.A. and its description. It means that there are qualified trainers in Portugal able to conduct those training sessions. For the ones that are not available in Portugal, it is also possible to request to central departments or other Bosch locations.

Each training has a target group related with to employee role. Generic roles are also centrally defined, so trainings are automatically assigned when employee’s curricula is defined. Then, manager has to ensure training enrolment for each employee.

Table 14 – Training Description

Training Name	**Description/ Training content**
BPS Basic Training (incl. BPS100)	• What is BPS? • General conditions • Balancing • Standardized work • Material supplier • Value stream mapping • Consumption control • Value stream design • Clarity
Leading in a BPS Plant	• Introduction to the BPS System Approach and the Improvable System • Identification of fields of action • Working with KPI trees: Derivation and description of target conditions • Clarity of material and information flow and decoupling • Working with standards and process confirmation. • Significance of pull system and levelling in the value stream • Effect of fluctuation (customer and process) and types of decoupling • Roles and responsibilities in the improvement process • A3 as a leadership and coaching tool • Preparation for module 2; the training content will be augmented by practical exercises
Working according to Standards	• Understand the BPS system approach and the importance of clarity • Introduction in value stream mapping and design • Observing on shopfloor standards and deviations and react target-orientated • Process analysis, process confirmation • Calculation of the customer tact (TT) and the target cycle time (TCT) • Verification of OEE-losses • Derivation and description of target conditions and how to visualize target conditions on the shopfloor • Dealing with critical situations with operators and team leaders (role play)
Pull & Levelling	• Simulation of a „classical" Push-Production • Introduction of Levelling and a Pull-System within a simulation game • Tracking of influence on stock, delivery service and cost • Learning of kanban Formula and calculation of kanban system with the help of a ball path • Roles and responsibilities in a pull & levelling system
Lean Logistic Basics	• Know about functionality of pull systems and levelling • Elements of pull systems: supermarket, milkrun, kanban, organizational aspects • Link to CIP an transparency • Calculation of a levelled pull system with the BOSCH kanban formula • Simulation and case studies to deepen understanding of subject
MTM	• MTM-Basic System (MTM-1), rules, exercises and analysing procedure • Basics for methodical-technical workplace design • Training for operators • Development and comparison of work methods
Lean Line Design	• Development of a Lean line (e.g. capacity calculation, customer tact, target cycle time) • Waste and its appearance in production lines • Analysis of an existing production line • Design of a waste-free working sequence • Layout design with focus on worker flow • Optimized workplace design (e.g. ergonomics, related guidelines, best practice) • Standards in production lines (e.g. impact, introduction, review, deviation management) • Operating of a production line (e.g. adjustment of capacity, order planning) • Good-Practice examples

In relation to Benchmark activities, the company has never had an official benchmark process. In 2010 has arisen an initiative to create a Benchmarking officer whose responsibility was from controlling department. However, the activities were mainly oriented to the financial and controlling areas. In 2012, result of the crisis, this function was over. Currently, there is a recognition that is necessary to have a systematic approach for benchmark activities. In the last years, it has been done several activities but without having a standard procedure.

4.7 Lean Wave methodology

Lean wave is a central initiative that aims performance optimization and creation of Lean Leadership culture in Bosch to create empowerment and sustainable business.

The vision of Lean wave considers the following elements:

- Increase of competitiveness;
- Effectiveness and efficiency in focus;
- Reduction of waste;
- Cost down;
- Structure adjusted;
- Capacity re-allocation to where it is most beneficial for profitable growth.

The mission is fostering a sustainable cultural change. For that, it is important to understand the current situation and then promote the continuous improvement, and Lean mindset for all indirect associates. So, Lean wave is a methodology oriented to apply Lean in indirect areas. The strategic focus is the implementation of Lean mind-set with Lean Leadership System elements. With such implementation, it is possible to achieve maturity level 4 and gain more than 15% productivity (Robert Bosch GmbH, 2021). The principles related to the methodology implementation are described:

- Living change and transformation with Passion;
- Collaboration with our customers & partners;
- Focus on results;
- Sustainability;
- Transparency;
- Self-Responsibility;
- Frequent feedback for personal growth at all levels.

Lean Leadership System that enables Lean mind-set is a focus of the methodology. The system considers 10 elements (Figure 34) by supporting teams in the continuous development of the work and team collaboration culture.

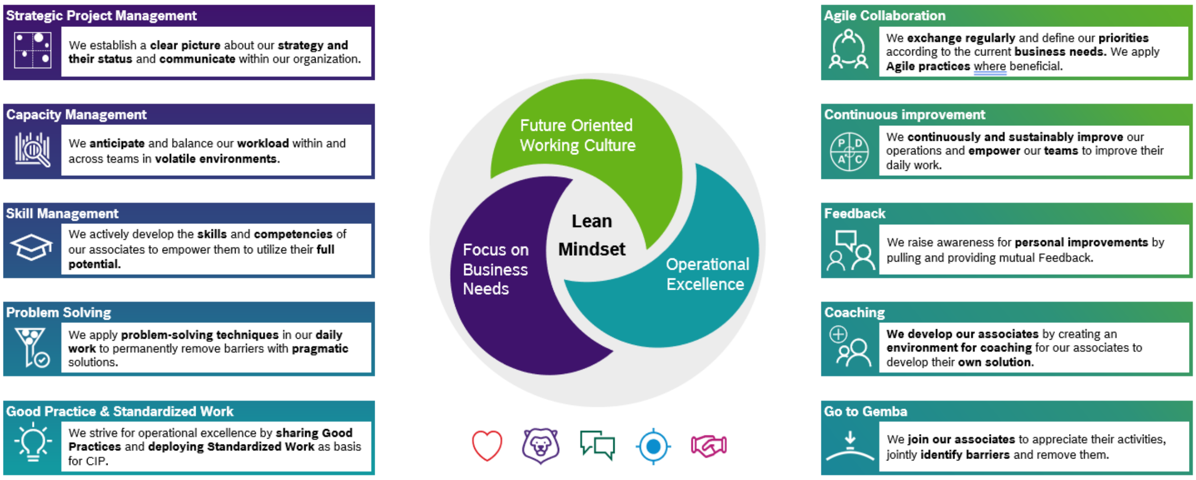


Figure 34 – Lean Leadership System elements according Robert Bosch GmbH (2021)

Lean Wave covers five dimensions of investigation starting from voice of customer and then the four flowing ones: processes, team performance, mind-set and behaviour, and organization and skills as represented in Figure 35. The transformational process included in those dimensions aims to increase productivity and enable associates for continuous improvement. Furthermore, it improves simultaneously customer satisfaction and associate's involvement (Robert Bosch GmbH, 2019).

Figure 35 – Lean dimensions according Robert Bosch GmbH (2019)

Methodology follows five phases which take roughly one year:

1) Preparation: project introduction and commitment to change the story;
2) Diagnosis: collect observations, use analytic tools, verify hypotheses, and visualize all findings;
3) Design: prioritize observations, estimate measures with potential, application of Lean Leadership System elements, and definition of Productivity target. Those are important elements to create a tactical implementation plan;

4) Implementation: Implement measures and quick wins previously defined. At the end of the wave, the maturity assessment is performed;
5) Sustainability: continuous improvement process (Robert Bosch GmbH, 2021).

Every tool used in each phase are standard and deployed by the central team responsible to define the process, lead the communication, and manage the roll-out. The implementation methodology in the plants is supported by an internal team previously trained. There are two main groups in the plant (Figure 36): the Lean team and the line organization team who is involved in the project. Lean team includes a Lean project leader responsible by the project; navigator who is responsible for process planning and execution, coaches group leader and employees, and runs the process; and the consultants who are responsible to define the process in the whole organization. Line organization team includes: the unit head, department head, and group leader, they are the sponsors of the change, define targets, and motivate team; the employees who participate with ideas and suggestions for improvements; Lean Champions who is the interface between Lean team and line organization team, she/ he removes barriers and assures Lean system after Implementation (Robert Bosch GmbH, 2021).

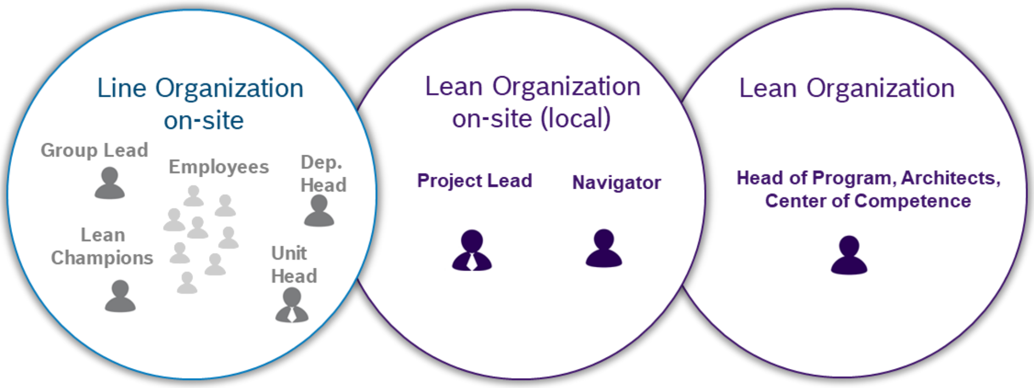


Figure 36 – Lean wave roles (Robert Bosch GmbH, 2021)

In Bosch Car Multimedia, there was a pilot project in 2019 in the quality department and then it was created a Lean roll-out considering the remaining departments. The roll-out plan considered eleven waves that includes one or two departments in each wave. At the end of 2020 started the first one and the last one is planned to 2024.

5 Description and critical analysis of the current situation

In this chapter it is described the current company's situation related to Lean production, and particularly, pull implementation based on different information's sources connected to Lean approach. This chapter presents the completed analysis of the case study as well as the instruments used. Section 5.1 presents mainly secondary data, which allowed to have a first overview about company performance status. In section 5.2, it is analysed, based on primary data, the reasons for not implementing pull. It is also described in general, the production control system used in the company, the responsible, and the departments involved in the process. Then, it is discussed the global key performance indicators related to and influenced by the production control system. Furthermore, it is presented the interviews' results. Finally, a critical analysis is presented, which shows problems in several areas related to the production control system and its implementation.

5.1 Strategic company performance status

In this section, it is presented some strategic key performance indicators that are strictly related with the production control system operation and Lean activities status. The chosen ones were: BPS assessment results, the BPS penetration rate concerning training, suggestions boxes, and operational KPI. Furthermore, the results of associative survey were a very important instrument to assess employee's opinion regarding several elements of the organization. The topics presented in this section represent relevant insights for the collection and analysis of primary data presented in section 5.2.

5.1.1 BPS assessment results

In section 4.4.4. it was described the BPS assessment. This is strictly related with Lean and PCS implementation because the assessment evaluates the application of BPS principles and their results on the value stream improvements. One of these principles is pull principle as the PCS of the value stream.

BPS assessment dated from 2018. It evaluated the existents three value streams in the plant at that time: Connected Information Solutions 1 (CI1), Connected Information Solutions 2 (CI2), and Chassis System Control (CC). As it was described in section 4.4.4, the assessment is done once a year. For CC Business Unit there is a specific assessment from CC auditors in order to have the same alignment between CC plants. CI1 and CI2 Business Units are audited for Car Multimedia division (CM) auditors.

Figure 37 shows the Plant maturity level's result according to BPS principles for CI1 and CI2 value streams. The result was 1,65 average on execution, and 1,85 on concept. The lowest level on execution and concept was related with failure prevention system concerning quality, levelling on the pacemaker process directly related with production control system, standardized shipping process, daily management on make area where KPIs are followed, and suppliers' interface. Pull, as a production control system did not exist, reason for not having evaluation on CI1 and CI2, because there was no evidence of concept defined and implemented. Additionally, the ones related with PCS such as levelling and customer interface had lower level of implementation that reveals a weakness on it.

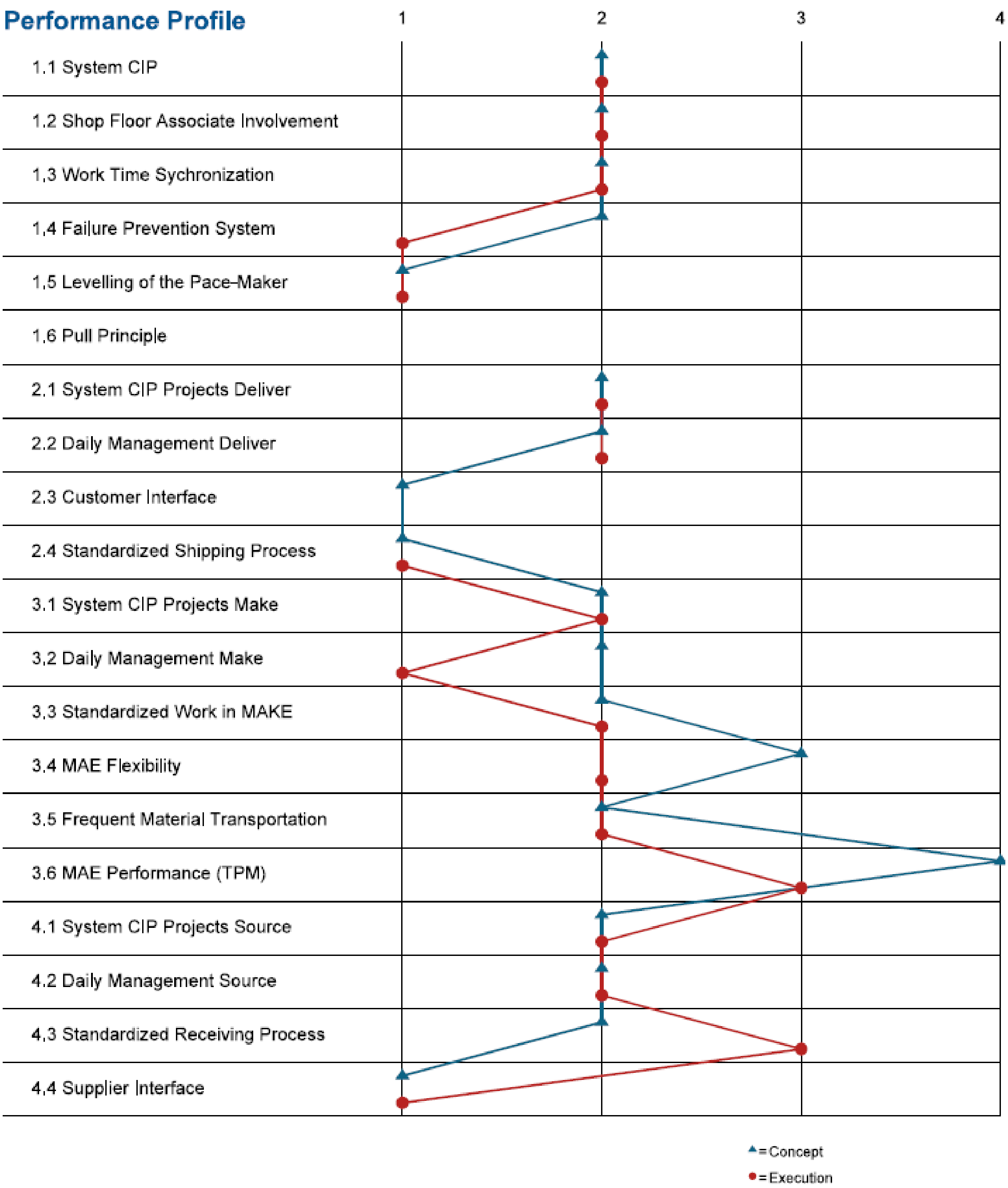


Figure 37 – Results of BPS Assessment 2018 for CI1 and CI2 value streams

Customer interface element was not also evaluated because it was not developed. This topic is particularly important for this thesis because is related with production control system, which demonstrates that pull strategy was not implemented. There are still room for improvement related with customer interface development. Value is the first Lean Thinking principle as explained in section 2.1.3, which consists in knowing customer's requirements, and what value represents for him/her. So, having a good relationship with customer is very important also for production control system selection as observed in section 2.4.4.

Levelling is one important element of pull, as it was demonstrated in section 2.4.2, by being one of the premises to avoid bullwhip effect, and to create stability in the processes.

The element which had better evaluation on execution concept is related TPM. Company is considered benchmark on this process, and in standardized receiving process.

Figure 38 shows the plant maturity level's result according BPS principles for CC value stream. The result was 1,5 average on execution and on concept. In this value stream, there were much more principles evaluated as basic ones compared with CI1 and CI2 value streams. In this value stream, system CIP approach was evaluated as basic on concept and execution. Additionally, related with pull, it was not proved the execution of levelling on pacemaker process. However, pull principle was evaluated as a basic (level one) on execution, but no concept was defined. Meaning that, there were some proves of pull implementation, however, there was no consistent concept developed to maintain the implementation.

Curiously, in this value stream, there were some principles like pull principle, daily management in every area, frequent material transportation, and TPM whose evaluation was better on execution than on concept. Like other value streams, highest value was related to TPM. However, the level was lower than CI1 and CI2.

Regarding levelling, which is an important element of pull, it had a basic concept developed but it was not implemented, the reason for having no evaluation on execution.

The analysis of BPS assessments showed that the company recognized that there were some important elements for pull implementation such as levelling and customer interface that still had problems, mainly lack of a concept definition. The implementation requires a concept and a procedure. Furthermore, this analysis demonstrated that some elements were more developed than others. The evaluation was not balanced between elements.

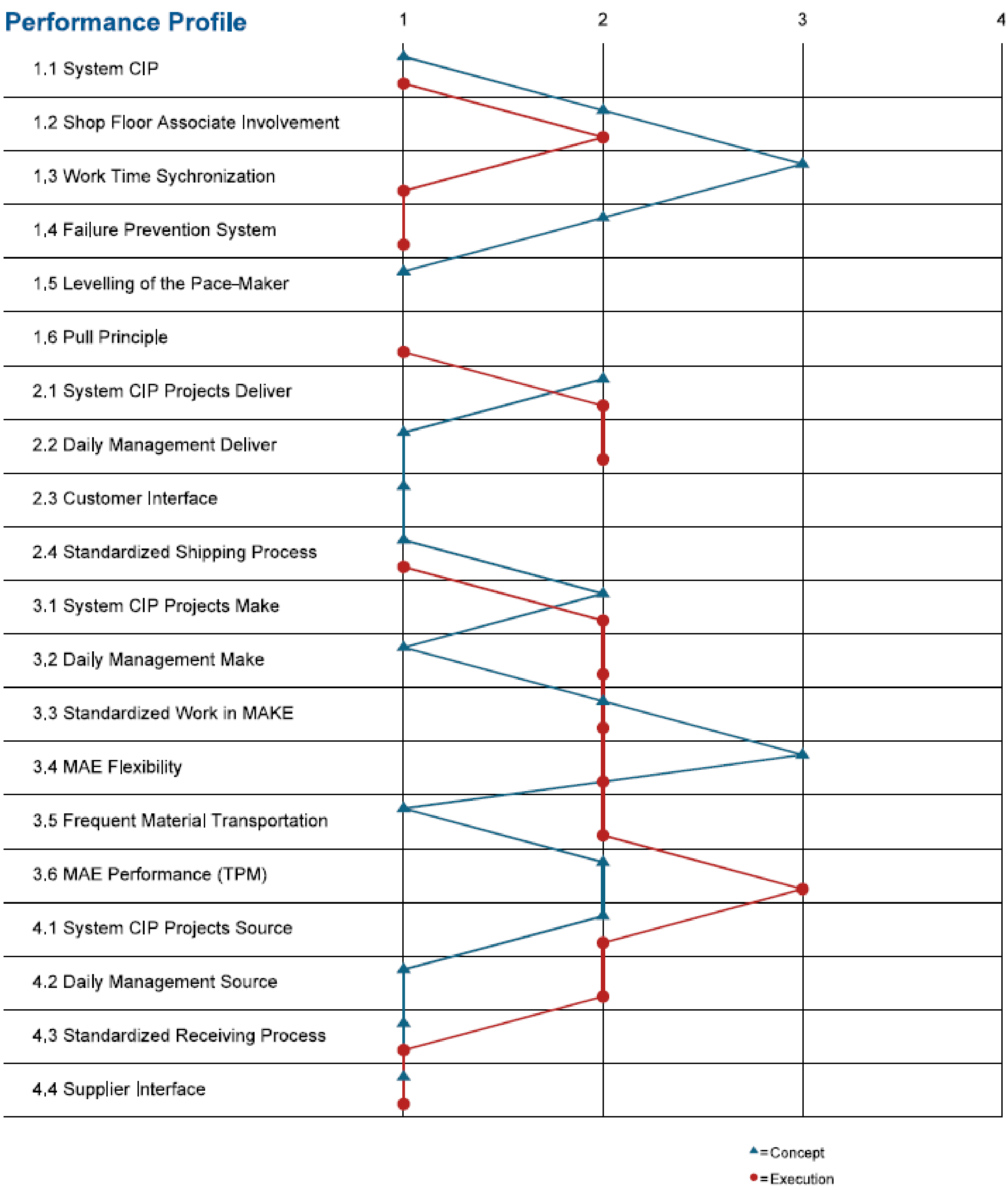


Figure 38 – Results of BPS Assessment 2018 for CC value stream

5.1.2 BPS penetration rate

In section 4.6, it was described the training concept offered by the company, which is according to BPS qualification concept. Therefore, it is being measured the penetration rate indicator. This indicator shows the ratio of people that have training in such knowledge's areas. Those trainings aim to train employees of different hierarchy levels in BPS principles and elements.

The global result of the penetration rate indicator dated to April 2019 was 32%, Table 15. The result shows a low level of training.

Table 15 – BPS Qualification Concept - Penetration Rate Result (April 2019)

	Number per target-group	BPS Basic Training (incl. BPS100)		Leading in a BPS Plant		Working acc.to Standards		Pull & Leveling		Lean Logistic Basics		MTM		Lean Line Design		Status 23.04.19
		pr	Target	pr	Target	pr	Target	pr	Target	pr	Target	pr	Target	pr	Target	
Plant Manager (PM, PC, PT, GM, TCR, site manager)	**2**	50%	90%	50%	90%											50%
all Directors (head of department) Production, LOG, TEF, QMM, PU, CTG, BPS, ENG*	**12**	92%	90%	58%	90%											74%
thereof Production, LOG, BPS	3									67%	90%					
all Managers (e.g. group leader) Production, LOG, TEF, QMM, PU, CTG, BPS, ENG*	**6**	100%	80%	67%	80%											59%
thereof Production, LOG, BPS	5									0%	80%					
all Planners manufacturing, logistic and TEF (technical functions)	**80**	38%	70%	4%	70%											21%
thereof industrial planners	21											19%	70%	38%	70%	
thereof production planners	23									43%	70%	0%	70%			
thereof logistic planners	36									14%	70%					
all Supervisors - Second level of leadership in manufacturing/value stream sections Production, LOG, TEF, QMM, ENG*, PM	**164**	51%	70%			13%	70%									30%
thereof production, LOG, MFE, PM	164							42%	70%							
thereof production	151											14%	70%			
Team leaders - First level of leadership in manufacturing/value stream sections Production, LOG, TEF, QMM, ENG*	**17**					71%	60%									71%
thereof production	0											#DIV/0!	60%			
Operator Production, LOG, TEF, QMM	**2056**					33%	60%									33%
Total		50%		15%		32%		42%		25%		13%		18%		**32%**
Management only																**30%**

* ENG functions only for plants with ETO production

Looking at the individual ones, only 50% of employees were trained in BPS basic. In this training is explained, in a general away, the reason for Bosch holds its production system methods, and pull principle is introduced as a basic level

The most critical groups were plant managers, planners, and supervisors, which only represents 50%, 38% and 51% of the trained employees. "Pull & Levelling" and "Lean Logistic Basics" are the main trainings related with PCS where different simulations with push and pull strategies are performed. Furthermore, importance of pull and its effect on value stream is shown. These two trainings were introduced in the company only in 2018. Table 15 shows that 42% of employees performed "Pull & Levelling" training, and only 25% performed "Lean Logistic Basics".

"Leading in a BPS Plant" is a training more dedicated to leadership roles because all continuous improvement process management is explained. Additionally, the effect of pull principle on the value stream is recognized. Furthermore, training is focused on leadership role in a Lean company. Mid and top-level managers had a lower level of training, which only represents 15%. This result demonstrated there was a big gap on leadership training.

On the operators' level, "Working according to standards" training, which shows the importance of standards in the shop floor, also had a lower level with 33%. For PCS, this training is important because operators understand the importance of working according to the cycle time to fulfil customer requirements, avoiding intermediate stocks.

Additionally, this result was also an effect of inexistence of BPS trainings during last years. “BPS Basic Training” was the only one that has been kept, because an internal trainer from human resources department carried out this training until 2018. Furthermore, since 2015 until 2018, company grew 60% in terms of number of employees, meaning that most of those employees did not have the mentioned trainings.

5.1.3 Suggestions boxes program

Suggestion boxes program is an initiative that aims to integrate employees in continuous improvement process. During the period that BPS section did not exist, human resources department was the responsible for suggestion boxes program. However, during that time program had a different focus and it was in standby due to resources restrictions. In 2019, suggestion boxes program was redesigned according to BPS requirements aiming to involve employees in continuous improvement process and reinforce Lean culture. The new suggestion boxes program started in October 2019.

All the employees can propose an improvement related to their work area, or even a general one. Suggestions can be categorized in five themes: quality; cost; delivery; health, safety, and environment; and people. The suggestion boxes follows an internal procedure, and the process flow is described in Appendix 8.

The suggestions procedure has five stages:

1) A valid suggestion that fulfils internal rules described in the procedure;
2) An accepted suggestion for analysis consists that the implementation’s manager recognizes as beneficial suggestion, but requires a deep analysis;
3) An accepted suggestion for implementation meaning that the implementation’s manager will implement it;
4) A not implemented suggestion is the one that the implementation’s manager decides not to implement the suggestion even after accepted;
5) An implemented suggestion is the one that was implemented by the implementation’s manager.

There are four main stakeholders involved in the process: the employee that give the improvement idea, the direct employees’ manager that is responsible to coach, support, and introduce suggestion in the platform; the suggestion program’s coordinator from BPS section is responsible to promote, support and validate suggestions, and the implementation's manager is responsible to analyse and implement the suggestion.

Each implemented suggestion provides twenty-five points as prize to be used in the internal shop.

5.1.4 Operational Key Performance Indicators

The company follows different KPIs mainly related with quality, costs, efficiency, and safety. Some KPIs are important for the PCS such as Levelling Performance, Overall Equipment Effectiveness (OEE), delivery performance, expedited shipments, and process lead time also called throughput time. Those indicators are related with PCS as observed in section 2.4. Levelling is one premise to implement pull. OEE shows the equipment stability. Delivery performance and expedited shipments are indicators that show the customer orders fulfilment and the extra cost required. Throughput time is related with WIP and stock management.

Levelling performance is the indicator that tracks the production plan fulfilment and the stability of pacemaker process. Pacemaker process from BPS point of view is the only one where customer signal enters in the process, further ones are controlled by pacemaker process. In summary, this process steers the whole production system in accordance with pull principle (Robert Bosch GmbH C/TEP, 2019). This indicator compares the production plan done by the planner (LOP) with real production, considering the quantity and sequence fulfilment, example in Figure 39. Levelling performance is tracked and reported every week and every month. Regarding quantity element, there is an allowed deviation of +/- 10%. Plant target for this indicator is 50%. Levelling performance results are influenced by internal and external factors. Internally, it may be influenced by processes instability that impacts directly line performance. Due to that, production plan is not fulfilled. It can also be influenced externally by customer orders changing like urgent orders.

	Leveling: production Schedule				Leveling Adherence
Plan	A 100	B 100	Exot (EPEI2) / C (EPEI 2) 200	D 300	
Day 1	A 100	B 100	Exot (2 Typ) 200	D 300	100%
Day 2	B 100	A 100	C 200	D 300	50%
Day 3	A go to backlog / D 100	B 100	Exot (2 Typ) 200	A-backlog 200	50%

Figure 39 – Example of Levelling pattern measurement
(Robert Bosch GmbH C/TEP, 2019)

OEE is a very important indicator that measures lines and equipment efficiency. This indicator is daily tracked in the daily meetings as well as monthly. This indicator is relevant for PCS because line losses affect production plan. If production plan is not fulfilled, additional measures must be taken in order to deliver required products. Additionally, the greater OEE, the greater safety stock should be planned in order to cushion production losses and not put customer needs in risk. Sometimes, additional measures such as freights deliveries are needed, which mean extra cost.

OEE is composed by three main factors: availability, performance, and quality. Those factors are calculated based on the big losses such as equipment failures, setup and adjustment, idling and minor stopping, reduced speed, defect in process, and reduced yield (Nakajima, 1988, 1989). OEE was presented inside the TPM philosophy, having a high importance for this topic (Nakajima, 1988).

In the company, availability includes technical losses such as machine breakdowns, and organizational losses such as material supplying faults, changeover losses, and other issues related. Performance losses are related with something that slows down production, employees absent, training, and other issues related. Quality is related with bad quality of the parts or process.

Delivery Performance is the indicator that measures customer orders fulfilment. That KPI tracks Bosch delivery data concerning quantity and date, in comparison with customer schedule data. Both date and quantity must be fulfilled 100% in order to get a positive evaluation. Meaning that company could fulfil the customer agreement related to the deliver. Non-compliance with such agreements may lead to penalties from customer side.

Expedited transport is related with extra transports from suppliers to Bosch due to its responsibility. Expedited shipments are another plant indicator related with extra shipments to customers. Those indicators represent every special transport required overhead of the planning. The extra costs avoid customers stoppages. There is a monthly tracking of number of expedited transports and shipments, and the respective cost.

Process throughput time measures the product's process time, which includes storage areas in between. It provides the information about product lead time and the comparison between value-adding activities and non-value-adding activities.

5.1.5 Associate survey

Since 2009, it is performed a global survey to all direct and indirect employees, every two years. The Associate Survey is conducted at all locations across the world. All employees who works in the company for, at least three months, can participate (Bosch_LOGIT, 2017).

Company recognizes the survey as an important tool for its own development. The survey's goal is to strengthen the culture of excellence, creativity, and innovation. Furthermore, it is intended to impulse the dialogue, identifying strengths and potentials for improvement as well as shaping change processes. The responsible is the coordinator of each division and the regional organization. LOGIT Management Consulting, which is an independent consultancy specialized in strategic associate surveys supported Bosch to perform the survey (Bosch_LOGIT, 2017).

The last survey was performed in 2017. It was distributed in fourteen categories that considers 65 sentences to be evaluated in overall. The categories evaluated were the following:

1) Direction and strategy;
2) Company transformation;
3) Mission statement and customer;
4) Excellence and improvement;
5) Changing;
6) Tasks and goals;
7) Working conditions;
8) Collaboration;
9) Communication and Development;
10) Evaluation of the last survey;
11) Sustainable engagement;
12) Health;
13) Diversity;
14) Questions to managers.

Each question can be evaluated in a rating scale from one to five according to the Table 16.

Table 16 – Questionnaire scale rating

1	**2**	**3**	**4**	**5**
% Yes		% uncertainty	**% No**	
Totally Agree	Partially Agree	Neither agree nor disagree	Partially Disagree	Totally Disagree

Topics that involve the strategy of the company, employee's involvement on company results, continuous improvement, leadership, and how they evaluate their job and responsibility in the company sustainability are the ones relevant for the conducted research. Each functional area has its own result that is compared with company average result, and with Business Unit. Some of those results are presented in Table 17.

Table 17 shows the average results of Bosch Braga plant and each area received its own result. Topics that were better evaluated by the employees are related with Company transformation, Sustainable engagement, and Diversity. Those topics are related with company and business growing, sustainability of the Bosch group and the possibility of harmonizing professional and personal life.

The ones that received lower punctuation are related with Tasks and goals, Collaboration and Evaluation of the last survey. Those categories are related with professional development, teamwork environment and collaboration between teams, and the continuous improvement activities based on the last survey results as well.

Table 17 – Results of the associative survey
(adapted from (Bosch, 2017)

Direction and strategy
67% of the employees answered that knew company strategy.
64% of the employees answered that agree company strategy.
70% of the employees answered that trust in Business Unit administration.
Mission statement and customer
54% of the employees answered that have access to the customer satisfaction information.
85% of the employees answered that customer is the focus of their team tasks.
Excellence and improvement
69% of the employees answered that their team follow the market/sector best practices.
81% of the employees answered that improve continuously.
68% of the employees answered that their team have the freedom for asking the status quo, break out routines and searching for new solutions.
71% of the employees answered that their team elements assume responsibility of the decisions and decisions taken.
62% of the employees answered that good ideas are implemented and valued in their team. 79% of the employees answered that mistakes are an opportunity for improvement and learn together as a team.
Changing
70% of the employees answered that every team element understands their role for the company strategy implementation.
Tasks and goals
92% of the employees answered that understand what is expected from their job.
78% of the employees answered that can totally apply their competences.
59% of the employees answered that their team elements assume responsibility of the decisions and decisions taken.
65% of the employees answered that receive valuable feedback about their work.
59% of the employees answered that when do a good is recognized and praised.
44% of the employees answered that if they do a good job, they will have better chance of doing a more interesting job.
71% of the employees answered that their leader support them as a mentor or coach
Collaboration
67% of the employees answered that there is a very good teamwork spirit inside their team.
57% of the employees answered that collaboration with other teams works well.
47% of the employees answered that collaboration with external teams of Bosch group works well.
55% of the employees answered that collaboration with other departments and roles is stimulated.
63% of the employees answered that communication between hierarchical levels and departments is open.
Communication and Development
78% of the employees answered that there is a good experience and knowledge sharing.
82% of the employees answered that try update their knowledge and increase qualification.
54% of the employees answered that can have access to the training programs and professional development.
Evaluation of the last survey
67% of the employees answered that the last survey was carefully analysed to derive countermeasures.
60% of the employees answered that implemented measures led to a visible improvement in their team.

5.2 Critical analysis and identification of the pull system implementation failure

In this section is presented the critical analysis done based on several research tools such as data analysis, observations, descriptions, and workshops performed in the company. It starts presenting the results of the main value streams of the company, production control system description, the continuous improvement projects results, and the results of KPIs which influence PCS. The analysis was crucial to identify the main root causes of the pull system implementation failure, also described in this section.

5.2.1 Predominance of push system and non-value-added activities

In the company, VSM is a common tool used for current situation mapping in order to map the process flow and derive CIP projects. It also works as a starting condition to design the future state as a part of continuous improvement process like Nadler (1967) proposed.

This tool is used as a working tool implemented in the plant for some years. Every value stream maps a representative product. VSM is done in the shop floor in order to visualize the flow and it is also an opportunity for process confirmation. Figure 85, Figure 86 and Figure 87 in the Appendix 9 represent VSM for Connected Information Solutions 1 (CI1), Connected Information Solutions 2 (CI2) and Chassis System Control (CC) value stream, referring first revision of 2019. Those value streams were the most representative ones in terms of business volume in 2019. Therefore, VSM is a standard tool used to map the main products. Each value stream manager is responsible for updating its value stream and BPS team support on execution and coaching.

VSM representation shows the complete flow from the suppliers, on the left side until (e.g., Figure 85) costumer site, on the right side. Commonly, only the most representative parts' suppliers or the part that pass through the entire value stream is represented. Then, every transport and waiting times before parts arrive to Bosch is represented as well as the information flow between company and suppliers. Inside company, every process is sequentially represented as wells its main KPIs.

Production plan is an important element of the VSM, so it is possible to understand how the production is steered. After product shipped, the material flow is represented until costumer site. Every transport, intermediate stock, and waiting times are represented. This kind of information is essential to measure process lead time and assure customer deliveries. Information flow between costumer and company is a crucial information for production planning that influence the process execution. Additionally, rooms of improvement are identified and marked as a flash kaizen (e.g., yellow, and red flashes in Figure 85).

Through the Value Stream Mapping presented, it was possible identify that push system was the predominant strategy. There was also identified non-value-added activities through whole value stream in the three value streams.

Figure 85 in Appendix 9 represents CC's value stream mapping, Figure 86 represents CI1's value stream mapping, and Figure 87 represents CI2's value stream mapping dated first quartile of 2019. Comparing the three value streams, CI2 value stream had more intermediate stocks and more disordered flow. CI1 had fewer process than CC and CI2. However, problems were the same as well as the PCS used was the same in both value streams. There were several opportunities for improvement and problems represented by yellow and red flashes. Those will be described next.

VSM shows there were different production plans for each production and shipping area and that is why pacemaker process was not clear. There was a weekly plan that was reworked every day on production. Related to production control system was mainly used push system between production areas and customer orders. Only one area that was controlled by a pull system was the raw material supermarket closed to the production lines, which used kanban system to replace consumed raw material from warehouse to the supermarket. Also related to PCS, production plan was not levelled, and the pacemaker process was not clearly identified.

Additionally, many problems were represented such as many intermediate stock points in between processes, which also represents additional transportations. Lack of standards and lack of 5S implemented in different areas were also identified. Furthermore, information flow also had problems because there was the need of daily double checks and updates.

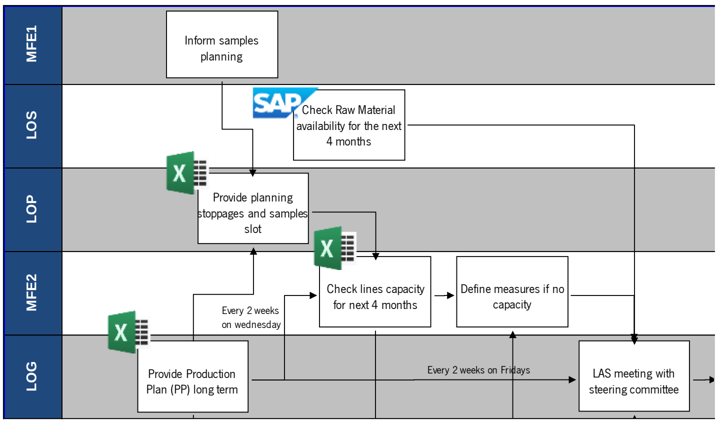
Looking at the value-adding activities in CI2's value stream, they represented much less time compared with non-value-adding, approximately 25 minutes (0,07%) compared with throughput time: approximately 24 days. Anyway, it still missed some processes in this accounting. This result show there was a lot of waste in the value stream.

Analysing different value streams from previous year (2018) and following one (2020), conclusion was that many problems remained the same during those three years. Therefore, the problems represented in the value stream were not solved. That also means continuous improvement was not being effective because was not visible as far as product has been matured. In terms of production control, there was still different production plans to be sent to different areas. Due to several causes, the weekly plan faced daily adjustments that causes bullwhip effect on the upstream processes and double work by redoing the plan every day. Additionally, material flow followed a push approach in mainly processes. There was undefined stock in between in almost every process.

So, with VSM was possible to identify that value stream had a lot of waiting times, inventory, and transport that were not in favour to one-piece-flow strategy. Value-adding activities only represented a low percentage of the throughput time due to the reasons already explained. Furthermore, pull principle was not implemented despite being tried for several times in the past. Moreover, it was still visible some problems regarding production planning and control system.

5.2.2 Production control system analysis

A wide study about Production Control System implemented was done in order to describe and analyse it. Appendix 3 shows a diagram that represents the PCS also part of the production planning implemented. The Diagram (example in Figure 40) illustrates the different process stakeholders (blue column), each process/ task is represented by a rectangle placed in a respective row, the IT tool (if applicable) used to perform the process is represented in the left side of the rectangle, and the arrows mean the process flow direction. Additionally, attached to some arrows, it is mentioned the task frequency. The remaining ones are daily tasks.



LOG - Plant Logistics/ MFE2 – Assembly/ LOP - Planning and Fulfilment/ LOS - Interface supplier/ MFE1 - Project Management

Figure 40 – Part of PCS Diagram

Moreover, the diagram allows to conclude there were many people interacting on PCS across the organizational structure, which is analysed in detail in section 5.2.2.3. Table 18 summarize the elements involved in PCS such as the number of departments (five), and number of sections (twenty-one).

Furthermore, the description of the entire process allowed to get a complete overview of IT tools used in the process by different sections, eleven in total. Same information was used in a different way and by different people that upload it in different tools depending on the area. The different IT tools use in the PCS showed lack of integration of the entire process because each area handled its own tool Final assembly is the production area where all pre-processes and final assembly lines are installed, raw material and PCBs are provided. This area was the one that uses more IT tools because it depended of several areas, so also different procedures was involved in. Despite having many existent IT tools, in some situations it was still needed manual reactions like calls due to some instability on the process and unpredictable situations.

Table 18 – Elements involved in PCS

Departments	5	Plant Logistics (LOG) Project Management (MFE1) Assembly (MFE2) Minifactory 2 – Assembly (MOE2) Minifactory 1 – SMT (MOE1)
Sections	21	Planning and Fulfilment (LOP) Interface supplier (LOS) Material Flow and Physics (LOM) MFE1-PM1/PMO MFE1-PM2 MFE2-SE MOE2x MOE1x
Tools	11	SAP Excel Niv+ Outlook – email KPP SMC KALO SOL102 Phone Printer Packing Formatting
SMT lines **Final Assembly lines**	32 104	MOE1 MOE2
Pre-processes types (functional pools)	7	ICT Coating Milling Gluing Bonding Manual assembly Packing formatting
Finished goods	~1900	Different, business units, families and variants
Customers plants **Delivery points**	~150 ~200	Europe Countries (88%) North America (10%) Asia (2%)
Directed Suppliers	~380	Around world (mostly in Asia)
Purchased Parts	~8200	Asia (88%) Europe (8%) Portugal (4%)

The process was done for every final assembly line (in MOE2), meaning that 104 final assembly production planning considered this process. Some of them had more complexity depending on number of pre-processes must be planned. However, every product had, at least a PCB, which required interaction between two main production areas such as MOE1 with 38 lines and MOE2. The production planning was done based on customer demand, around 150 customer plants that means 150 different destinations. This factor increases the process's complexity since the same product might have different destinations. In the other side of the chain are the suppliers, more than 500 different suppliers that provided more than 8000 parts.

The analysis demonstrated the complexity of the process due to some characteristics according to some authors (Saurin & Gonzalez, 2013; Soliman & Saurin, 2020) as already discussed in section 2.3.2. The PCS described had mostly characteristics such as quantity and diversity of elements interacting each other that becomes the system very complex, and difficult to manage and change it. Furthermore, there were several causes of variability represents a problem when the system is running. However, some resilience factors might work as a facilitator to minimize such unexpected variability. All complexity characteristics are described in the Table 19.

Table 19 - Examples of complexity characteristics in the case study

Characteristics of complex socio-technical system	**Examples**
Large number of dynamically interactive elements	• Number of departments, sections and people interacting in the PCS • Number of production lines to be managed • Number of Part number of finished goods • Interaction of IT tools • Number of process steps • Interactions between final assembly, SMT, pre-processes and logistics
Wide diversity of elements	• Diversity of functions • Levels of hierarchy • Product diversity • Diversity in production arrangements (e.g.: lines, cells, functional pools) • Diversity of procedures • Diversity IT tools • Diversity of purchased parts • Diversity of customer plants • Diversity of suppliers
Unexpected variability	• Changing daily priorities (e.g. frequent rescheduling due to unexpected conditions) • Variability in customer demand • Technical breakdowns • Defective products • Variability in the production line output • Lack of raw material
Resilience	• Daily meetings to monitor and take decisions • Ability to quickly react • Production capacity slack • Workload distribution • Negotiation with customers

5.2.2.1 Production Planning process gaps

Production planning was performed for long, mid, and short-term by logistic planners. The long-term planning refers to the combination of real orders management and the forecast for the next six until twenty-one rolling months. It was performed once per month. The purpose of long-term planning was to prepare in advance for the possible customer fluctuations and adjust production resources, raw material, and stocks. MRP system automatically distributes orders for a period based on next twenty-one month's forecast, target stock, minimum order quantity, and supplier lead time, The mid-term planning refers to the next four months and it was performed twice per month. The production planning was based on real customer orders even they might change during the period. This information is very important, and it was discussed in a specific meeting – LAS with every stakeholder involved in the process to assure the customer demand. This planning was an important input to assure the raw material availability, storage space, extra transport needs, and production resources planning in detail. The responsible for raw material planning performed the raw material availability simulation to check if customer demand will be fulfilled. Additionally, possible extra costs due to fluctuations had also to be analysed (Lopes, 2016).

The short-term planning refers to the weekly basis that included the production of each day by reference product and production sequence. According to the Levelling rules, the production plan should be levelled taking into account the ABC analysis (volumes distribution) and XYZ (customer pick up frequency). Production plan was sent to MOE1 (PCB production) in the previous week. Then, MOE1 planners performed production plan for SMD area. MOE1 had its own process but there was not a specific standard for that. Production lines were planned according to line capacity and availability. Logistic planners also sent the plan to MOE2 (final assembly). Commonly, the production plan was called levelling although levelling method was not fully attained in the most production lines. In upstream processes like pre-assemblies, there was not a standard planning procedure, it was manual management. Referring raw material, planners were the responsible for operating management of the supplier deliveries, supplier's capacity and orders changing (Lopes, 2016).

During the workshops, informal talks with pull system implementation team and with production planners, some concerns related with main tasks of production planning process were observed. As mentioned in the previous sections, production planners from final assembly had different topics to manage. Their daily standard tasks were described in Figure 41. The main topics were related with customer contact, orders management, special transport, and backlog management. In fact, the instability of process proved by the KPI results in section 5.2.5 might request those daily tasks. From the planners' point of view, those tasks took most of their capacity and the production planning itself was not the focus of their work.

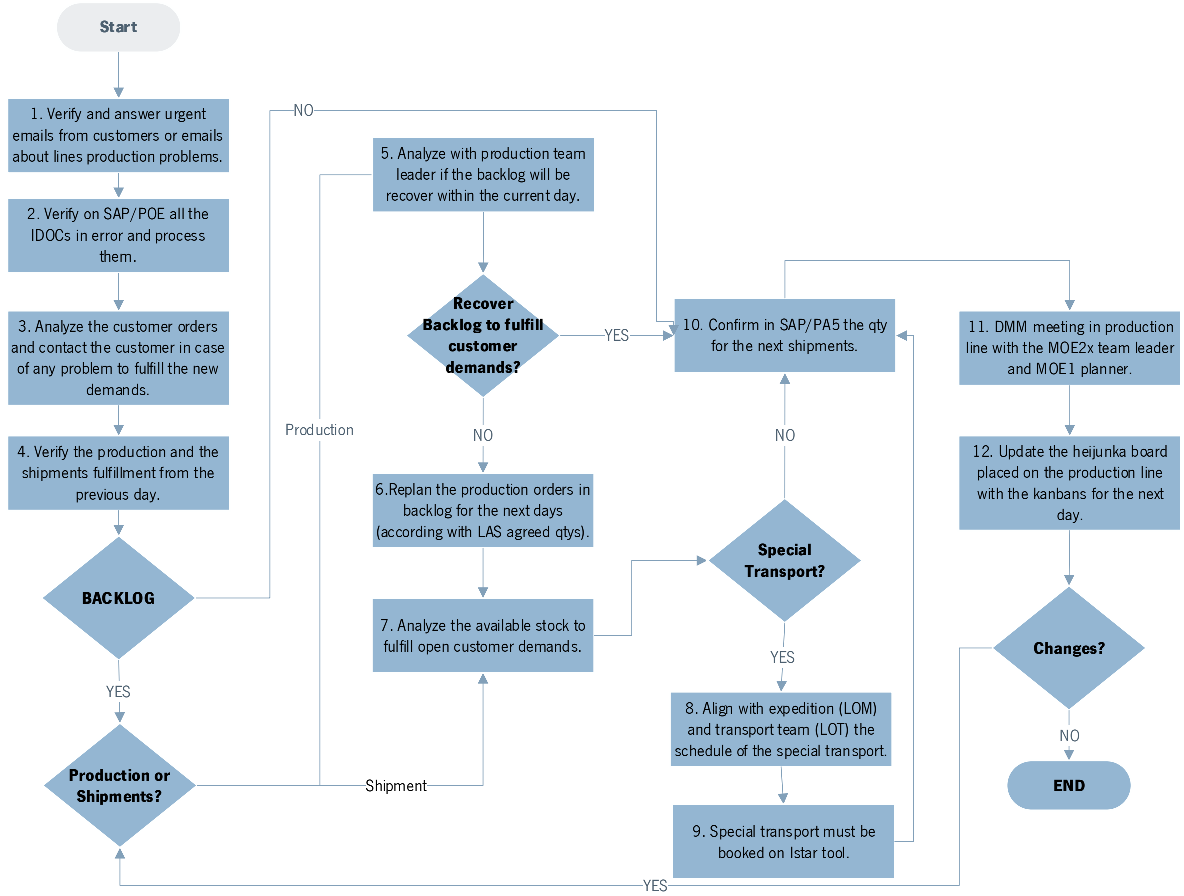


Figure 41 – Planner's daily tasks
(Adapted from BrgP/LOG (2019))

Additional tasks, which are described in Table 20, were not in a daily basis, but they were also part of the planner's responsibilities.

Table 20 – Planner's additional tasks
(Adapted from BrgP/LOG (2019))

Monthly	**Weekly**	**Others**
LAS meeting (Twice a month)	Levelling	13 digits creation
Monthly forecast meeting & protocol	Weekly file "cobertura" (stock coverage) 5 days	Simulation Request
Forecast planning in SAP		Reports Analysis

This process was implemented in the company as described before. As a multinational company, in other locations, process works with some adaptations, however the standard process is defined. According to Bosch central standard, production planners has the following responsibilities (Robert Bosch GmbH, 2020):

- Production planning and scheduling;
- Execution of regular automatic material requirements planning, such as MRP runs in the SAP system, and processing of the results of material requirements planning immediately afterwards. This takes place at least once a week for all materials in a plant;

- Creation of a levelling pattern (production planning) on a weekly basis and subsequent derivation of the number of kanbans in the control cycle from the levelling pattern for the consumption-controlled construction stages with high consumption;
- Separate production planning and control for C parts using backward scheduling based on requirements;
- Permanent tracking of deliveries in coordination with production – if needed system based;
- Coordination of deviations in cooperation with production, procurement, and product planning;
- Participation in material flow production projects;
- Master data maintenance;
- Definition of kanban control cycles, supermarkets (work in progress) and levelling pattern;
- Apply inventory management processes, in particular:
    a) Monitoring of inventory development
    b) Reduction of excess and blocked stocks
    c) Tracking of stocks with maximum storage time.
    d) Maintain special stocks on material number level using the "Special stocks" indicator.
- Apply bottleneck management processes as required, in particular:
    a) Early warning system
    b) Visualization of bottleneck parts
    c) Escalation processes in logistics and purchasing
    d) backlog tracking

According to the previous description there were some differences mainly regarding kanban control cycles and supermarkets referring pull system. The description shows an integrated perspective of production planning and control that differ from what was implemented in the company. Finished goods planners from logistics were organized per customer, they were only concentrated in customer orders fulfilment and finished goods stocks. Raw material planners were organized per material type and supplier, focused on procurement process. SMD planners were organized per production lines, focused on SMD lines capacity, their utilization and supply final assembly.

The final assembly responsible were organized per production lines, which were related to product family and they were concerning about their area and fulfilling production planning. There were many difficulties to track the WIP and information flow management. So, the production planning and control implemented was a fragmented process, with many interactions, not well defined and not clear for the stakeholders. There were different departments and sections doing similar activities using different procedures. There were many communication problems between different areas because process was not holistic one. Furthermore, it was functionally organized according to the organizational structure (5.2.2.3).

5.2.2.2 Workshops

In order to describe the production control system in Braga Plant, some workshops were performed under some pull system projects implementation. The process description was supported with VSM for different products families and with workshops named Value Stream Information Flow Design (Robert Bosch GmbH, 2018b).

The Value Stream Information Flow Design workshop is based on the same procedure of Value Stream design in indirect Areas (VSDiA) (C/HPE Etzel, 2010), which includes IT landscape and their connectivity as is shown in Figure 42.

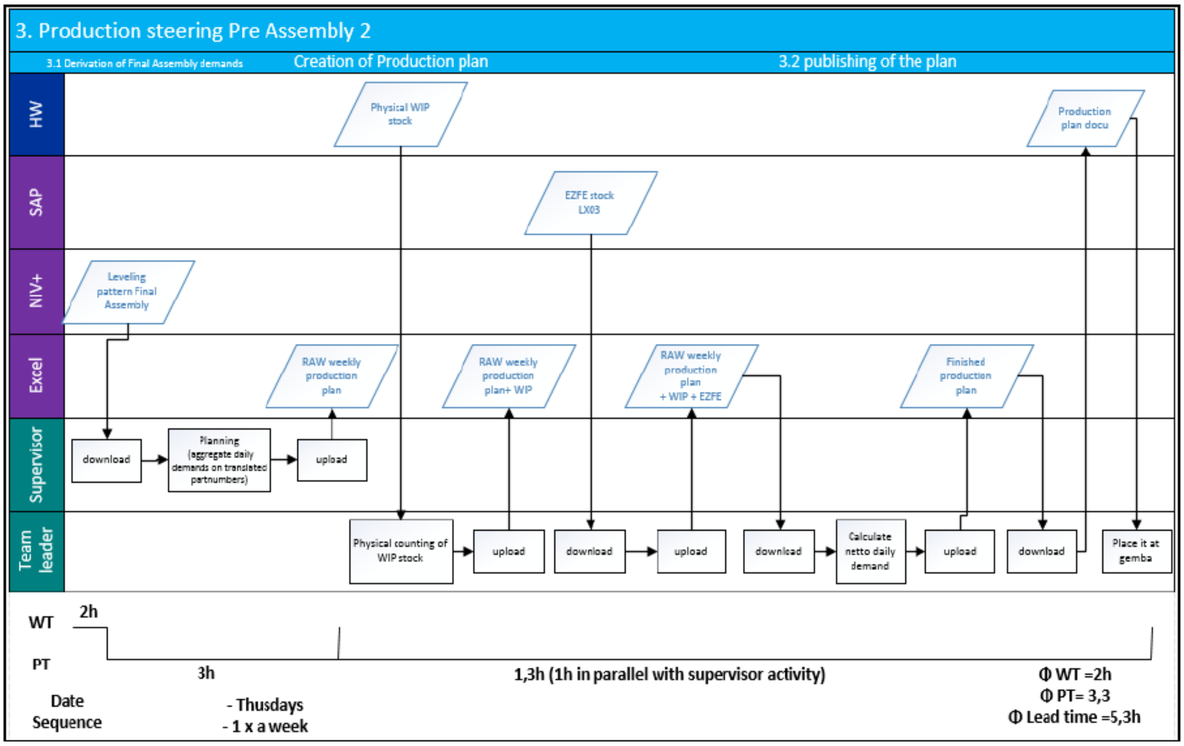


Figure 42 – Example of a Value Stream Information Flow Design
(Robert Bosch GmbH, 2018b)

Like VSDiA, this method couple VSM/ VSD and information flow chart. Additionally, this method brings transparency in the information processes and links between indirect areas, hardware, and software used, Figure 43. Method arises due to new software and technologies that have appeared in the last years and the necessity to bring transparency in the processes involved.

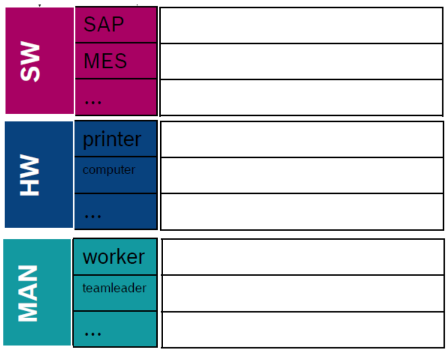


Figure 43 – Example of Value Stream Information Flow Design categories

The intention of those workshops was to map the current situation of production control system in the plant and to bring transparency in the information flow (Figure 44). The value added and non-value-added activities were not evaluated because the focus was really to understand and to describe the process.

First workshop was performed focused on specific product and only applicable in the described processes. Figure 44 shows the tool representation, and how it can be visualized at the end of the workshop. The workshop was performed only with a small group, responsible by that product. This workshop was important to clarify some unknown procedures by the team. It was also clear the lack of standards. The results showed that there were some misunderstandings about the standards, production planning and control procedures were not clear for all the elements involved, and the responsibilities as well. Additionally, due to that reasons there were some communication problems that led some conflicts about decisions taken.

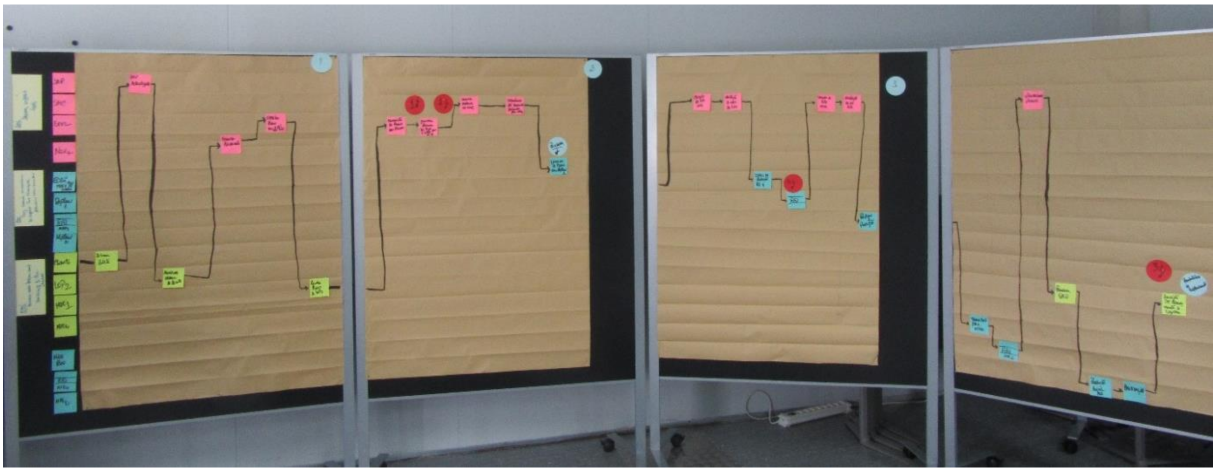


Figure 44 – Result of 1st workshop

Later, it was performed another workshop with same intention: describe production control system. At this time, it was done a deep analysis, considering every process on the plant. Therefore, the result was more complex compared with previous one, more people was involved, and the level of detail was deeper, as it is possible to observe by the higher number of elements in Figure 45, compared with previous one.

This activity and the additional observations were crucial to describe PCS used in the company presented in section 5.2.2.

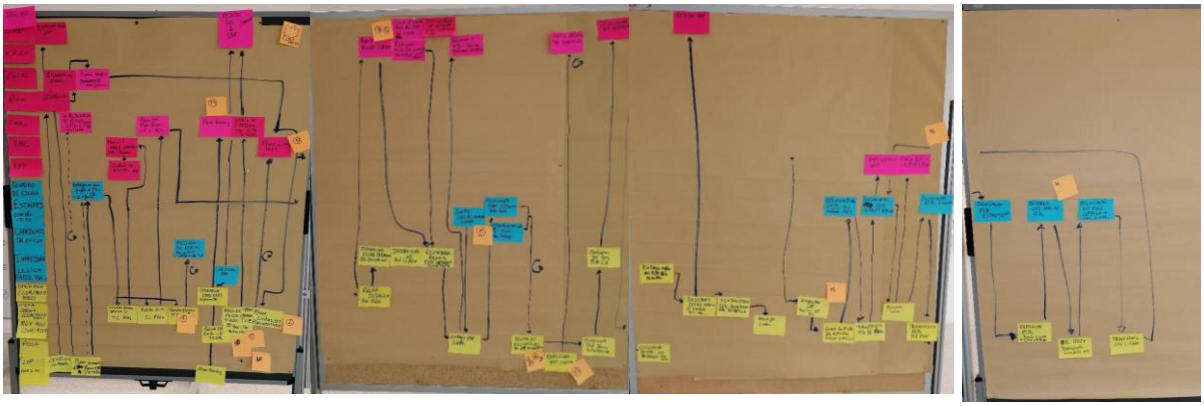


Figure 45 – Result of 2nd workshop

The second workshop was very important to understand the PCS implemented, the difficulties, and some problems. This process was not described before, which represents a big issue. As a result of the workshop, Appendix 3 describes the completed process flow, the section responsible for the process, and the IT solution used, a summary of Figure 45.

Additionally, with this activity, it was possible to observe that PCS was a very complex process in the company, which involves many people. However, LOG, MOE1, and MOE2 departments were the main process's drivers. Another conclusion is there were many communication problems because the procedures were not known by each other. They belong to different functional areas, so very often there were conflicts.

5.2.2.3 Complex organizational structure

The organizational structure is an important point to be analysed because it shows the relationship between areas, and its connection in the PCS process. The complete organizational structure was presented in section 4.3, where it is possible to confirm company had implemented a classical functional organizational structure. A functional structure is characterized by a group of people with similar skills that perform the same function with multi layers of authority between employees and top management (Rishipal, 2014). In Figure 46, it is represented all departments also sections involved in PCS, so four hierarchical levels inside plant. Both technical and commercial management areas (level1) were involved in the process. Additionally, Value Stream Manager belongs to the third level of the hierarchy from MOE1 and MOE2, also identified in Figure 46.

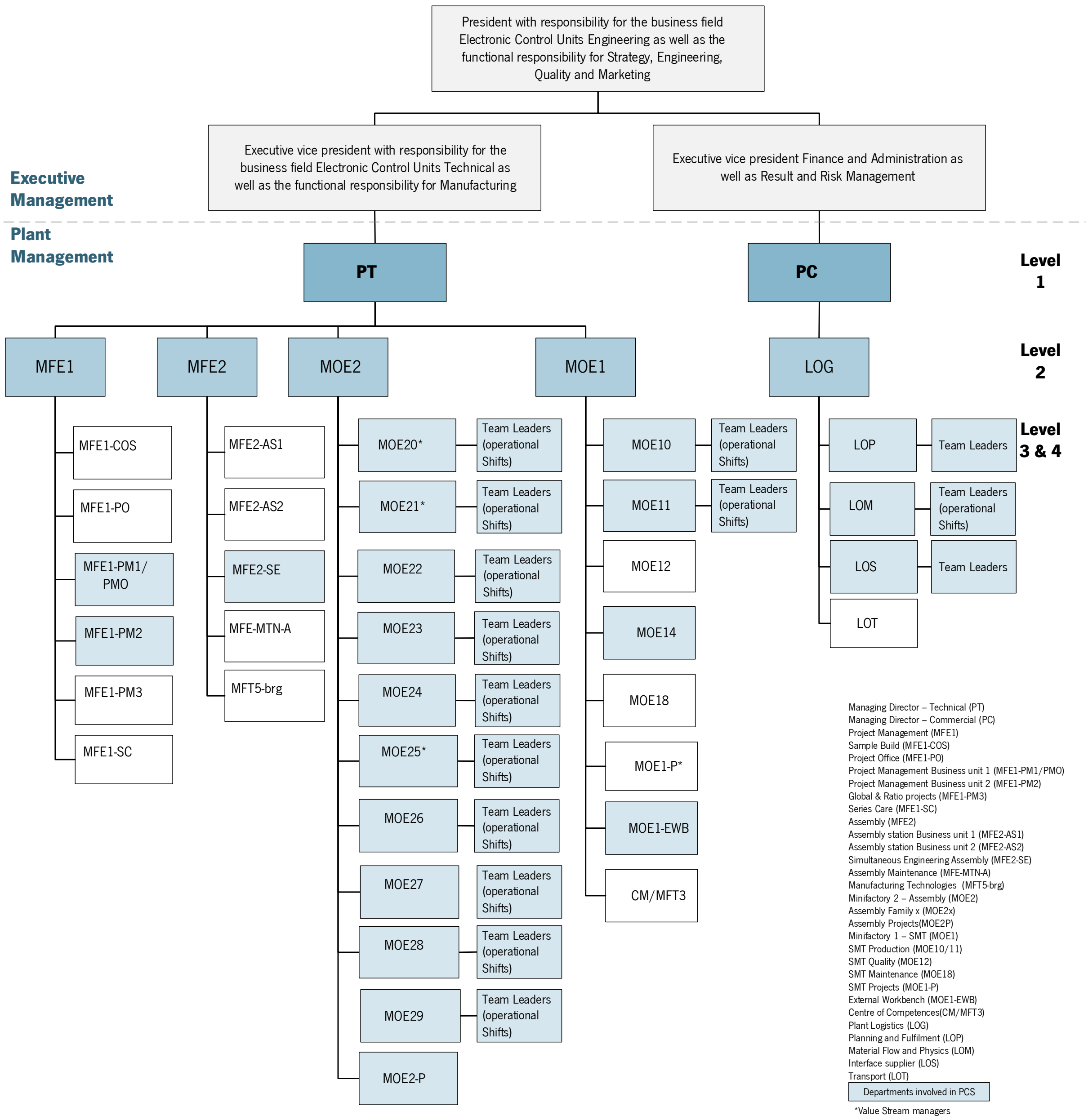


Figure 46 – Organizational structure involved in PCS

On the technical side, four departments had a role on the PCS process. MFE1 had basically the plan overview for sample building; MFE2 was responsible to calculate the final assembly lines capacity; MOE2 had the responsibility to check if the existent human resources are enough and manage the daily business; MOE1 had the responsibility to calculate the SMT lines capacity, check if the existent human resources are enough, makes production planning for SMT lines, and manage the daily business.

On the commercial side, logistic (LOG) played an important role on PCS: they were the customer orders contact, received customer plan for long and short terms, and they had to assure raw material planning. Additionally, they also were responsible for inbound and outbound process and internal material supplying.

Twenty sections are involved in PCS that shows the huge number of people that might influence the process. In most of the MOE1, MOE2 and LOM sections, there were different work shifts with many line team leaders, in some cases there was a rotating pattern shift, and they should interact with a large number of elements. There were many hierarchy levels, not only concerning PCS but for the general processes that might impact the company agility.

So, according to Saurin and Gonzalez (2013) and Soliman and Saurin (2020), this organizational structure may represent a complex system due to a "*large number of dynamically interacting elements*" and "*Wide diversity of elements*". In this case, the complex system was due to the number of departments, sections and people actively involved in the process. Furthermore, there were different hierarchical levels with different objectives that tends to increase the variety. The complexity of the systems impacts human management, mainly on socio-technical systems that involve human operators (Flumerfelt et al., 2014).

Additionally, having two different plant managers with different goals might impact the process due to strait split between technical and commercial area. Logistics department belonged to commercial plant managers. The remaining four departments belonged to technical plant manager. That might cause some communication problems, and objectives misalignment. In fact, the organizational structure shows a clear division between commercial and technical area. According to some observations, this topic impacts the operational activities because there was different point of views, and managers were different. It also impacted the value stream managers activities since that logistics issues belonged to the other area. Some decisions from technical area impacted directly on the commercial area, and the other way around. In section 2.3.2 is referred that Germany tradition is in favour with functional organizations. It negatively impacts cross-functional collaboration (Womack & Jones, 1994).

Besides the division on the plant level, there is also another important point related to the relation between technical and commercial plant manager: there is no official relation between them. Each of them reported officially to the vice president of each area, who reported to the president of the unit. Meaning that there was no official entity that manages both areas in the plant, only in the upper level of the executive management, which is located in Germany. This fact might put in risk the strategy definition and its transparent communication.

The existence of two distinct areas impacts a lot the PCS because this process included elements of both areas and it was not easy to combine different point of views. This problem was particularly important referring PCS because both areas should be aligned, mainly for pull system implementation. For instance, levelling was logistics' responsibility but the implementation of pull system in the production areas was production's responsibility. If strategy was not aligned, process would not work.

During the workshops, some participants stated that it seemed that they did not belong to the same factory because processes were not well known and there were many communication problems. Those issues were also observed in the management level.

5.2.2.4 Pull system implementation team analysis

In 2018, company defined as a strategy project whose goal was the pull and levelling implementation in a pilot project. This request was also aligned with Bosch central strategy for pull and levelling implementation.

To make this project possible, it was decided to create a multidisciplinary team from different departments that interfere in the process. So, team was composed by logistics, production from two main areas and BPS.

Since team did not have too much experience on this kind of processes, the learning phase was essential to understand the concept and create a team spirit. So, it took roughly four months to understand concepts and to create a systematic for the implementation on the plant. Additionally, during this process, company realised that most of the involved people on production planning and control did not have enough knowledge about pull and its requirements. Production planners had a poor level of knowledge about levelling, and they did not have enough production data to do it. Additionally, planners did not identify and did not accept very well new tasks. Their tasks were related with customer contact in different plants, logistic issues such as shipping and transport, and stock management. Due to that, related trainings were requested, and some employees were qualified. Anyway, there was still many developments in this area.

In order to have a place for that team works together, it was created a room, internally called "sala de Guerra" like an *obeya* room (section 2.1.4) where they could meet, discuss, make workshops, and expose ideas. Figure 47 shows three examples of the tools used for information sharing in the walls of the room, the value stream mapping of the initial situation, the value stream design showing the expected changes at the end of the project, and a list of ongoing tasks of the project. All this kind of information was exposed for everyone knows.

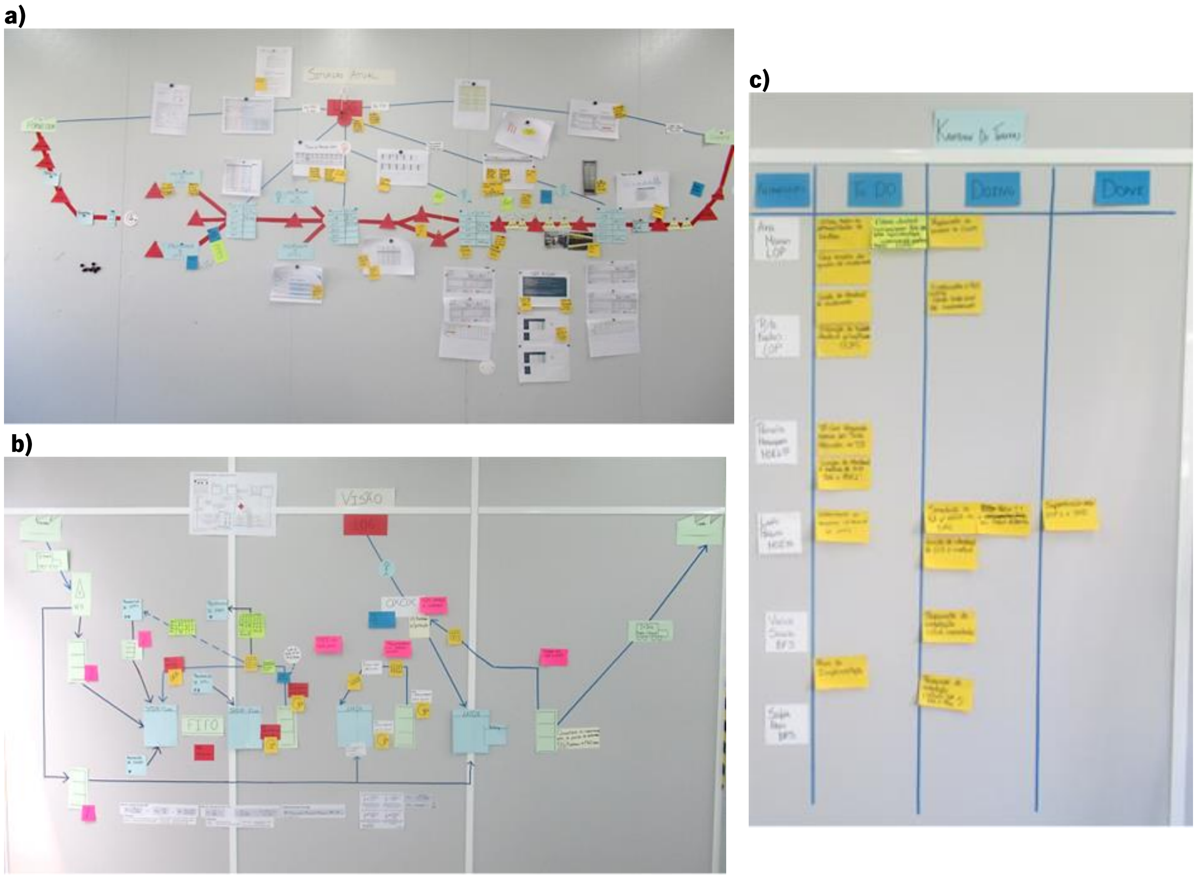


Figure 47 – Examples of obeya room information: a) Value Stream Map b) Value Stream Design c) Kanban task list board

In the beginning of the project, weekly meetings with management were done to present the project status.

At that time, a kanban management software has been developed. So, team had to learn how to use the software, by knowing its potentials, and adapt to company requirements. Additionally, during project extra requirements were requested in order to fulfil some Bosch needs. According to the team, this phase took roughly six months until deeply understand software outcomes.

As the project progressed, some activities were promoted in order to everyone involved in the process such as production team leaders from different shifts get same understanding about pull and levelling concept. So, trainings and simulation games were performed to demonstrate the procedure, advantages, and results. Additionally, their inputs from daily management and difficulties they faced was important for the implementation.

After some months project was implemented. During stabilization phase, teams followed up and monitored relevant indicators. However, they mentioned that some problems arise, and implementation fall apart when project's responsibility changed. Other reason pointed was the customer fluctuations that disturb levelling plan.

After this project concluded, team has been participated in other pull related projects and some lessons learn from previous experience were part of the implementation process. Some activities such as levelling and the kanban system workshops were performed in order to understand main problems and improve the results. In Figure 48, it is presented the main problem identified that impacts levelling execution. Ishikawa shows the operational problems found by implementation the team.

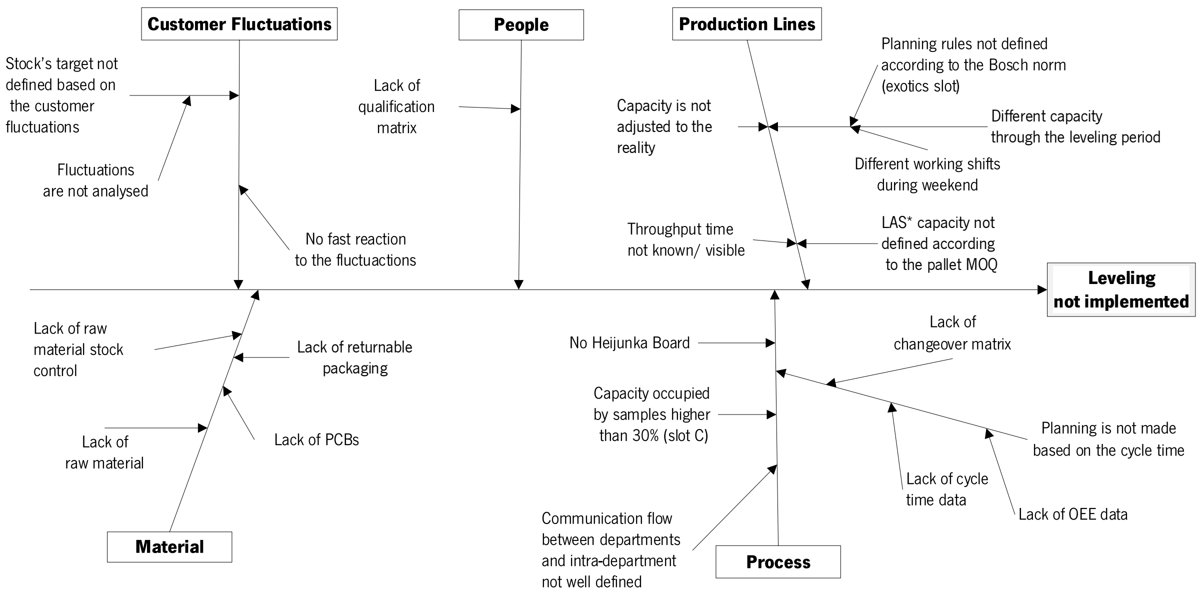


Figure 48 – Ishikawa of root causes impacts on levelling implementation

Related to the production lines capacity, several issues related with line capacity. Production lines' capacity was not adjusted to the reality, throughput time was not visible therefore it was difficult to plan, capacity defined in the LAS meeting (Steering committee conference related forecast and orders quantity) was not according customer orders, among other problems.

Related to customer's fluctuations, it missed analysis and reaction processes defined for that. It was pointed lack of qualification matrix on responsible by the production planning.

Related with material, there were different type of missing material such as PCBs (internal production), raw material, and returnable packaging. Additionally, there was lack of raw material control.

Related with levelling process, several root causes were identified such as: there was no *heijunka* board, where backlogs, backflow, and safety stock were analysed; samples occupied more than was supposed to that impacted the line capacity and lack of communication process definition between departments and inside department. Additionally, planning was not made based on the line cycle time due to lack of cycle time data, lack of changeover matrix, and lack of OEE data. In summary, there were some problems related production plan process and the way it was created. Production planning was not created taken into account important factors such as real product routings, updated change over time, throughput time, production slots for exotics because this information was not available, and Bosch guideline for levelling was not followed. Additionally, assembly production planners' role final was related to customer orders contact and deliveries management. Planners were not focused on production planning itself. Their main activities were not related to the production planning, they spent most of their capacity managing customer orders and contacts, organizing transports, stocks in different supply chain points.

Concerning kanban system implementation on the upstream processes, it was also identified the main reason for the problems faced by the implementation team (Figure 49). Among several reasons, the production planning and control process were the most representative reason. Pacemaker process not levelled represented an issue on the kanban system implementation and all the reasons was presented in Figure 48.

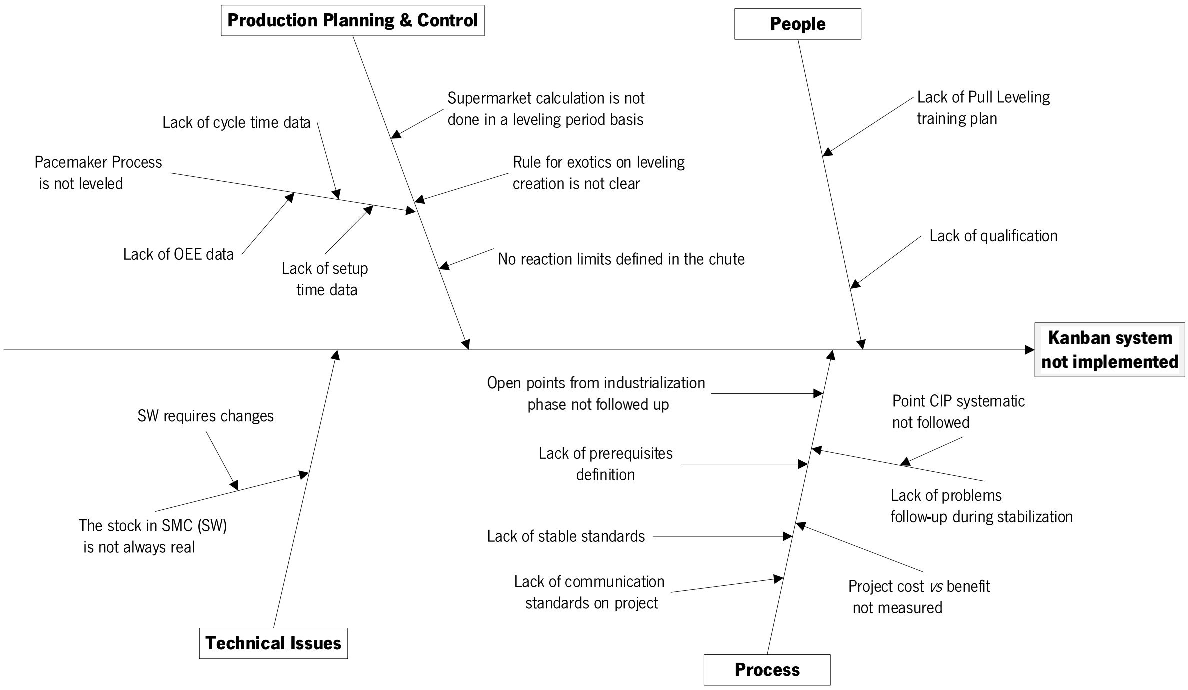


Figure 49 – Ishikawa of root causes impacts on kanban system implementation

Supermarket from kanban loop was not calculated on the levelling period frequency, meaning that was not updated. It was also mentioned problems regarding planning rules for exotics and the lack of reaction limits. On the process, it was pointed lack of communication standards for this kind of projects, lack of requirements definition, the difficulty of stablishing standards, there was an absence of cost and benefits measuring, and a general lack of follow up problems even during industrialization and Point CIP projects. Those problems show some fragilities on systematics. From the technical point of view, software that managed kanban had some troubles on the stock visualization, different from real one and some changes were needed to fulfil Bosch requirements. Training issues and lack of qualification were a problem once again.

5.2.3 Continuous improvement project results

The BPS system CIP approach described in section 4.5.1. is being performed in the company during the last four years. During these years, projects revision was done twice a year for each Business Area (Chassis System Control (CC), Driver Information (DI), Instrumentation Systems (IS), Manufacturing Systems (MS), and Powertrain Solutions (PS). Project's revision consists in a workshop where Value Stream Manager of each area presents the critical indicators in the value stream. Based on those indicators, some potential improvements are raised and discussed to create a new improvement project. Furthermore, the open projects coming from the previous revision are discussed and evaluated in order to decide if make sense to maintain or cancelled. It is considered an open project every project that results from the System CIP project revision workshop, even the ones that moved from the previous revision.

The analysis of continuous improvements projects was relevant in this research because Lean culture described in section 2.1.4 is based on continuous improvement mins-set, by reducing what is not considering value. Therefore, in the conducted research, continuous improvement tools should be part of the case study analysis.

Table 21 shows that the total System CIP projects per Business Area as well the open and closed projects in 2016 and 2017. In 2016, it was closed 24,5% of the total projects and 28% in 2017.

Table 21 – System CIP Projects Results 2016 and 2017

	2016			2017		
Business Area	Open Projects	Closed Projects		Open Projects	Closed Projects	
CC	36	9	25,0%	31	11	35,5%
DI	38	7	18,4%	39	10	25,6%
IS	38	16	42,1%	28	10	35,7%
MS	49	10	20,4%	33	8	24,2%
PS	43	8	18,6%	26	5	19,2%
Total	**204**	**50**	**24,5%**	**157**	**44**	**28,0%**

As it was described in section 4.5.2, after closed System CIP project, meaning that project achieves the target, therefore project should move to point CIP phase. This is a very important phase because new standards should stabilize, and indicators result confirm the project stabilization. Table 22 presents the number of projects that moves to Point CIP phase. In 2016, 70% of the closed projects stabilized in Point CIP, and 68,2%, in 2017.

In 2018, there was some difference in the business areas distribution due to organizational changes. So instead of having five business areas, only four was considered. Additionally, it was also included

"Concept Projects". Those type of projects were general ones, not value stream specific; they were common to all of them and divided in the three main areas: source, make and deliver.

Table 22 – Projects that achieved stability – Point CIP 2016 and 2017

	2016			2017		
Business Area	Closed Projects	Point CIP		Closed Projects	Point CIP	
CC	9	5	55,6%	11	5	45,5%
DI	7	4	57,1%	10	9	90,0%
IS	16	13	81,3%	10	10	100,0%
MS	10	10	100,0%	8	5	62,5%
PS	8	3	37,5%	5	1	20,0%
Total	**50**	**35**	**70,0%**	**44**	**30**	**68,2%**

In 2018, period of revision was also changed from twice a year to four times a year. The purpose of this change was to conclude project faster and improve the maturity level related to the system CIP projects results. Table 23 shows the project results, of the year 2018. The percentage of total closed projects was 16,2%, meaning that the percentage of closed projects decreased. Related to point CIP (Table 24), 52,6% of the projects achieved the stabilized period.

Table 23 – System CIP Projects Results 2018

	2018		
Business Area	Open Projects	Closed Projects	
CC	25	4	16,0%
CI1	42	8	19,0%
CI2	62	11	17,7%
MS	11	6	54,5%
Concept	94	9	9,6%
Total	**234**	**38**	**16,2%**
Total w/o Concept	**140**	**29**	**20,7%**

Table 24 – Projects that achieved stability – Point CIP 2018

	2018		
Business Area	Closed Projects	Point CIP	
CC	4	1	25,0%
CI1	8	7	87,5%
CI2	11	11	100,0%
MS	6	0	0,0%
Concept	9	1	11,1%
Total	**38**	**20**	**52,6%**
Total w/o Concept	**29**	**19**	**65,5%**

Data collection related to the CIP projects was a hard work because there was no systematic of cataloguing this kind of information about projects. Additionally, there was no statistics recorded about closed projects. Project documentation was saved in folders organized by year, for each value stream and projects period. In each value stream folder was listed all the projects that belong to. The procedure adopted to collect this data was the following: open all folders and search for the documentation that proved the project is closed, which represents 595 projects. Same procedure was done for the projects that achieved stability in Point CIP phase.

Since the end of 2018, a new informatics platform was introduced in order to easily visualize all projects. Platform follows the System CIP methodology and allows to have a clear overview about projects and all the related information. Figure 50 shows the status of the system CIP project until May 2019 according to PDCA tool. It shows there were 56 open projects in overall.

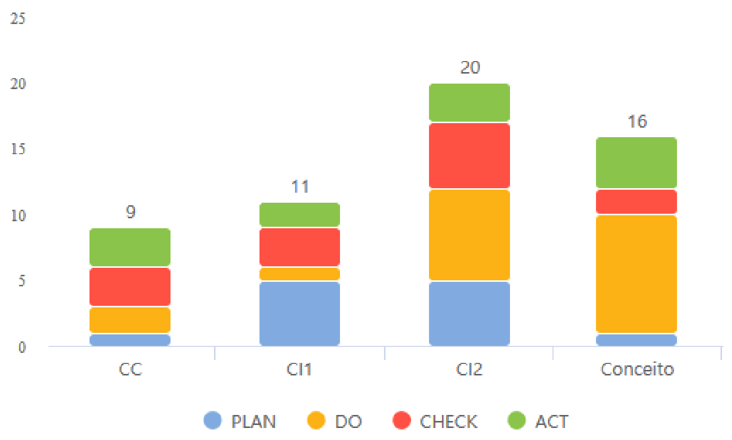


Figure 50 – Open projects/ area of the System CIP projects (until May 2019) (adapted from internal Bosch platforms)

Related to the year 2019, there were 43 open projects and one closed as Figure 51 shows, which represents 2,3%. Twelve projects moved from 2018 to 2019 and they are shown as an open project due to not be concluded in the planned date and still open.

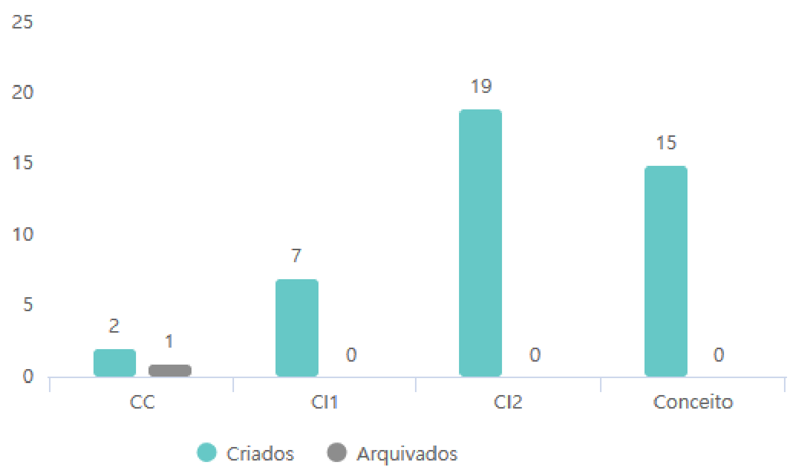


Figure 51 – Closed and opened projects in 2019 (until May 2019)

Later on, it was additionally collected, and analysed system CIP projects related with pull. Since the end of 2018 until June 2021, it was created seven projects. Some of those projects could not be successfully implemented even after many trials. Three of seven created projects were closed (43%). There were some difficulties, but team tried to keep the standards running even during Covid pandemic situation in 2020/ 2021. Those projects were applied in a specific area, it did not involve the completed manufacturing process of a product, so the impact was not significantly in the organization.

The results of continuous improvement projects reflect some concerns regarding people management, project scope clarification, and the way that leadership look at those activities. On section 5.3.3 is presented the main reasons of having so many projects not concluded, and it is explained the difficulties in detail.

5.2.4 Suggestion boxes program results

Since the suggestion boxes program started until May 2021, 2480 suggestions were given according to the category's distribution represented in Figure 52. Quality and health, safety and environment categories were the most representative with 58,7%.

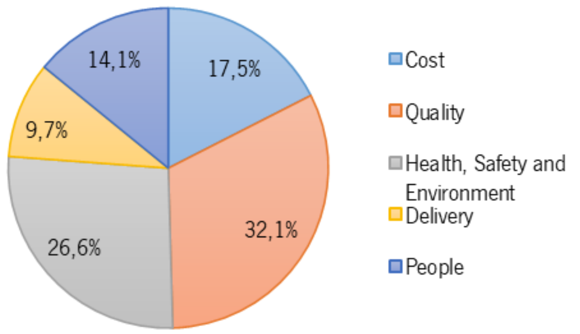


Figure 52 – Suggestions distribution according categories (Oct 2019 – May 2021)

Figure 53 represents the suggestion status and it is possible to see that 56,2% of suggestions were rejected. 28% of suggestions were implemented that still represented a lower percentage compared with rejected ones.

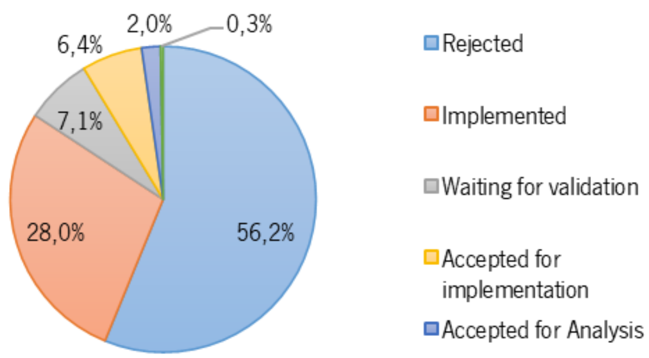


Figure 53 – Suggestion's status (Oct 2019 – May 2021)

In order to understand the impact of suggestion boxes program in production control system, a specific analysis was done. Therefore, all suggestions were evaluated, and the ones related with planning and production control represented only 2,7% (Figure 54). Only 18,8% of those suggestions were implemented that represents 0,1% of the total suggestions.

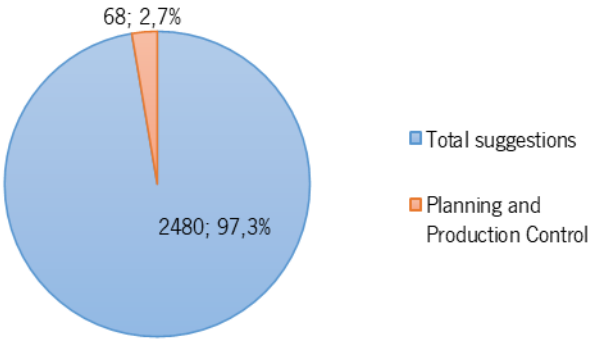


Figure 54 – Comparison between total of suggestions, and the planning and production control related

Suggestions related with planning and production control (2,7%) were categorized according to Figure 55: improvements related with material orders, pull system concept, stock management in the shop floor, the need of visual management to improve the communication process, 5S, improvements with direct cost impact, and the current standards improvement. From those, 23,5% were related with pull concept and 50% of them were concerned with IT tools improvements, since there were several activities ongoing to introduce digitalization in this process. The suggestions related material order, visual management, and stock management also confirmed some existent problems in the production control process visible in the shop floor as observed in section 5.2.2. Another observation coming from those suggestions analysis is that they were still very superficial when approaching production control. Anyway, besides of having a few suggestions related pull, low percentage of them were implemented.

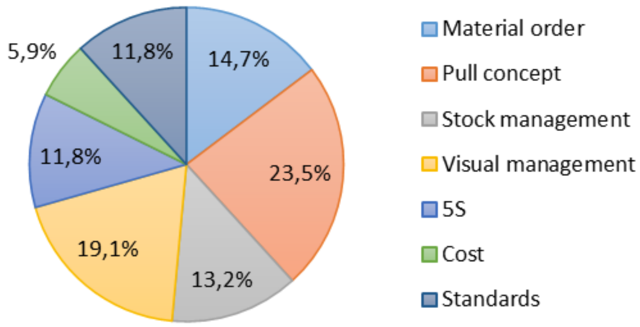


Figure 55 – Categories distribution of planning and production control suggestions

Planning and production control, mainly pull system was not yet representative in the suggestion boxes program. Data is referred to one year and eight months period because the new program was still recent. Suggestions came mainly from direct employees of production areas that were more focused on other topics. Additionally, the fact of pull system was still not mature and not fully implemented also might have impact in the results.

5.2.5 Operational KPIs below of the target

This section presents some operational KPIs whose results were below of the defined target and represented a problem for PCS implementation. In section 5.1.4 was described operational KPIs that influences PCS. In this section, it will be done a critical analysis concerning its results.

5.2.5.1 Levelling performance

This section presents levelling performance results. This KPI has already described in section 5.1.4. In 2019, 13 of the 43 final assembly lines (30%) fulfilled that objective. In average, levelling adherence of those lines was 40%. Meaning that in 43 existent final assembly lines, only 40% of the production plans were accomplished according levelling rules. Overall company and value stream results are visible in Figure 56.

Figure 56 – Levelling Performance results from 2019 a) overall company, b) CC, c) CI1, d) CI2 value streams

Figure 56 a) and b) shows the results by month where a positive trend is visible. In the first five months, results were around 35%. From June onwards, levelling adherence improved considerably. This difference was mainly influenced by huge improvements on CC value stream (Figure 56 b)), which did a big effort to level production plans and started a pull system implementation. In this business unit, levelling becomes a focus for the team and the results show accordingly. In CI1 value stream, levelling performance was instable in the first half of the year, then it became more stable and achieved the target. In CI2 value stream, levelling performance never achieved the target during year 2019.

5.2.5.2 OEE results

There has been done a survey of the overall OEE results in period of 2019, which considered all existent lines of the final assembly area. Final assembly is the most closed process to the customer in terms of product flow. This is the reason to place pacemaker in there in most of the lines.

On Figure 57 is presented the OEE overall result of final assembly area by month, including all lines. On average, OEE was 85,45% that was roughly 5% above of target defined by the company. Fluctuation from minimum and maximum value was 6%. Results showed some instability during year, and target was never achieved.

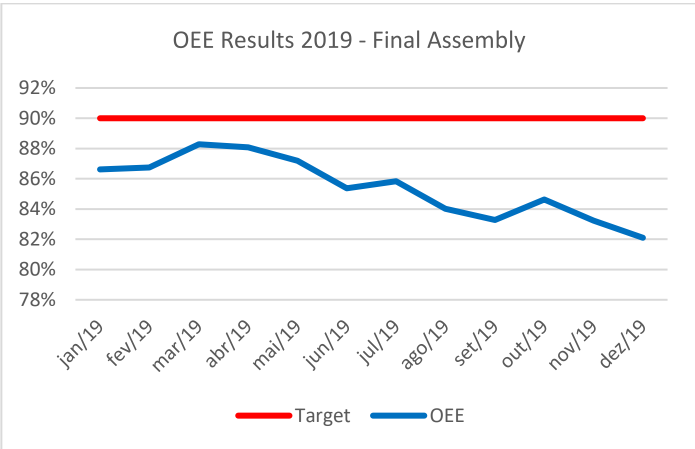


Figure 57 – OEE results from2019 on Final Assembly

Three main losses that were considered on OEE calculation were: availability, performance and quality represented by the OEE tree on Figure 58.

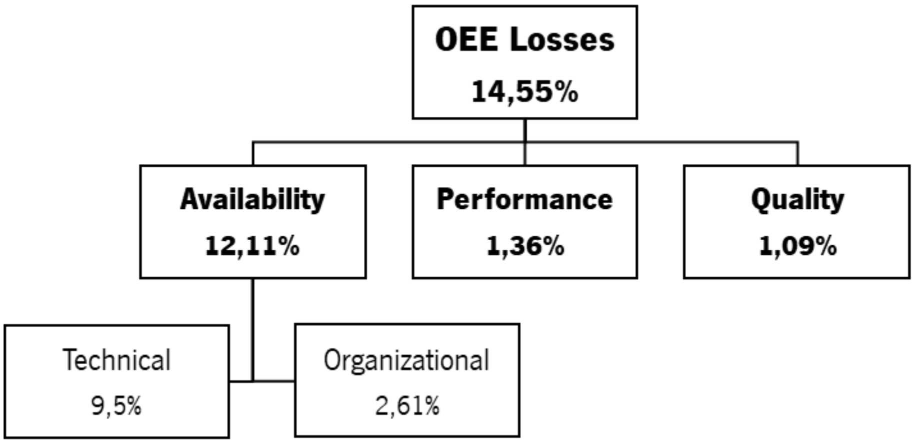


Figure 58 – OEE losses tree results from 2019 on Final Assembly

Factor most impact OEE losses was the availability. Availability represents 12,11% that represented 83% of total losses. Inside availability, technical losses were the most representative, 9,5% of them, which represented 65% of total losses. Meaning that problems related with machine breakdown were the most representative reasons of production line losses in final assembly area.

Losses directly related with PCS were the material supplying fault that included missing PCBs from MOE1 area, faults of raw material supplying from logistic area, missing material due to out-of-stock caused by suppliers' issues and missing material from MOE2's pre-processes. Results are presented in Table 25 that shows the main causes related with raw material supplying. It represented 27387 man hours losses in 2019. From those losses, 86% were related with suppliers delivering.

Table 25 – Losses related with lack of material supplying in Final Assembly 2019

Man Hours Losses		
Lack of Pre-Processes supplying	**Lack of PCB supplying**	**Lack of Raw Material supplying**
332,50	7 816,85	27 387,23
1%	22%	77%

Like the other KPI analysis, it was also analysed the OEE per value stream. In Figure 59 is represented the monthly results and the comparison with the plant target. In general. CC's value stream had better performance, achieving the target in some months. Furthermore, the results over the months were smoother compared with the other value streams. In the CI1 and CI2's value streams, target was never achieved and there was fluctuation at least in CI1. The more detailed the analysis was per value stream or even per machine, more focused might be the improvements.

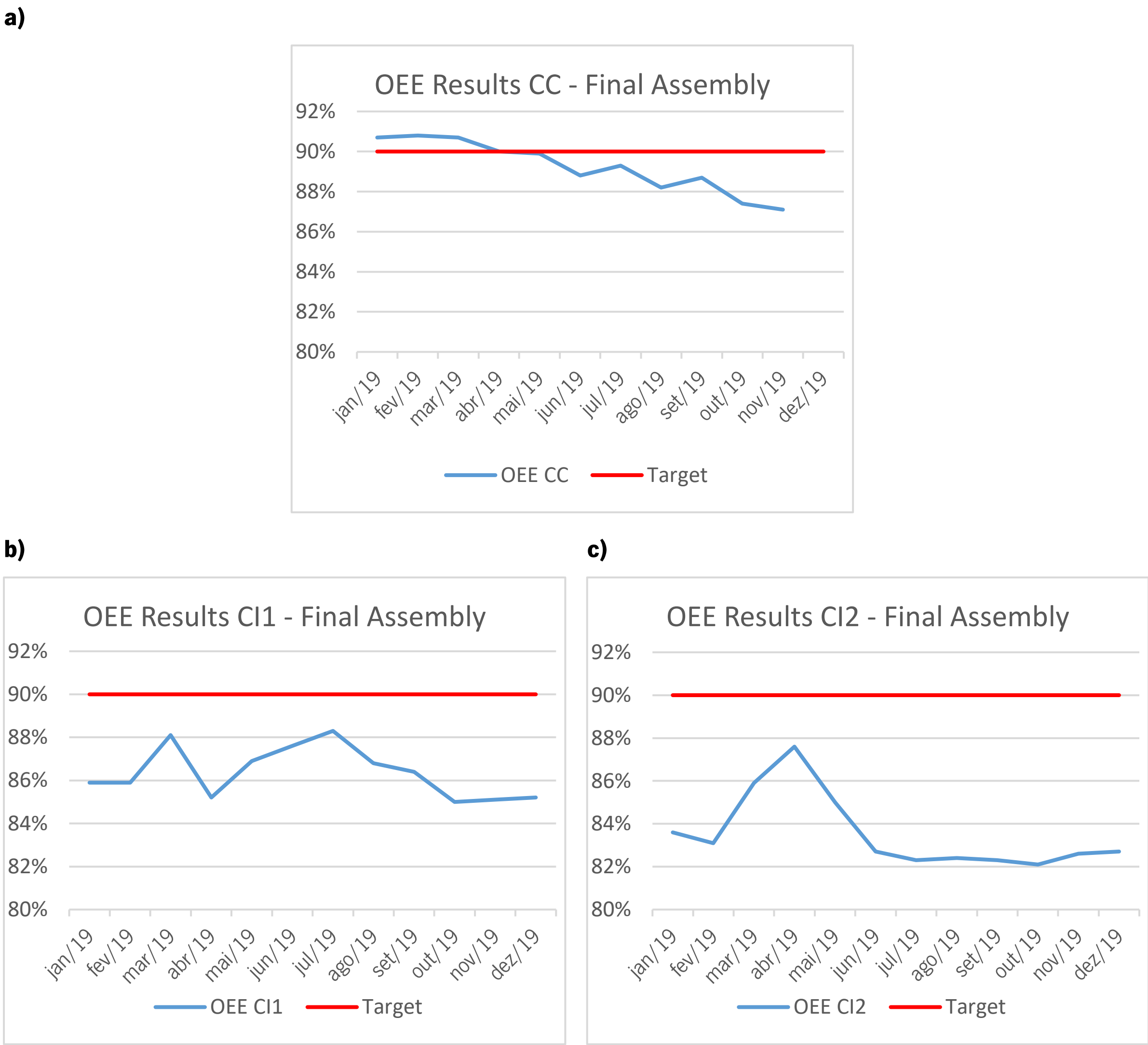


Figure 59 – OEE Results 2019 a) CC, b) CI1, c) CI2 value streams

5.2.5.3 Delivery performance and logistics customer complaints

The following analysis was related with the delivery performance results. This indicator represented in Figure 60 shows instability over the year in every value stream.

In CC's value stream, results were inside the target for consecutive months (ninety-three percent), however there was some instability and some months far away of the target (e.g., minus twelve percent). In the CI1's value stream there was also instability (range from minus twelve percent to plus two percent) and it only achieved the target two months. This was an interesting result because levelling performance, presented in section 5.2.5.1, and customer fluctuations, presented in 5.2.5.4 were more stable compared with other value streams.

Figure 60 – Delivery Performance results from 2019 a) CC, b) CI1, c) CI2 value streams

Delivery performance was more stable (range from minus six percent and plus three percent) in the CI2's value stream. However, looking at levelling performance and customer fluctuations, they were the more instable indicators compared with other value streams. This behaviour was the opposite of the CI1's value stream.

This analysis showed the importance of analysing KPIs in an integrated away. Analysing isolated KPIs might not give the complete picture. There was no overall plant result for this KPI.

Delivery performance is related to the orders' fulfilment in time and in quantity, however, it was not the only indicator tracked concerning logistic process. In 2019, there were 309 logistics customer's complaints. Those complaints were not related with product functionality, but only with delivery process. Also, 75% of customer's complaints were related with special deliveries and backlogs, the most relevant complaints looking at Figure 61 a).

Special deliveries meaning that company could not fulfil orders without extra measures like special transports that were not originally planned. Backlog represents orders that were not accomplished. Both reasons are strongly related with production planning and control system process. These results showed the fragility of the process that puts customer's satisfaction in risk. Other representative claims are related with packaging labelling, also the product's packaging and pallet itself. The remaining ones (Figure 61 b)) concerns other problem clusters, not so much representative compared with mentioned above.

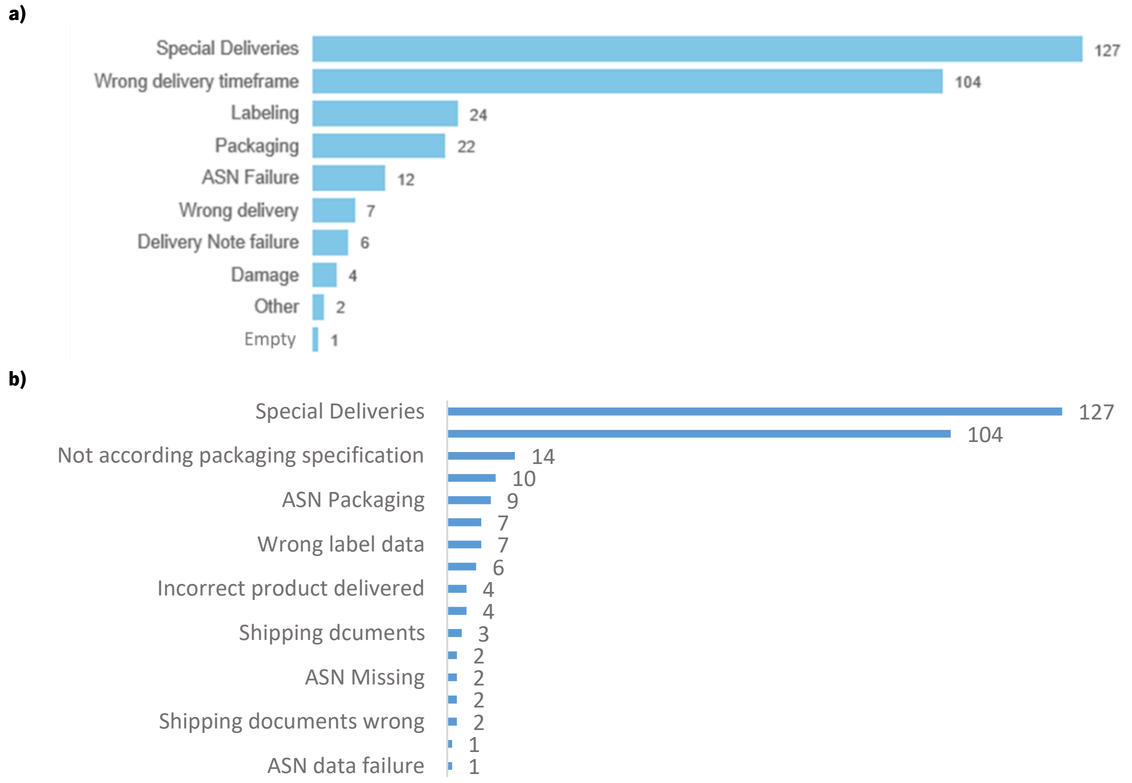


Figure 61 – Top failures a) per cluster 2019, b) per sub clustering 2019
(Bosch/BrgP LOI, 2021)

5.2.5.4 Customer fluctuations

Customer fluctuations was not a main KPI tracked by the company, however, they were analysed in order to understand the difficulty found out during the conducted research. For that, it was analysed in a weekly base customer's forecast, real orders, and company deliveries during a period of thirty-four weeks in 2019. Figure 62 represents the method used for the analysis. From calendar week (CW) nineteen to CW fifty-two, it was analysed the customer forecast's fluctuations related to the next months. The premise was considering product volumes, and not part number changing. Analysis was done for the overall company and for each value stream that allowed to find different conclusions. CC's value stream was very representative in relation of volumes and overall results were influenced by its volumes. As the analysis goes into a product level, the detail level would be higher.

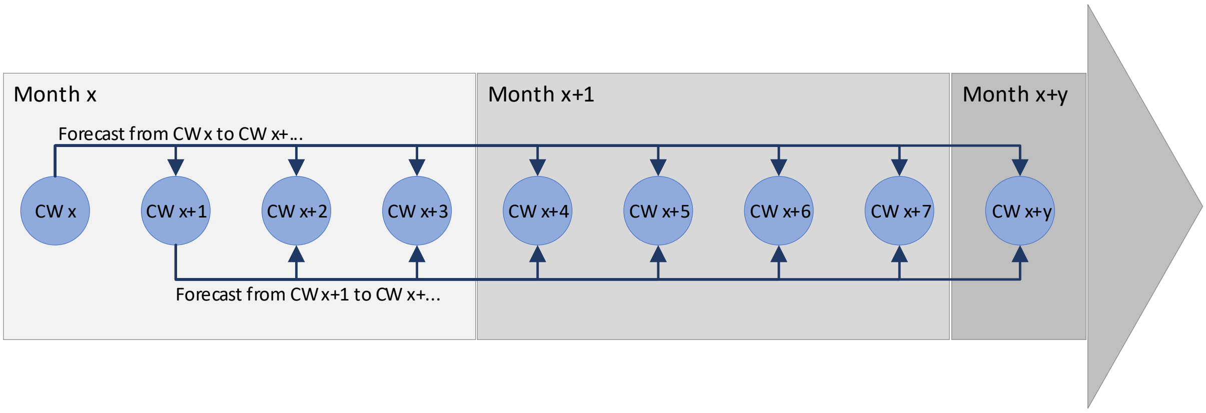


Figure 62 – Representation of analysis method for customer fluctuations

The long-term forecast analysis (Figure 63) shows that in the CI2's value stream, customers' fluctuation was huge, it varied from plus 81% and minus 35% during the given period.

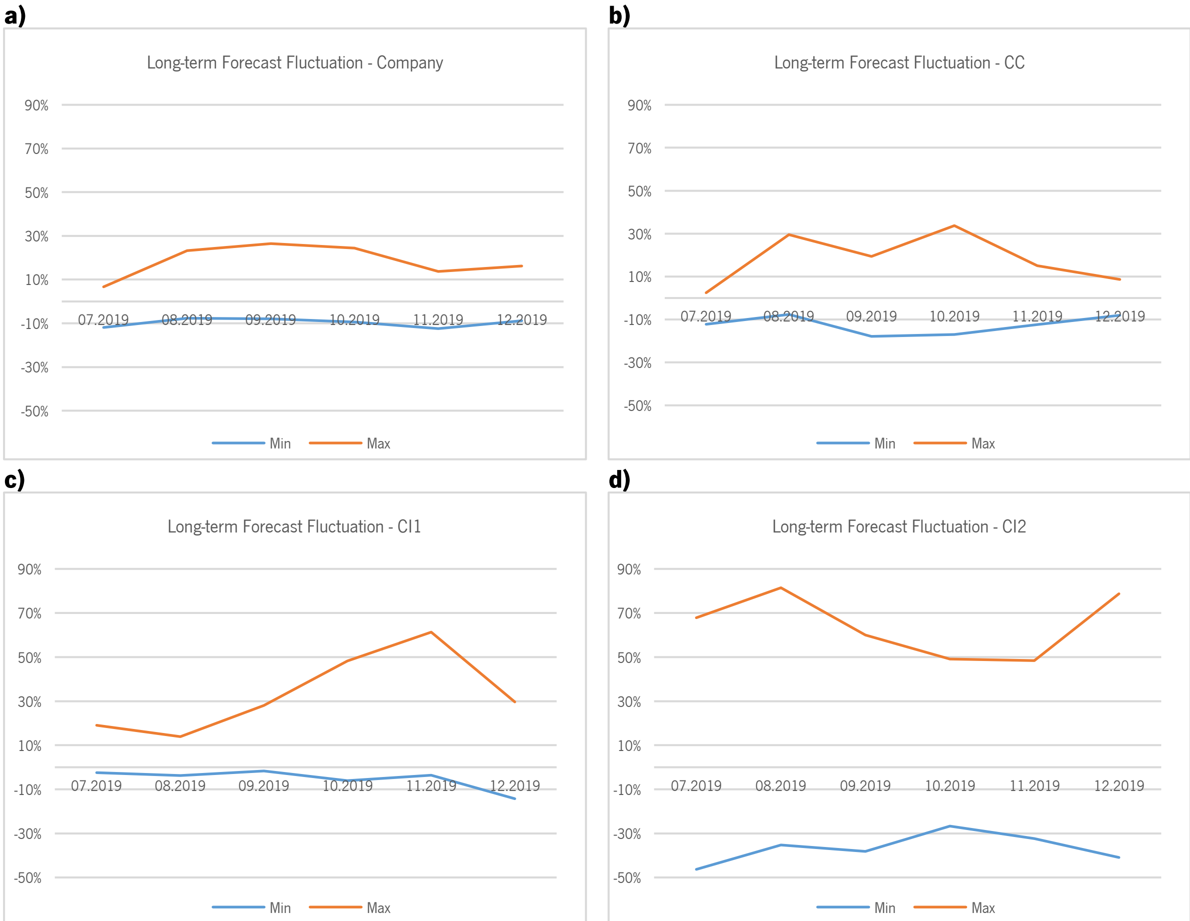


Figure 63 – Long-term forecast customer fluctuations a) overall company b) c) d) per value stream

This behaviour was constant during the year, which represented a huge instability for production planning. Looking only at the overall fluctuations in Figure 63 a), it is not possible to see this problem. In CC's value stream, customers' fluctuation varied from plus 34% and minus 18% during the given period. In the CI1, fluctuations were more evident on the upper limit after September that achieved levels around 62%. Lower limit was stable and within 10% range.

Since that customer flexibility contracts usually range from plus/ minus 10%, 15% or 20%, such fluctuation would have a big impact on the production planning also the orders fulfilment.

Another analysis was related to the fluctuations inside the same month in which orders were placed, the short-term period. Figure 64 shows that the fluctuation was smoother compared with long-term analysis, as expected. Overall company, the CI1 and CI2's value streams results showed that fluctuations vary between plus/ minus 5%. CC had a bigger increment in December that was also visible on the overall company. However, the CI2's behaviour was completely different. Fluctuations were bigger even inside of the same month.

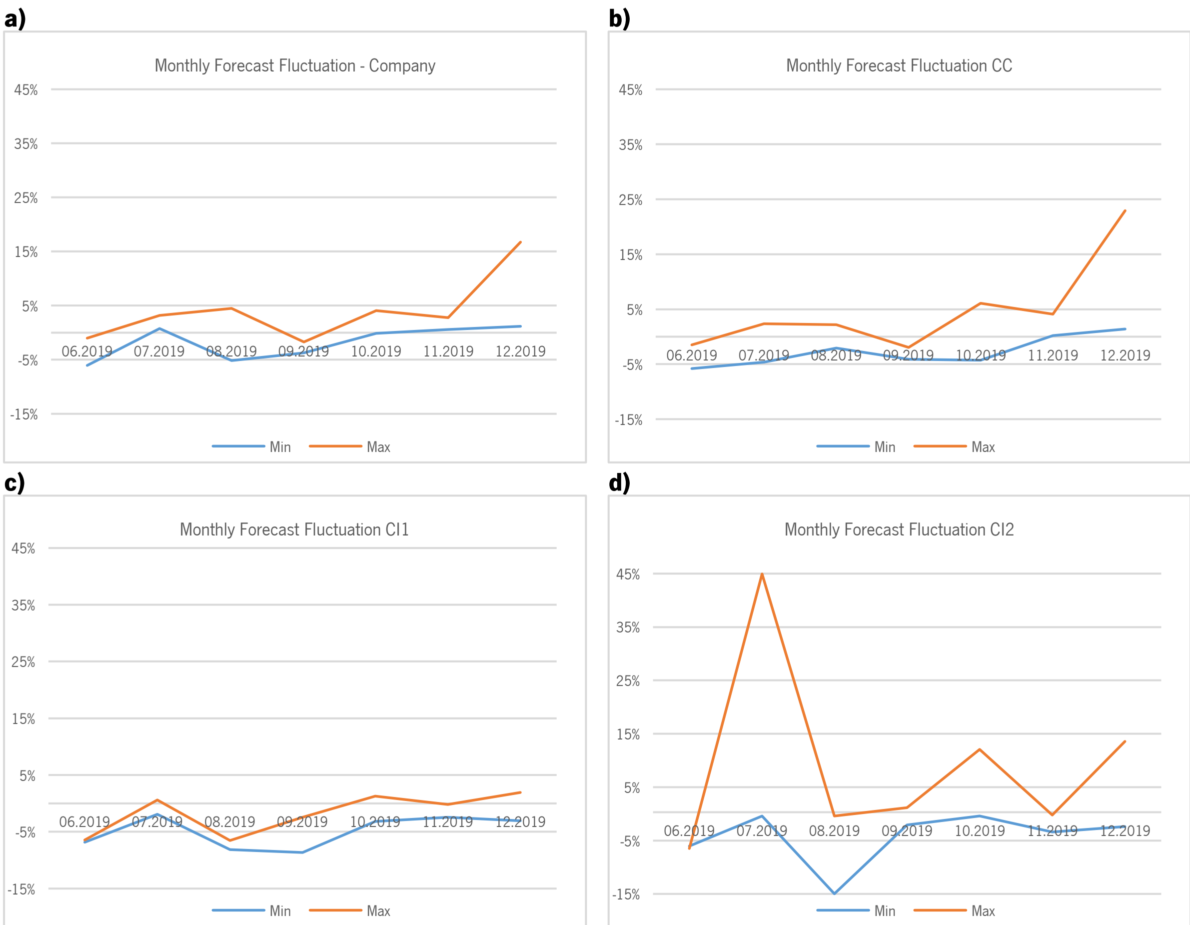


Figure 64 – Monthly forecast customer fluctuations a) overall company b) c) d) per value stream

The comparison between the real deliveries in each month with forecast from the last month and the current one was also analysed. Figure 65 shows that company delivered to customer, in the majority cases, less quantity than forecast of previous and current month, in the CC and CI1's value streams. In the CI2, there was some instability: in some months company delivers more than the forecast, in other months not. Instability showed in previous analysis (Figure 63 and Figure 64) might impact the result.

Figure 65 – Comparison between Deliveries and Forecast of last and current month a) overall company b) c) d) per value stream

Figure 66 shows a different analysis with the cumulative orders in backlog status from calendar week nineteen to calendar week fifty-two. Looking at the volumes, the CC's value stream was very representative. Calendar week fifty-five onwards, there was a huge quantity of backlog orders, such as 171 thousand units in calendar week fifty-five. This result was expectable because deliver was always below of forecast as Figure 64 shows. CI1's value stream had less backlog orders and were more stable compared with others in spite of having peaks after calendar week forty. This result was also related with smoother fluctuations that Figure 63 and Figure 64 show. CI2's value stream also accumulated backlog orders, having some peaks during the analysing period. Both value streams had a common behaviour: backlog orders increased in the end of the year. According to planners' responsible, after holidays period in August, it was always difficult to recover such delayed orders.

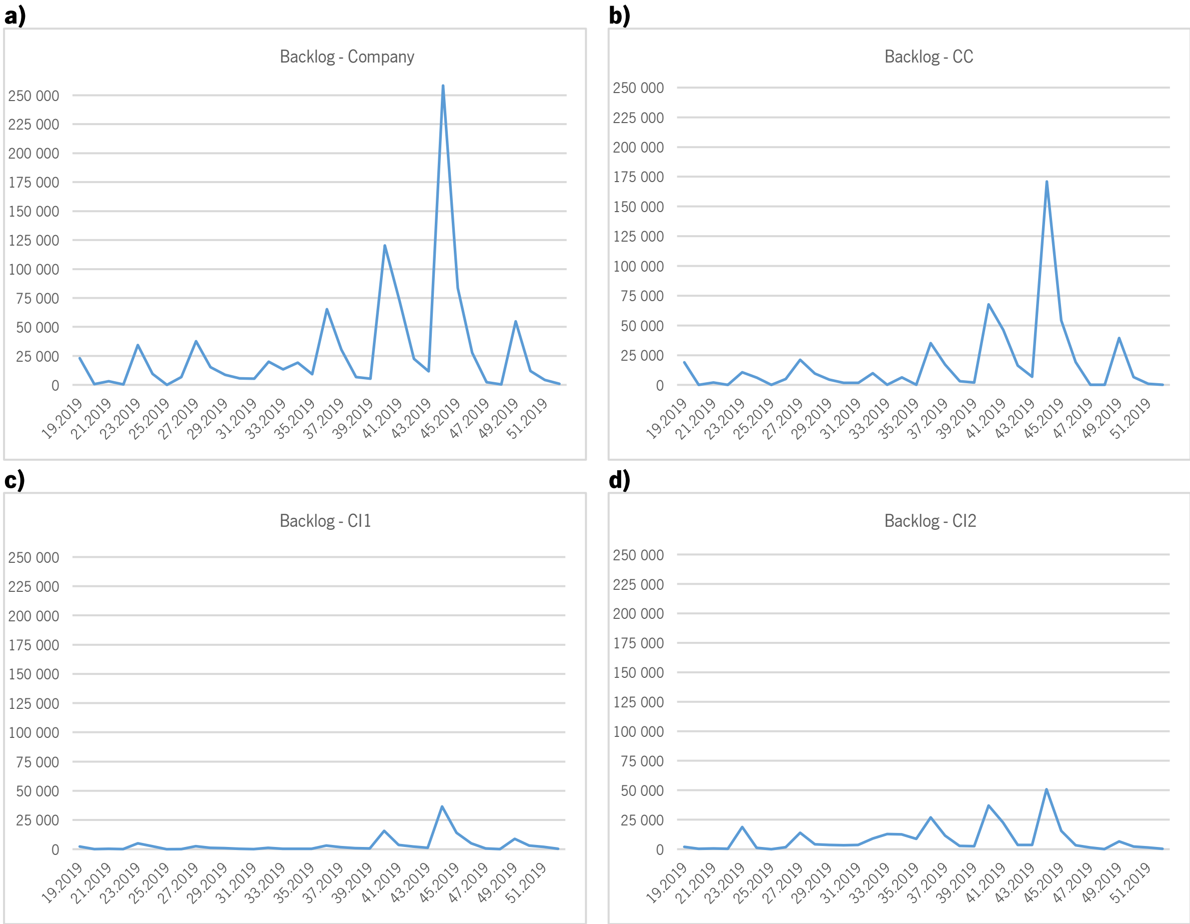


Figure 66 – Cumulative backlog a) overall company b) c) d) per value stream

5.2.5.5 Expedited transport and shipments

Expedited shipments were tracked every month. Figure 67 represents the results number of expedited shipments and the respective cost per value stream in 2019.

In total, about 1453 extra shipments were accounted that represented a value around 3 million euros. The most relevant was CI2's value stream considering the cost evaluation. In terms of number of expedited shipments, CI1 and CI2 were similar. CC's value stream was the least representative one. The results of this indicator showed some relation with the other indicators previously presented, such as customer's fluctuations, levelling performance, and OEE that strictly impact special freights.

Referring expedited transports from suppliers, the monthly results were not available. Many times, cost was negotiated with suppliers to check the responsibility of unplanned special transports. The negotiation could take some months or even years. The total cost of inbound expedited transports was around 1,17 million euros. In summary, company spent 4,17 million euros in special transports in 2019.

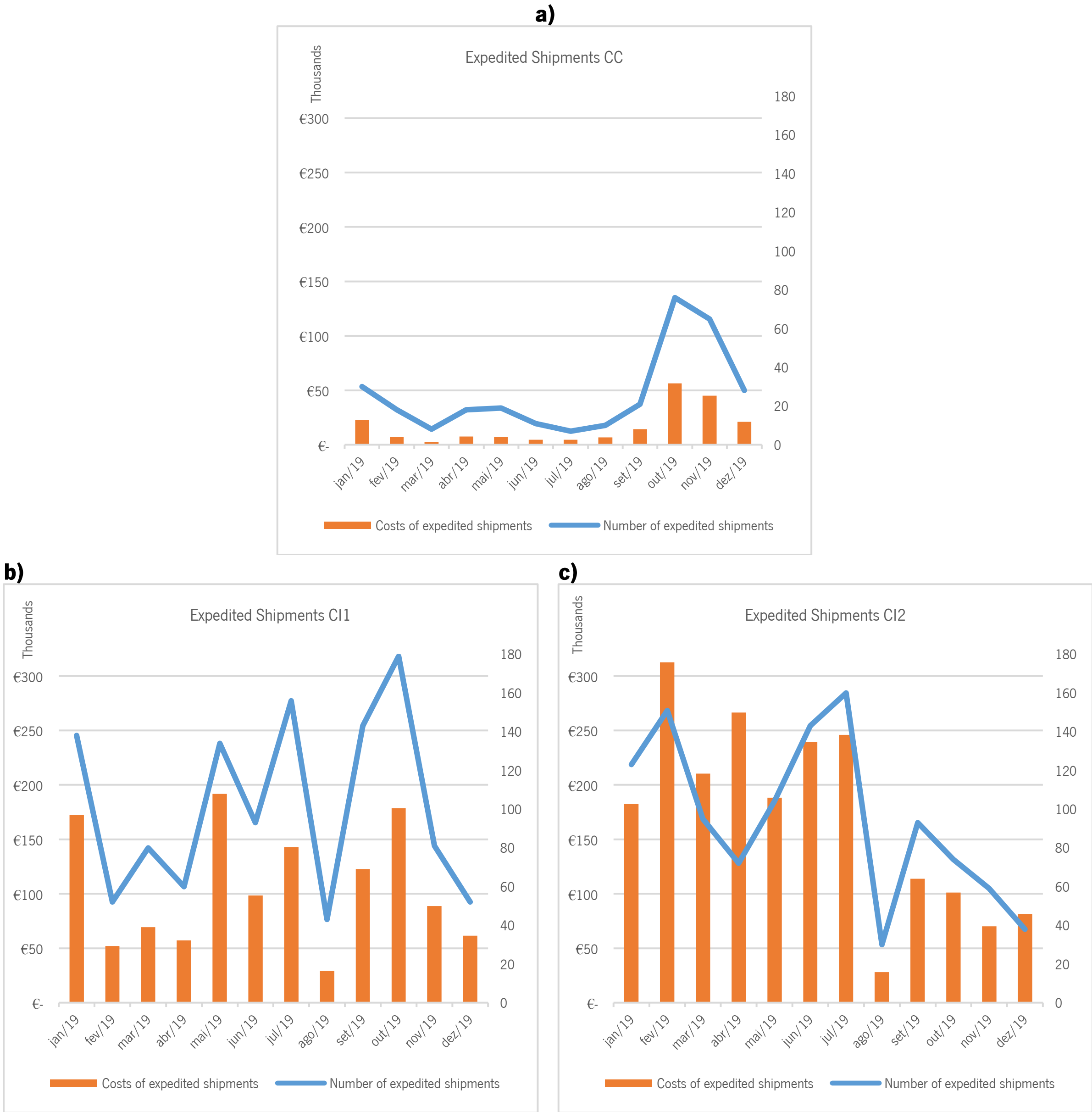


Figure 67 – Costs and number of expedited shipments a), b) c) per value stream

5.2.5.6 Process Throughput Time

Process Throughput Time was not a monthly tracked indicator. During the value stream mapping of each value stream, it was usually calculated and visible in the VSM as mentioned in 5.2.1. However, it was not monitoring with high focus. The calculation behind was manual and not very rigorous because there were not enough digital solutions for WIP management. There were also some difficulties to get data from some processes since most of the processes worked with push principles, so inventory was fluctuating over the processes and time.

This indicator is strictly related with flow of Lean Thinking third principle, which make value-adding and non-value-adding activities visible. With that, those bottlenecks should be eliminated in order to have higher flexibility for customer requirements, complying also with pull principle.

5.3 Interviews Analysis

In this section are presented the results of the interview's analysis, whose procedure was described in section 5.2.2.3. Seventeen semi-structured interviews were performed with three different groups (operational, value stream manager, and manager) that interfere in the pull implementation. Besides pull system analysis, other topics were evaluated since other elements might interfere on the implementation. Therefore, seven main subjects: 1) Lean production, 2) pull system, 3) continuous improvement, 4) training, 5) Employees' involvement on continuous improvement, 6) organisational structure and 7) plant strategy, defined in section 3.2.2, are analysed in the next sections. The interview guideline is presented in Appendix 2.

The interviews were transcribed, codified, and analysed using pareto principle, as referred in section 3.2.3. In the topics 1) Lean production, 2) pull system and 3) continuous improvement, the analysis was also done based on results categorization. In section 3.2.3, it was explained the whole methodology used.

The main results of the interviews were published in a paper for a conference (Araújo et al., 2021) and in the company during project's status presentation in 2020.

5.3.1 Main difficulties of Lean Production implementation

One of the subjects approached on the interview was the difficulties and challenges of Lean production implementation. Results are presented on Figure 68. Like the following sections it is presented an overview concerning general main difficulties of Lean production implementation that belongs to people, organizational, and leadership category, and then split by category.

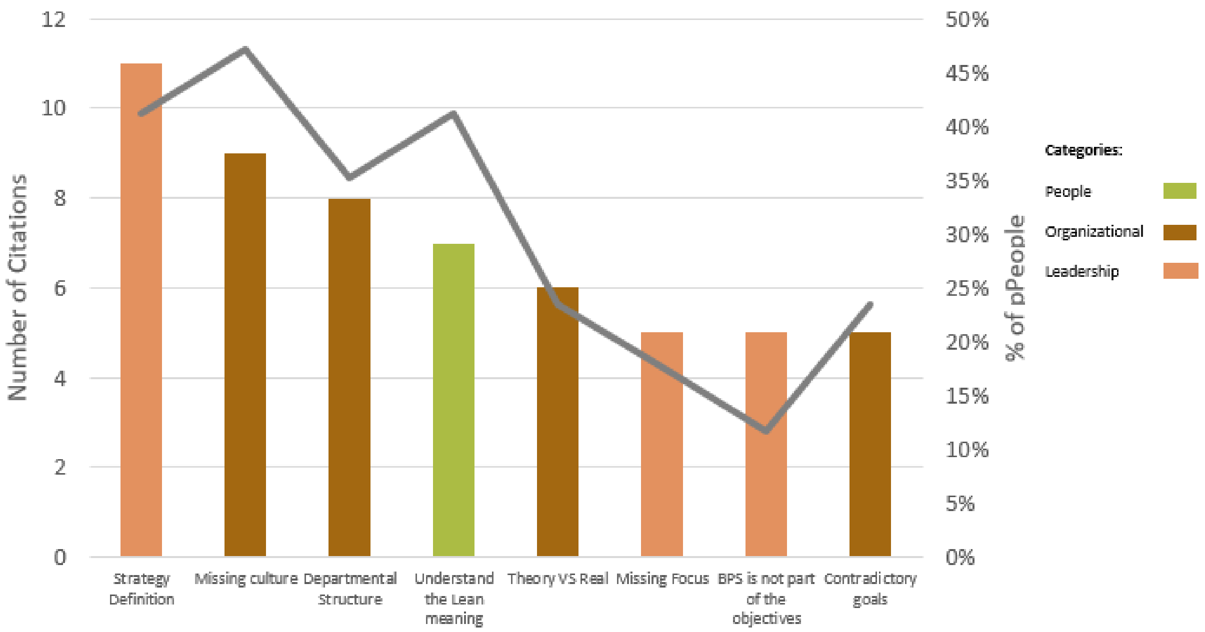


Figure 68 – Main difficulties of Lean Production Implementation

One of the difficulties pointed was related with Lean production definition. Everyone should have knowledge about Lean meaning, and the really meaning of a Lean company. In fact, Pettersen (2009), Cowger (2016), and Schonberger (2019) mention there is no clear and concise Lean definition. This might lead to a lack of communication, and different goals lead to misunderstanding among practitioners. Existent research (Achanga et al., 2006; Lodgaard et al., 2016; Netland, 2016) shows the importance of knowledge of managers and practitioners on the successful Lean implementation .

On leadership category, strategy definition was the main difficult referred. It missed a clear strategy defined followed by every department. Forty-one percent of the interviewees in this study said there was no clear strategy defined by the top management. According to Achanga et al., (2006), company strategy should be clearly defined by managers. This factor is one of the factors that contribute for a successful Lean implementation. At that moment, each department tried to achieve its own objectives independently of the global company strategy. Different departments belonged to different plant managers and followed their guidelines. It was also mentioned that some areas are more focused on continuous improvement than others, and that is the reason for having better results and development. So, people were focused on the activities and were working on that. This reason is connected with next one: continuous improvement process was not part of the objectives of the most people. Lodgaard et al. (2016) also reported in their research that lack of defined roles and responsibilities for Lean is a barrier for Lean implementation. Authors also noted that workers thought that "*lean was not part of their job*".

Many interviewees referred that missed a Lean culture. Everyone in the company should live that culture and improve continuously. However, only some of them understood and tried to push those topics. As Dorval et al. (2019) mention, Lean culture "*remains very superficial"* on the literature review and there is still some ambiguity. However, as mentioned in section 2.2.3, the organizational culture represents an important factor in the Lean process implementation (Achanga et al., 2006; Erthal & Marques, 2018; Lodgaard et al., 2016; Yadav et al., 2017).

The departmental structure was also pointed as a barrier to implement. This point is related organizational structure. Each department worked individually without a holistic overview and due to that, it was difficult to implement some tools and procedures. Additionally, sometimes these departments were working for contradictory goals and the difficulty was much higher. Cox and Clark (1984) refer that most of organizations have conflicts of objectives between different functional areas.

Last difficulty is related with difficulty of implementing theoretical concepts on the company reality. Sometimes it was not possible, or it is difficult to apply every Lean principle according to the literature.

Related with difficulty pointed out by the interviewees, Takeuchi et al., (2008) referred that each company should adapt practices to the company culture, copy practices is not the right approach.

On the category analysis, there are two additional categories such as technical issues concerning technical problems and project creation.

It was also mentioned as a difficulty of Lean implementation, the processes and equipment instability that results lower levels of efficiency. There were some difficulties on the development and implementation of continuous improvement projects. Furthermore, it missed cause-effect relation in the project creation because sometimes results did not bring benefits or at least the expected ones. Additionally, on the people category, it was mentioned there was lack of knowledge about Lean and it was much more difficult when company is larger.

Table 26 – Main Difficulties of Lean Production Implementation per category

Leadership	People	Organizational	Technical Issues	Project Creation
Strategy Definition	Understand the Lean meaning	Missing culture	Instable Processes	Continuous improvement projects creation
	Missing Knowledge	Departmental Structure		Missing cause-effect relation
		Theory VS Real		

5.3.2 Main difficulties of pull system implementation

One of the main subjects of the interview was related with production control system focused on pull principle implementation. Pull systems implementation has been one of the company objectives in the last years. However, company has facing some difficulties in this process. Figure 69 shows main difficulties mentioned by the interviewees. Sixteen reasons from different categories such as People, organizational, leadership, technical issues and external were mentioned.

Concerning people, lack of knowledge to apply the concept was a unanimous reason for the interviewees. Consequently, people did not understand the real benefits of pull implementation due to lack of enough knowledge. Since pull system is one Lean principle, this finding has already referred as a barrier to implement Lean, so it is a common difficulty on the implementation.

Departmental structure was also mentioned as a barrier for the implementation because it interferes in several departments with different objectives and focus. This is in line with Womack and Jones (1994) research that argue that functional organizational structure may create some misalignment between function goals and organizational goals. Pull system implementation depends on holistic overview and it cannot be compared with other tools. Those tools might be implemented individually such as 5S, and Total Productive Maintenance (TPM) for instance. So, there was a need to change paradigm related to productivity, planning methods, and people mindset. And concerning paradigms, the next one:

"*production lines must not stop*", was also identified in Bosch production culture. With pull system approach, it will only be produced production needed, and then lines might stop. This approach was still not well accepted because line equipment was very expensive and should be used as much as possible. Furthermore, operators' productivity was also a concern. So, the main concern was still related with equipment and operators that cannot stop, even producing what was not required. This is the first waste overproduction described in section 2.1.2 that causes other kind of wastes.

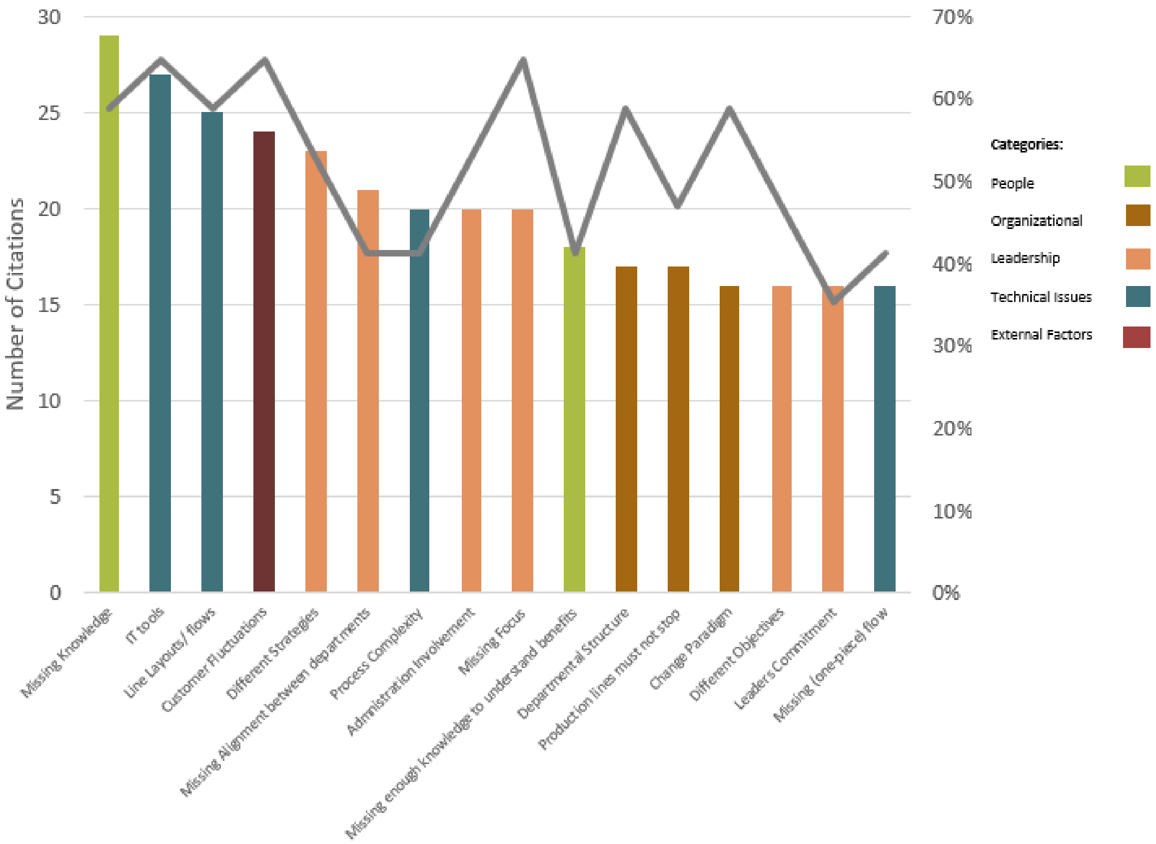


Figure 69 – Main difficulties of pull system Implementation

In this analysis arises a new category: external factors whose main problem reported was customer's fluctuations. Interviewees mentioned some customers had a lot of fluctuations and instable orders. Therefore, it became difficult to have levelled plans. These difficulties were also mentioned in other studies as having negative impact on levelled production plans (Soliman & Saurin, 2020). Having levelled plans allows one-piece flow production, the third Lean principle that is closely related with low work-in-process levels and higher flexibility (Schonberger, 2019). Implementing levelling offers benefits such as more flexibility to the customer demand, attention to controlled inventories, balanced workload of the operators and machines, achieving process stability, and smoothed demand effect of levelling, already described in section 2.4.2 (Liker, 2004). The variability of customer orders is a known problem reported in other studies that directly impact production control systems, namely pull that leads to daily adjustments in the production plan, urgencies management, and resources. That issues put in risk the supermarkets performance, stabilization of standards, and levelled production plans, as well as the quality levels of the products (Soliman & Saurin, 2020). This problem was also reported by operational team in section 5.2.2.4, and in the literature review in section 2.4.4 as well.

Schonberger (2019) also presents problems related with effect of out of synchronism between production/ upstream processes, and the high variability of demand that might cause by on hand back orders, by another hand leftovers. Krajewski et al. (1987) performed a study to evaluate factors that impact manufacturing performance using MRP and kanban system. Authors found that customer forecast variation impacts inventory levels and customer service, when the forecast's uncertainty is in weekly basis. The inflexibility and rigidity of Lean production schedules has been criticized in some studies (Christopher, 2000; Mason-Jones et al., 2000; Naylor et al., 1999), a reason for Mason-Jones et al. (2000) and Towill and Christopher (2002) suggest an integration between Lean and agile looking at the supply chain management.

On leadership, it was mentioned again problems related with strategy, there were different strategies for the same company, and strategy changes frequently. Different strategies led to lack of alignment between departments, each one was working individually and not for a common goal. Therefore, different objectives between departments, most of them contradictory, was a problematic point because pull system involves a team from different areas. As observed in section 5.2.2.3, the complexity of the organizational structure that impacts PCS was huge.

Additionally, it was mentioned that administration involvement was fundamental for pull implementation, without administration involvement was not possible to implement. The fact of having two administrators might bring some difficulties for instance. Some research (Achanga et al., 2006; Amaro et al., 2020a; Cowger, 2016; Lodgaard et al., 2016; Schonberger, 2019) show the importance of administrators believe in Lean fundamentals and are committed with its implementation, as mentioned before in section 5.2.3.2.

When a new tool / procedure is developed or implemented, it requires hard work, available time to work on it, focus from management. In pull implementation missed focus from the organization and leader's commitment. Their involvement and support are important to take decisions and overcome difficulties.

Related to technical topics, it missed a production control IT tool that supports implementation because it was almost impossible to manage all processes manually due to the huge quantity of existent product references. The difficulty of handling a manual kanban system was also reported by Kim (1985). Another barrier for the implementation was the company physical structure: plant layout was not oriented to the flow. There were many production pools and pre-assemblies that did not favour Lean approach because those pre-assemblies created intermediate stocks that are a barrier for one-piece flow. Sometimes those pools were not closed to the final assembly lines, so further transport were required. This problem can be observed in the VSM described in section 5.2.1. Deleersnyder et al. (1989) identified the lines flow as a main problem to implement pull, and functional layouts should be converted in flow lines operating with product families (Sepheri, 1986). Additionally, many complex and instable processes limited the implementation because they were not flexible enough to react easily to the customer fluctuations.

On category analysis (Table 27) there is no significant differences. It was not considered some reasons in leadership and technical topics when compared with general overview.

Table 27 – Main Difficulties of pull system Implementation per category

Leadership	**People**	**Organizational**	**Technical Issues**	**External factors**
Different Strategies	Missing Knowledge	Departmental Structure	IT tools	Customer Fluctuations
Missing Alignment between departments	Missing enough knowledge to understand benefits	Production lines must not stop	Line Layouts/ flows	
		Change Paradigm	Process Complexity	
			Missing one-piece flow	

Eighty-three percentage of the operational team stated they did not have previous experience in pull system projects or related ones, so it was the first time they had contact with pull system in the industry. Therefore, people that was involved with that kind of projects demonstrated lack of knowledge when started working on it. Besides lack of knowledge, they also mentioned lack of experience. In section 5.1.2 it is demonstrated that levels of training were lower, and many people did not have the enough training related to this topic. In section 5.2.2.4, it also mentioned that problem. As previously mentioned in section 2.2.2, knowledge and training are a powerful boost for Lean implementation.

According to these results, there are the common causes for Lean Production and pull system implementation is not working. Those causes are related to Leadership category concerning strategy definition and lack of focus on the topic, lack of knowledge about Lean Production and pull system in People category, and the departmental/ functional structure concerning organizational category. In Table 28 is presented a summary. However, there is no relation between continuous improvement process failures.

Table 28 – Difficulties of Lean Production and pull system Implementation (common causes)

Leadership	**People**	**Organizational**
Strategy Definition	Understand the Lean meaning	Departmental Structure
Missing Focus	Missing Knowledge	
	Missing enough knowledge to understand benefits	

In terms of strategy defined for pull system implementation, there are a big dispersion of results data. Different people mentioned different strategy measures, so it was not possible to conclude which was the strategy. Maybe this result has some relation with following description about main difficulties of pull system strategy stated by interviewees and their level of knowledge about strategy. This result also demonstrates communication problems on the strategy deployment.

Interviewees also mentioned there was no clear strategy to implement pull system and that was the main difficulty. It can also be confirmed on Figure 70 where only 29% of interviewees knew the objective of next year, 43% had doubts, and 29% did not answer the question.

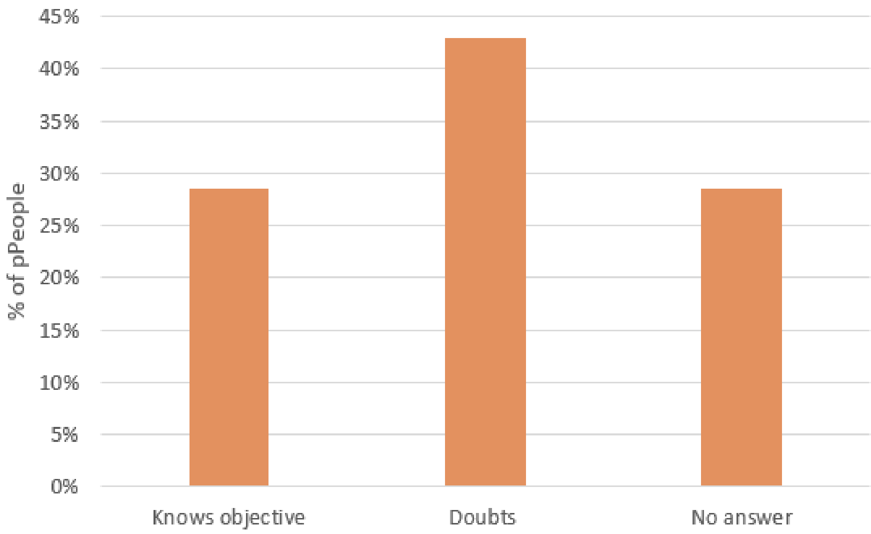


Figure 70 – Objective to achieve pull system

5.3.3 Main reasons for continuous improvement process fail

In section 5.1.1, it was presented continuous improvement projects results since 2016 until May 2019. The results show there was a problem on this process due to the percentage of closed projects. In 2016, only 24,5% of the projects were closed, 28% in 2017, and 20,7% in 2018. Those projects involved resources and time consuming. However, projects had a lower success rate. There was no positive trend over the evaluated three years. Additionally, the fact of this results was not available, means that closed projects were not tracked, and company did not follow this indicator.

According to the interviewee's answers related to the reasons for continuous improvement projects having a lower level of implementation, the main reasons are presented in Figure 71. From this evaluation resulted four categories such as leadership, people, organizational and project creation. Reasons presented in Figure 71 belong to three categories: people, continuous improvement project creation, and leadership. Firstly, it is going to be presented the general analysis and then the evaluation by category, similar to the previous sections.

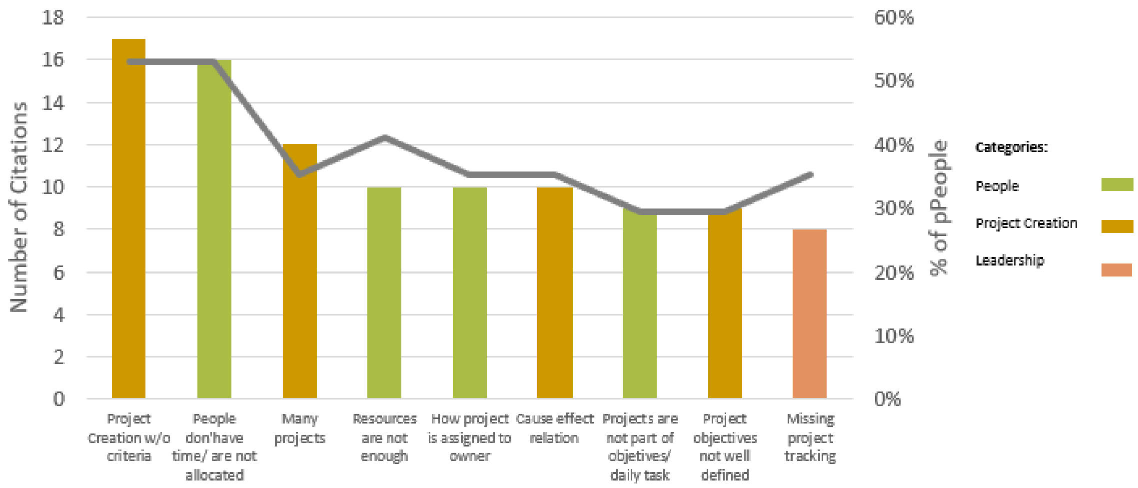


Figure 71 – Main Reasons for continuous improvement fail

People allocated to the projects did not have availability to develop it because their workload did not include that kind of projects. So, if continuous improvement projects were not part of people objectives, projects would not be the focus. This is in line with Lodgaard et al.(2016) research that mentioned that roles and responsibilities not clearly defined are barriers to Lean implementation.

Another problem was related with project assignment criteria to the project owner. Sometimes, it was not involved the right person in the project, and people did not understand very well project purpose, consequently people got demotivated. In section 5.1.5, survey shows that topics related with task and goals were the ones with worst evaluation. Lack of motivation is also mentioned as a barrier in other studies because involvement of workers on continuous improvement is a key factor for its sustainability (Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016; Vicente et al., 2015). The following reason is also connected with previous one. The resources with knowledge to develop such projects were not enough, as observed in section 5.1.2 that shows lower level of training. In fact, like in many other activities, it is also necessary to have available resources for continuous improvement and this problem also represents a barriers (Garcia-Sabater & Marin-Garcia, 2011).

Interviewees mentioned that some continuous improvement projects were created without criteria because objectives and indicators to improve were not well defined. This reason was the most cited reason for continuous improvement process fail that belongs to project creation category. Connected with the previous reason is the missing of cause effect relation during the project creation. Sometimes it was not possible to measure the results' impact because project KPI tree was not well defined although having central guidelines (Robert Bosch GmbH, 2018c). Another reason pointed was related to the quantity of project created and capacity to develop it because as observed in section 5.2.3, every year there are many projects. Related to necessity of measuring continuous improvement programmes, there are some findings point out by some authors (Garcia-Sabater & Marin-Garcia, 2011; Netland et al., 2020). The effect and quality of continuous improvement should be visible into financial indicators since operational indicators have been improved. However, not all improvements need financial methods. For instance, shop floor improvements or other minor improvements may use qualitative methods that encourage workers to participate in continuous improvements (Garcia-Sabater & Marin-Garcia, 2011; Netland et al., 2020).

On the leadership category, it was mentioned that missed project tracking, monitoring and team support from managers' side. And the management commitment and involvement is fundamental for continuous improvement activities (Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2020).

For the analysis, it was evaluated the results split by categories (Table 29) as mentioned previously in order to have an overview by subject. The leadership category was also included missing focus from managers on the project conclusion and missing time to coach project team in order to support and motivate them to understand project scope and conclude it with success.

Table 29 – Main reasons for continuous improvement fail per category

Leadership	**People**	**Organizational**	**Project Creation**
Missing project tracking	People do not have time/ are not allocated	Missing planning Strategies	Project Creation without criteria
Missing Focus	Resources are not enough	Missing resources management per VS	Many projects
Missing Time for coaching	The way how project is assigned to owner	Dependency between departments	

Related to people and project creation categories, reasons are the same as the general overview as can be seen in Figure 71.

In the organizational category, three main reasons were pointed such as lack of planning strategies. Meaning that there was a tendency to spend less time on the planning phase than on execution, and it should be the opposite. The planning strategies also included the project team selection and resources management.

Lack of resources management was also an organizational problem on this category. Value stream managers, which were responsible for their value stream continuous improvement projects, could not manage resources working on their projects. Due to that they could not change or influence individual objectives of the team and their availability for the project.

Another problem mentioned was the dependency between departments when a project depends on different ones. Therefore, it was more difficult to conclude projects whose project team belonged to different departments that had different objectives from each other. This problem is related with organizational structure mentioned in section 5.3.1. This difficulty was also mentioned by Garcia-Sabater & Marin-Garcia (2011) that confirm in their research the importance of having a person dedicated to continuous improvement who coordinates and lead the activities. This person manages required resources, and coaches teams. For that, this person should have enough empowerment. This point will be detailed discussed in section 5.3.5.

5.3.4 Impact of training on Lean Company

In section 5.1.2, it is presented the percentage of people trained in Lean concepts such as basic ones, and the ones related with PCS, mainly pull systems. In general, the training result shows that most of employees were not trained in Lean and pull, mainly the PCS's key players were not trained in "Pull & Levelling" and "Lean Logistic Basics".

Part of the interview approached training topic since training rate in BPS subject was around 30% at that time, meaning a lower level of training. Each interviewee stated there was a strategy to improve this result and the measures to achieve better result can be visualized in Figure 72.

In relation of having relation between those training results and continuous improvement project results, 50% of interviewees mentioned there was no relation proved between both results. Anyway, 50% of interviewees stated there was project owners assigned to those projects without training. One of the reasons mentioned in section 5.3.3, as the main reason of continuous improvement process fail, was the way that the project was assigned to the project owner.

Furthermore, when questioning about the existence of qualification matrix, 100% of the interviewees stated there was no qualification matrix for indirect people. Training and knowledge were the most mentioned root cause for Lean production, pull system and continuous improvement implementation difficulties. 30% of people trained in this subject was not being enough. This difficulty is in line with many researches (Amaro et al., 2020a; Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016) that point out education and training as an enabler to select the right tools and practices. Knowing the right tools allows to make decisions. The importance of training is also applicable for managers (Achanga et al., 2006; Lodgaard et al., 2016).

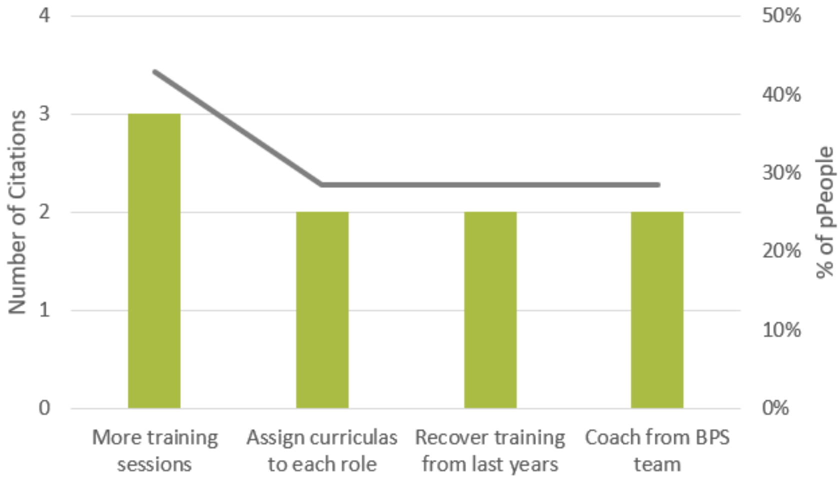


Figure 72 – Strategy to improve training results

During some years, BPS team was extinct, which was already explained in section 5.1.2. Due to that many trainings were not performed. As strategy for 2019, it was defined to recover the last years without BPS trainings. This strategy considered the increase of training sessions in order to have as much as possible trained people with knowledge. Additionally, there was an intention that BPS team coach people in BPS tools.

Furthermore, it was planned to assign existent curricula to each role in the company. The curricula are defined by central human resources department in order to standardize roles and trainings assigned to each role.

Anyway, most of the interviewed managers recognized that training is fundamental for people understanding some requests, to promote continuous improvement, and for employees' involvement. However, it was mentioned some general problems (Figure 73) related to trainings. The high absenteeism rate on the sessions, and resources constraints did not allow that employees attend to the trainings.

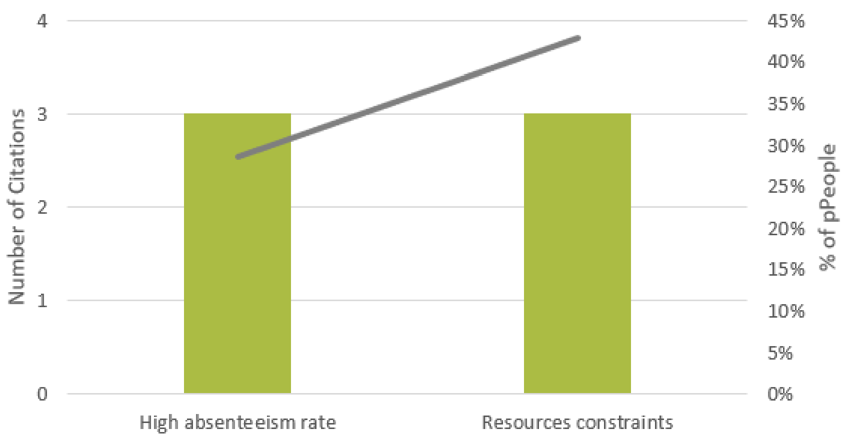


Figure 73 – General problems regarding training sessions

5.3.5 Employees Involvement on Continuous improvement

Related to the employees' involvement on continuous improvement, it was consensual that suggestion boxes' planning was the company strategy for employees' involvement. At the end of 2019, company restarted the program after some years on hold. During the interviews, it was clear that suggestions program would be restarted as a plant strategy. According to Lodgaard et al. (2020), management level is one of the levels involved on activities of continuous improvement by strategy definition.

Although being a defined strategy to implement, there was a kind of scepticism due to the previous experience. Furthermore, there were also concerns such as resources constraints to implement suggestions (Figure 74).

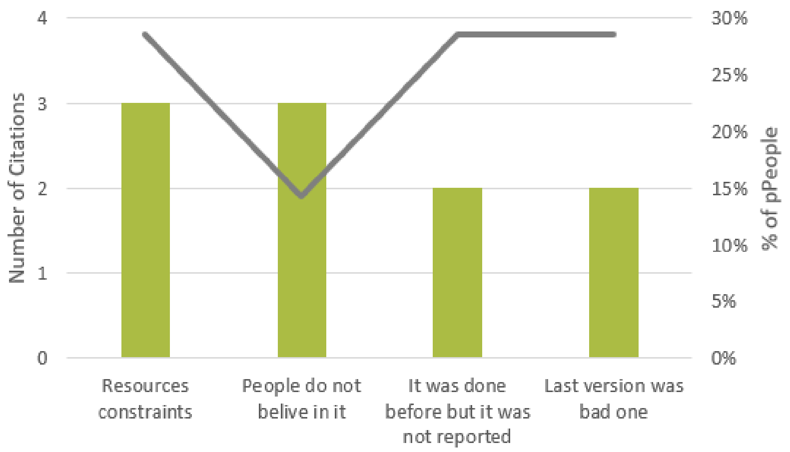


Figure 74 – Concerns related to suggestion boxes

This factor is referred by Lodgaard et al. (2020) and Garcia-Sabater and Marin-Garcia (2011). The resources' availability for continuous improvement activities, and the people's involvement is an important factor for a successful implementation. Additionally, improvements on shop floor using only qualitative methods motivate and encourage employees to arise small improvements (Netland et al., 2020).

In Figure 74, it can be visualized other concerns related suggestion boxes that were directly linked with bad results from the past. In section 5.1.3, it is possible to observe that the most recent results were not also positive, there were still many rejected suggestions. Some interviewees mentioned that operator's suggestions were already implemented before without this systematic method. As such, results showed lack of systematic on suggestion program. Monden (1998) presents suggestion system and Quality Control circle systematics. Both systems were well structured. Those systems are seen as serious activity for the company, emphasizing the importance of trust and credibility relationship between employees and leaders. The suggestion system also considers improvements related with kanban system, which means improvements on inventory level. So, it also shows the relationship between PCS and continuous improvement.

5.3.6 Impact of organizational structure on continuous improvement process

During interview some organizational topics were approached mainly value stream manager whose role was very important on continuous improvement projects. Value stream manager was responsible for this kind of projects in him/ her value stream.

Value Stream Manager only influenced the area who belonged to. This was the main problem reported. Therefore, value stream manager belonged to the production area, he or she did not influence logistics area because it was a different department. So, continuous improvement was not done in a holistic way because value stream manager could not interfere in different areas and did not have enough empowerment to take some decisions (Table 30).

Table 30 – Value stream manager role on the organization

	Value Stream Manager role impact on continuous improvement process		**Impact of departmental structure and Value Stream Manager role**	**Value Stream organization**
	Value Stream Manager influences area that belongs to	Missing empowerment	Value Stream Manager and hierarchical level on the organization	Value Stream organization vs Organization Reality
% of People	82%	64%	33%	50%

The described problem is connected with departmental structure. Value stream manager did not have a hierarchical position on the organization that allowed him/ her to take decisions because he/ she was a section manager, under the departmental managers. As it was resented in section 5.2.2.3, value stream manager did not even impact PCS. Garcia-Sabater and Marin-Garcia (2011) talk about a person dedicated and responsible for continuous improvement called "*continuous improvement manager*" and authors also found similar results. The continuous improvement manager should have a hierarchical position that only depends on the plant manager in order to be independent from other departments. This person should be only focused on continuous improvement, otherwise other tasks will consume most of the time.

Fifty-six percent of the interviewees said that departmental structure was a barrier for Value Stream Manager involvement on continuous improvement process. Related to value stream organization, 50% of interviewees recognized that value stream manager role was not according to the theoretical value stream organization, and due to that, there was some difficulties on the function execution. In fact, according to Mascitelli (2007) value stream organization does not match with presented organization.

The Value Stream Manager accumulated other functions such as production section manager similar to other colleagues, so its main role was not continuous improvement. This person depends on its functional manager that also depends on technical plant manager, as Figure 46 in section 5.2.2.3 shows. Additionally, being a production section manager from MOE1 or MOE2 was more difficult to affect logistics areas since that logistics belonged to commercial area, which was managed by commercial plant manager. Value Stream Manager belonged to technical area, which was managed by technical plant manager. This might be one the reasons for 82% of interviewees mentioned that Value Stream Manager only influenced the area that belongs to. In fact, the functional structure influenced him/ her activities. Logistics belonged to a different plant manager. However, Value Stream Manager would intervene in those areas, which also represented a difficulty. So, having two plant managers influencing on Lean and pull system implementation may be a barrier on its implementation. However, this topic came also from executive management in the which was also split between technical, and commercial and financial areas. According to Garcia-Sabater and Marin-Garcia (2011), if Value Stream Manager does not only depends of the plant manager, its tasks can be disabled by other departments due to missing position on the hierarchy. This issue was visible in this case study.

5.3.7 Plant strategy

One of the company strategy topics in 2019 was to become a benchmark company in Lean. In order to understand plant strategy to achieve this objective, this topic was part of the questioning. Similar to pull system implementation strategy analysed on section 5.3.2, results revealed a big dispersion in terms of data. Due to that it was not possible to conclude which was the strategy to become a benchmark Lean company. Different managers answered different perspectives that revealed some indefiniteness on the strategy, also lack of communication on the deployment process.

This result was directly connected with difficulties related with strategy definition on Lean implementation mentioned by 41% of the interviewees on section 5.3.1. It also can be concluded the strategy did not cover the main problems found. As mentioned before, the vision and company strategy should be clear from management. Management's support and commitment was one of the main Lean enablers (Achanga et al., 2006; Amaro et al., 2020a; Lodgaard et al., 2016, 2020).

Additionally, when interviewed managers were questioned if BPS results were part of their objectives, 86% (Figure 75) said yes. Nevertheless, 14% of the interviewees that influenced on the plant decisions mentioned that BPS was not relevant for their objectives.

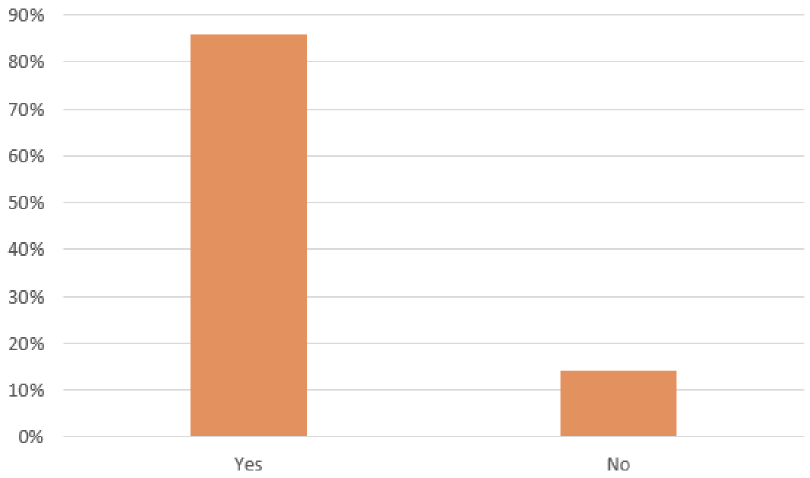


Figure 75 – Percentage of managers having BPS as objective

When operational teams were interrogated about their knowledge related to plant strategy to become a Benchmarking Lean company, 57% (Figure 76) of them said that they knew the strategy and they were involved in some projects related to production control, 5S, flow optimization project, and others in indirect areas. Those results were interesting. On the managers level, plant strategy results were not conclusive, and there was no pattern looking at the answers, but on the operational levels seemed to have according to the Figure 76.

During the interview process, Lean Wave methodology explained in section 4.7 has not been implemented. Therefore, it was not part of the strategy. The methodology might minimize some of those described problems.

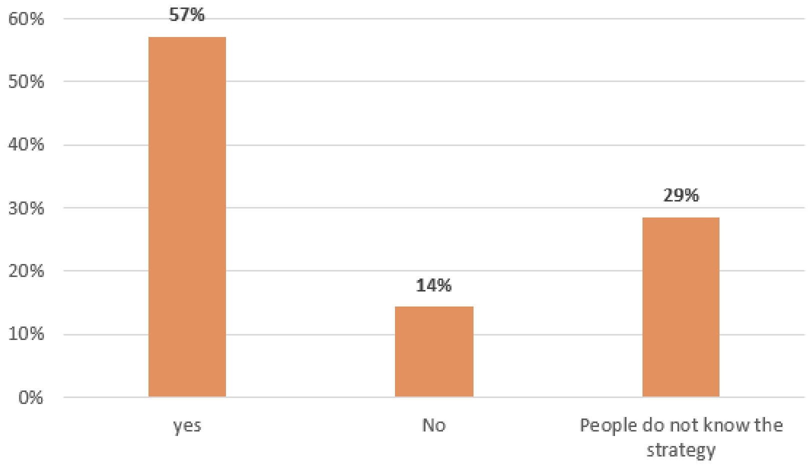


Figure 76 – Percentage of operational people knows plant strategy as a Benchmarking Lean company

5.4 Synthesis of the identified problems

In the light of the analysis, several barriers of Lean and pull implementation on the case study were identified. The company of the case study had already implemented some Lean tools such as 5S, TPM, standardized work, and many others. The continuous improvement methodology and procedures were also known and implemented. Company has a huge dimension, and Lean theoretical fundamentals well developed and deployed by central departments. However, the analysis demonstrated some fragilities regarding Lean implementation consistency, mainly on pull system implementation.

First evidence that something was not working according to Lean culture was the continuous improvement project results. Those results showed low percentage of success for several running years. Besides continuous improvement project's results, other source of information described such as Value Stream Mapping, Lean training results, the PCS implemented in the company, the organizational structure description, and the analysis provided a strong support for the main problems findings.

Concerning continuous improvement projects creation, it was observed some problems related with their creation: there were many projects every year and there was no capacity to develop each one. Additionally, some projects were created without criteria and it was not visible the cause-effect relation of those projects. Such problems caused people's demotivation.

In general, leadership was pointed as barrier for Lean, pull system and continuous improvement implementation, and sustainability. Lack of focus on continuous improvement and lack of continuous improvement project tracking by leaders were some barriers found. Additionally, managers did not have time to coach teams for continuous improvement. This fact was directly related with organizational culture and with the functional organizational structure implemented as well.

The importance of human resources in Lean implementation was mentioned by several authors (Achanga et al., 2006; Amaro et al., 2020a; Garcia-Sabater & Marin-Garcia, 2011; Lodgaard et al., 2016, 2020; Monden, 1998; Netland, 2016; Netland et al., 2020). This topic was one of the fragilities identified in this study. The results of associate survey also showed some fragilities regarding this topic because topics such as professional development, teamwork environment, and collaboration had the lowest rating. After 2017, survey was not repeated, which reveals the lower importance of employees' feedback for the company. The results of this survey would be also an outcome for continuous improvement activities, seeking for a learning organization. However, initiatives such as Lean Wave demonstrated that company was aware of needs of changing leadership style.

Another observation was that company did not have its own sustainability report. There was the group report and the information about Bosch Portugal but was not plant specific. This fact revealed a huge gap concerning sustainability whose pillars are economy, society, and environment. Society pillar demonstrated concerns related to people's satisfaction, actual and future well-being of the employees, and social cohesion. Such topics have a huge importance for Lean culture.

Problems related with lack of knowledge and training in Lean fundamentals were mentioned as a barrier of such implementation processes. Lack of knowledge was widely observed concerning pull system. Only a fewer group of people had enough qualification in the topic. At the end of the case study analyses, it was observed that most of the people involved in those projects had already left the company, and knowledge was not transferred.

Regarding human resources, the workload distribution management on continuous improvement process were also a problem. Value Stream Managers, which was responsible by continuous improvement projects, could not manage project resources due to functional structure organization. Human resources were not managed by value stream, they were allocated to a functional area. They had their main tasks, and additionally, they often were enrolled in continuous improvement activities.

Concerning organizational issues, the most predominant problem that interferes on Lean and pull system implementation was the departmental also called functional structure implemented. Conflicts between departmental and organizational goals were widely observed. Furthermore, it was observed missing of a clear strategy deployed in different levels of the hierarchy. This fact caused several communication problems and misalignment related plant strategy. Additionally, the hierarchical functional structure with several levels did not allow fast decision taken and the agility that was required nowadays.

Another important aspect that should be highlighted was regarding Lean culture that was not throughout in the company. There were several Lean tools applied and some continuous improvement activities, but they were not part of a daily culture that involves everyone. Also related with employees' involvement, it was observed some fragilities on the process such as the suggestion boxes implementation that has failed in the oldest version. Suggestions program is also closely related with continuous improvement process. Besides that, employees' involvement is highly recommended in a Lean culture. The suggestions program also showed some problems since that more than 56% were rejected and only 28% were implemented.

Furthermore, concerning the organizational structure, Value Stream Manager could not work on continuous improvement holistically. Him/ her position on the hierarchy level did not allow the empowerment and focus required. Value Stream Manager was commonly a production section manager whose main tasks were production management related. Meaning that one of the crucial areas such as logistics was not part of the focus because logistics belonged to a different department and plant manager. Basically, role design represented a barrier for continuous improvement concerning complete value stream.

In order to understand problems on pull system implementation, a deep analysis of the implemented PCS was done. This process revealed a huge complexity, it involved many people from different departments that follows different procedures and IT tools. Furthermore, the general plant layouts and internal flows were a barrier for pull implementation. The existence of functional pools increased the complexity. The one-piece flow principle was inexistent.

As an external factor, the customer fluctuations were also mentioned as an important barrier for pull implementation. Beside those topics, the organizational structure represented a complex element due to functional silos and levels of hierarchy involved.

Furthermore, analysis found out some problems regarding PCS process definition. The production planning itself was done in a different way by three entities: MOE1 for SMT lines, MOE2 for pre-processes, LOG for final assemblies and raw material. This function and PCS process were not clearly defined and integrated in the whole organization. Additionally, it was identified that production planning for final assembly, where finished goods were produced, was neglected because that task was not the main planners' task. Planners were more focused on customer's orders and logistics topics than production planning and control. Therefore, the existence of two pronounce areas involved in PCS, technical and commercial with different goals was a barrier in pull system implementation as PCS. This issue was also visible in the organizational structure because commercial and technical managers did not have official relation inside the company. They officially reported to different entities of the executive management, out of the location. Looking only at plant organizational structure, it seemed to have two different companies. It might represent a problem for the strategy definition.

Analysis of some operational KPIs related with production planning and control was also included in the diagnosis of current situation. These KPIs such as OEE, delivery performance, and many others showed that all of them were out of the target. Levelling that represents a boundary condition for pull implementation was not implemented in most of the lines. There was still a huge difficulty to create a production plan according to the levelling method. OEE results proved the instability of final assembly lines, the one where production plan was created. Customer fluctuations represented a huge problem for levelling and pull system implementation. They should be handled carefully in a basis for continuous improvement. Throughput time was not measured due to several difficulties such as lack of inventories monitoring. So, it was not possible to monitoring WIP throughput the value stream. Results of those KPIs showed there are some rooms for improvements concerning PCS procedures.

In Table 31, it was presented the summary of main problems identified previously described, including the root causes, the related waste that was presented in section 2.1.2, and the main outcomes of each one.

The findings showed a relation between several important elements regarding Lean implementation. Those elements, resultant from the conducted study, were consistent with existing literature.

Table 31 – Summary of main problems identified in the case study (1/2)

Category	**Problem**	**Root Cause**	**Waste**	**Outcome**
Leadership Organization Operational People	Levelling not implemented	•Customer fluctuations •Lack of knowledge •Lack of master data •Communication problems between departments •Lack of leadership involvement •Among others	•Overproduction •Waiting time •Transport •Stocks •Underutilization of the human potential	Pull system cannot be implemented
Leadership Operational People	Low number of continuous improvement project closed	•Many projects •Projects without criteria •Lack of projects tracking by leaders •Missing culture	•Underutilization of the human potential •Waiting time	•No cause-effect relation •Demotivated teams
Leadership	Missing sustainability report	It is used the national report	•Overproduction •Underutilization of the human potential •Defects	Demonstrate lack of concern about people, society, and environment
Leadership	Value stream managers miss empowerment	Departmental structure	•Underutilization of the human potential	•Decision taken delays •Impacts only in some areas
Leadership Organization	Communication problems and conflicts between areas	•Departmental structure •Missing strategy definition	•Underutilization of the human potential •Waiting time •Over processing	•Lack of agility •Decision taken delays
Organization	Complex organization	•Departmental structure with several hierarchical levels	•Underutilization of the human potential •Waiting time	Lack of agility
Organization	Finished good planners are not focused on production planning and control	Function is not well defined	•Underutilization of the human potential •Defects •Over processing	•Production planning and control function is neglected •Pull system is not seen holistically and is not implemented
Organization	Logistics is not the focus of continuous improvement activities	•Most of the value stream managers belongs to production areas •Departmental structure •Division between technical and commercial areas	•Underutilization of the human potential •Waiting time	•Pull system is not seen holistically and is not implemented •Low influence in logistics
Organization	Contradictory goals	•Departmental structure •Missing strategy definition	•Underutilization of the human potential •Defects •Over processing	Conflicts between areas and “power games”

Category	Problem	Root Cause	Waste	Outcome
Operational	Customer fluctuations	•Lack of customer fluctuations analysis •Missing a close relation with customers	Overproduction	•Delivery performance •Expedited transports
Operational	Missing One-piece flow	•Production pools •Lack of holistic evaluation about material flow	•Overproduction •Waiting time •Transport •Stocks	•Delays •Push strategy •Communication problems •Missing material
Operational	Inventory/ WIP between processes	•Lack of one-piece-flow •Production control function not well defined	•Waiting time •Transport •Stocks	WIP levels is not monitored
Operational	Operational KPI out of the target	Instable processes	•Overproduction •Waiting time Transport	•Extra costs •Customer dissatisfaction
Operational	Different departments doing same function: Production planning and control	•Process is not described/ standardized •Lack of standards •Division between technical and commercial areas	•Overproduction •Waiting time •Defects •Transport	•Low delivery performance •Expedited transports •Lack of agility •Conflicts between departments
People	Continuous improvements activities not part of the employees' objectives	•Departmental structure •Workload distribution management •Logistics belongs to commercial area	•Underutilization of the human potential	Continuous improvement activities are not priority
People	Lower level of motivation	Lack of professional development, teamwork environment and collaboration	•Underutilization of the human potential	•Turnover •Demotivated teams
People	Lack of knowledge	•Low level of training •Bad integration plan •Managers do not have time to coach teams for continuous improvement	•Underutilization of the human potential	•Difficulty of execute tasks and continuous improvement projects •Difficulty of implementing pull system
People	Small number of implemented suggestions	•Missing culture Lack of resources	Underutilization of the human potential	•Demotivated teams •People do not believe in the system

6 Conceptual model development

The outcomes of the case study identify some gaps regarding Lean and pull system implementation in different dimensions. Furthermore, the literature review identifies crucial elements that determine a successful Lean company. The analysis of both led to develop a conceptual model based on Lean culture elements that includes four dimensions: Leadership, Organizational, Operational, and People (LOOP) for a production control system implementation in a Lean environment which fulfil the current market requirements. This model aims to answer the research objectives defined in the beginning of this research. In this chapter, the model development is presented in detail.

6.1 Proposed Lean Culture in the model's "basic framework"

Although organizational culture was not the focus of this thesis, according to the research that has been performed, a strong culture that perceives Lean Thinking principles is strongly recommended for a successful Lean implementation. The analysis of the current situation, described in chapter 5, indirectly shows a need for organizational culture change. The proposed model would not be completed without talking about organizational culture. Therefore, in the four model dimensions, Lean cultural elements should always be present and disseminated within the whole company, since it will take some time to be effectively changed (Schein, 1984). Leaders, mainly top management, play a key role in this process because their values and assumptions will be followed by other members (Schein, 2004). Elements presented in Figure 77 are part of the Lean culture proposed in this model.

Figure 77 – Elements of Lean culture

"Respect for people", the first one and bold marked, is one of the TPS values, also referred by Schein (2004) model as a base word for organizational culture concept in Japanese industry, and an important element of social-technical systems (section 2.3.3) as well. The proposals for implementation included in model dimensions have also an underlying culture based on such elements:

- respect for people, as explained before;
- continuous improvement mind-set with focus in waste reduction and in achieving the fifth Lean Thinking principle perfection should be always present;
- lead with humility, meaning that leaders create an environment where employees feel respected and their ideas valued;
- problem solving activities that support continuous improvement activities and fast reaction to deviations, in which workers should participate;
- customer satisfaction, which should lead the organization;
- promotion of a teamwork mind-set in daily business in order to create a collaborative spirit and cross-functional sharing;
- flexibility of human resources and equipment that enables answering customer demands and knowledge development for new market requirements;
- leadership commitment as a crucial factor to support continuous improvement activities and Lean as an organizational culture;
- open communication, meaning that leaders promote a transparent and clear communication about company strategy, group targets, and current situation, as well as create an open environment where workers can be creative and provide feedback;
- empowerment, meaning that leaders encourage their workers to act with autonomy and responsibility about their own decisions.

The three culture elements, according to Schein (1984), namely artefacts and creations, values, and basic assumptions, should be reflected in each culture element presented. The culture elements presented in Figure 77 should be lived by everyone, influenced by the leadership and by the business environment. However, leaders play an important role in this process of shaping the Lean culture.

6.2 Model dimensions

According to the analysis, several problems were demonstrated as being a barrier for Lean and pull implementation. Those problems are widely described in the literature referred in section 2.2. Although there are some models and methodologies of Lean implementation referred in section 2.1.4, no one presents the relation between Lean and the selection and implementation of production control systems, mainly the pull strategy. Furthermore, no one presents a holistic approach that includes different aspects of other dimensions that have not been focused before.

Based on literature review and the analysis of the presented case study, a conceptual model was developed to answer the initial research objectives. As such, this conceptual model includes four dimensions that cover the presented gap: 1) Leadership, 2) Organization, 3) Operational, and 4) People. Attending to these dimensions the model was called LOOP. These four dimensions should be embraced by a Lean culture, noted in the previous section.

The dimensions were developed based on categorized problems found during the research and corroborated by the literature. These four dimensions should be related to each other since they cannot be implemented individually. The research conducted research showed that there are strong evidences that there are several conditions to be met for a successful Lean implementation. Due to that, this model proposes an integrated approach of different dimensions with the same level of importance.

Figure 78 represents the LOOP model proposed. The curved path that connects the four dimensions represents the relations between each other, as explained above. Lean culture involves all dimensions and should be part of the organization principles and values.

Figure 78 – LOOP model

For each dimension, a proposal for its implementation and a method for executing it was defined (next sections). Additionally, for each proposal, a tool to carry out the method and the responsible for implementing it were also defined. Furthermore, a KPI was defined for the proposal's effectiveness measurement.

6.2.1 Dimension "Leadership"

The importance of leadership on Lean implementation has already been mentioned in section 2.2.1. Managers play an important role and should be the ones committed to this topic (Achanga et al., 2006; Amaro et al., 2020a; Cowger, 2016; Lodgaard et al., 2016; Schonberger, 2019). Managers should have a strong Lean culture orientation, committed with continuous improvement activities and people should feel their involvement. Managers also have a key role to clearly communicate the company's strategy and guide employees into achieving target results. Due to that, some proposals for the model implementation were identified in Table 32. Those proposals cover the gap identified in the analysis and important elements recognized in the literature.

These proposals are related with the company's strategy definition that should include continuous improvement activities. This strategy should be clearly defined and deployed by everyone to avoid misunderstandings and conflicts between stakeholders in different levels of hierarchy. Additionally, continuous improvement activities should be followed up by leaders, demonstrating their commitment by supporting and guiding teams to make decisions. Promotion of continuous improvement activities and stimulation of this kind of culture should be part of the managers' responsibilities. They should be the main promoters of Lean production and show the results of its implementation.

Table 32 – Model proposals for Leadership dimension (1/2)

#	Proposal	How	Tool	Who	KPI
L1	Clear strategy definition deployed by top management. Cause-effect relation.	Communicate general plant strategy and product/ value streams specific strategy.	•Balanced Scorecard (general objectives/ initiatives plan/ KPI). •Meeting/ workshop/ Vodcast •*Hoshin Kanri* Matrix	Top managers	•Results of Balanced scorecard •Employee's satisfaction
L2	Strategy deployed from top managers to middle managers and shop floor employees.	Promote activities to explain strategy, adapting information and type of communication to each hierarchical level. Explain the impact of each area.	•Meeting/ workshop •Video podcast	Top & middle managers	Employee's satisfaction
L3	Continuous Improvement as part of the strategy.	Define clear strategy measures for continuous improvement.	Balance Scorecard (initiatives plan for continuous improvement)	Top managers	• Results of Balanced scorecard

#	Proposal	How	Tool	Who	KPI
					• Number of implemented suggestions
L4	Define KPI targets per value stream/ Product (they should not contradict KPI outside V.S.).	Communicate targets and their derivation.	Balance Scorecard (Support of KPI trees per value stream/ product)	Top managers & value stream/ product leaders	Results of value stream KPIs
L5	KPI follow up in order define improvements.	Results follow up every month. Explaining the impact of each product area/ value stream.	•Monthly discussion with teams •Action plan definition	Value stream/ product leaders & middle managers	Operational KPI
L6	Adapt leadership style for continuous improvement promotion and commitment.	Participate and coach actively teams for continuous improvement, promoting suggestion boxes.	Create mechanism and stimulate continuous improvement activities	All managers	•Results continuous improvement projects/ activities. •Suggestion boxes adherence and implementation
L7	Close continuous improvement follows up.	Continuous improvement activities/ projects follow up.	Project meeting follow up/ presentation	Value stream/ product leaders & middle managers	Operational KPI
L8	Create and prioritize continuous improvement projects/ activities according available resources	Project Workload calculation. Distribute projects by team and prioritize activities.	Daily follow up – Agile methods like team board/ kanban board	All managers	Results continuous improvement projects/ activities.
L10	Lean Leadership system elements in whole organization. Idea is not differentiating Lean to indirect areas and Lean to production systems. Lean is a culture.	Apply Lean Leadership elements in whole organization, not only in the indirect areas.	•Specific trainings in Lean Leadership •Use same tools proposed in Lean wave methodology and complement it with literature	All managers	•Results of Balanced scorecard •Employee's satisfaction •Results continuous improvement projects/ activities.

KPIs follow up should be part of the managers' role that should relate to the defined strategy. That target might help to understand continuous improvement of the project's purposes and their derivation. This could be done in the beginning of the project by the manager and the project owner. The closed project follow ups might support its implementation and the project team's feelings. The relation between strategy and project status will give managers the tools and enough know-how to prioritize and manage activities.

Another proposal is related with lean leadership concepts, which strive for employee's development and their empowerment. This topic is closely related with Lean culture presented in section 2.1.4 and Lean leadership in section 2.1.5, which encourage employees to learn with mistakes and look at the problems as an opportunity for improvement. This can be done using a different attitude, avoiding a penalty approach, using the mistakes as lessons learned and for continuous improvement. Furthermore, leaders should promote feedback culture, hearing the employee's ideas. Leaders should be coaches and spread the Lean Thinking values.

6.2.2 Dimension "Organization"

According to the analysis, several problems were observed concerning organizational structure, such as misalignment of responsibilities, missing empowerment, and bad communication between departmental functions. Those problems have been influencing implementation of continuous improvement activities because the focus is not on value stream improvement. Furthermore, this analysis also found that functional structure is also a barrier for pull system implementation as a production control system. Additionally, literature (Mascitelli, 2007; Womack & Jones, 1994) recommends an organizational structure also connected to value stream improvement.

Table 33 shows all proposals related to organization dimension included in the model. The first proposal is the recommendation of changing organizational structure due to the reasons explained above and described in detail in section 5.2. The purpose of this proposal is to orient organizational structure for the value stream, avoid communication and targets misalignment between functional areas, as well as to remove complexity of the PCS process. With that, the expectation is to obtain better results regarding continuous improvement projects once that functional structure is oriented to the product. It does not mean including every functional area in this kind of organization. However, in the areas that interfere with the production control system described in section 5.2.2, this possibility should be analysed. Furthermore, it is also expected a higher collaboration between teams inside the value stream and a break out from functional barriers. To assure communication between different value streams and between areas that might not be included in the value stream, the creation of a communication plan and other tools to guarantee communication flow and standards accomplishment is proposed.

Table 33 – Model proposals for Organization dimension (1/2)

#	Proposal	How	Tool	Who	KPI
Or1	Recommendation: change the current organizational structure or adapt the existing one to be able for collaborative environment. Functional structure does not fit pull requirements.	•New organizational structure, changing from functional oriented to product oriented or matrix (e.g., value stream organization). Define Areas that integrate this kind of organization. •Check employees' expectations and perceptions and explain the main new organization purpose	•Organizational structure changing •Survey and workshop with employees	All company	•Plant KPIs (SQCD) •BPS assessment
Or2	Value stream/ product leader with hierarchical position that enables to make decisions, influencing every area that belongs to value stream	New organizational structure, changing from functional oriented to product oriented. Define roles and responsibilities on the organization.	RASIC matrix	Top managers	•Plant KPIs (SQCD) •BPS assessment
Or3	Create a value stream/ product leader responsible for the continuous improvement activities	Define roles and responsibilities on the organization (including continuous improvement objectives)	RASIC matrix	Top managers	•Plant KPIs (SQCD) •Results continuous improvement projects/ activities
Or4	Create a resources management strategy by value stream in order to manage value stream and employee's workload.	Allocate resources to the value stream teams in accordance with product-oriented structure.	RASIC matrix	Top managers	•Results continuous improvement projects/ activities •Employee's satisfaction
Or5	Define clear roles/ responsibilities for areas outside product-oriented organization.	Define roles and responsibilities on the organization.	RASIC matrix	Top managers	Standard deviations
Or6	Assure communication and define interactions between different value streams and areas outside value stream organization.	Create a communication plan between areas inside/ outside VS.	Communication plan.	Middle managers	Number of mistakes due to miscommunication
Or7	Assure standards fulfilment in each value stream	Create a communication plan between VS in order to assure general and technical standards fulfilment.	•Communication plan. •Work instructions •Procedures	Middle managers	Standard deviations

#	Proposal	How	Tool	Who	KPI
			•Open point lesson/ one-page report		
Or8	Design production planning and control function	•Identify every area that require production planning role and clearly define the function. •Evaluate the advantages of splitting production planning role and shipping process customer contact for final assembly.	•Function description •RASIC matrix	Employees and managers	•Delivery / Levelling performance Employee's satisfaction
Or9	Develop supplier and customer's relationship to better control inventory levels and allows agile reaction.	•Develop suppliers to better level inventory levels, avoid out of stock which affect PCS and apply continuous improvement activities.	•Supply chain management	Supply chain designer	•Levelling performance •Expedited transports •Lead time •Delivery performance •Inventory

Other proposals are related to the creation of a responsible for the value stream, focused on following up the KPIs and promoting continuous improvement of its value stream. That person should have enough empowerment to make decisions, prioritize activities, and manage resources accordingly.

One of the main conclusions of this research was that production planning function has a huge room for improvement. There are many factors that contribute to a lower performance of this process. Therefore, it is proposed to redesign the function and evaluate if there are advantages in splitting the production planning from the other activities that planners currently have. The purpose is to have a more precise production planning process. Related with external topics is the proposal that recommends the suppliers development to create trusty relationships. Suppliers and customers' relationship is essential because it is closely related with PCS and puts it in risk. This point is particularly important when volatile markets come up and an agile reaction is required.

6.2.3 Dimension "Operational"

Related to the operational dimension, Table 34 identifies all proposals to implement the LOOP model. Main proposals are related with production control system since that was the focus of this research. Besides all Lean tools and methods widely known in the literature, this model describes additional proposals covering main problems identified in the analysis.

Table 34 – Model proposals for Operational dimension (1/2)

#	Proposal	How	Tool	Who	KPI
Op1	Evaluate pros and cons of having one-piece-flow instead of pre-assemblies and production pools.	Evaluate different layout alternatives: •Inventories, space, transport, and lead time calculation. •Risks Identification (quality/ ergonomics/ safety/ supplying/ line feeding) •Cost impact	•Layout design/ Mockup •Sankey Diagram •Spaghetti Diagram/ route diagram •Calculation (inventory, space, etc.) •Risk Analysis •Simulation tools/ games •Decision methods	Employees and managers	•Lead time •Inventory •Productivity •OEE •Delivery performance (between processes)
Op2	Production planning and Control process defined and standardized for everyone to know.	•Map and define Production planning and Control process. •Training for everyone to know the procedures.	•VSDiA •RASIC matrix •Training, coaching sessions	Employees and managers	•Levelling performance •Throughput time •OEE
Op3	Evaluate production control criteria	•Table 5 – Criteria to select Production Control	•Criteria evaluation •Decision methods •Simulation tools	All production planner	•Lead time •Levelling performance •Inventory •Productivity •OEE
Op4	Continuous improvement project purpose identification	Define clear targets and impact of continuous improvement projects.	•KPI Tree •Financial methods	Value stream/ product leaders	•Results continuous improvement projects/ activities •Employee's satisfaction
Op5	Operational KPIs follow up.	Track the main operational KPIs in order to derive continuous improvement activities	Daily and monthly follow up meetings	All managers including shop floor team leaders	Operational KPIs
Op6	Create transparency related production control throughout value stream chain and an easier method of manage it.	Use an integrated IT tool for production planning and control	BMLP (Bosch Manufacturing and Logistics Platform) includes PROCON	Centrally deployed and roll out by IT responsible in Braga	•Delivery / Levelling performance •Throughput time •OEE •Expedited transports
Op7	Customer fluctuations analysis to negotiate with customer possible agreements and adapt supply chain. Improve	Create a responsible and a standard for Customer fluctuations. Create a communication standard between customer and plant in order to improve PCS and reduce bullwhip effect in the supply chain.	•Customer demand analysis. •Customer fluctuations Analysis. •Communication plan between customer and plant	Customer contact (orders related)	•Customer fluctuations •Delivery performance

#	Proposal	How	Tool	Who	KPI
	customer interface.				
Op8	Implement a hybrid lean and agile process: agile methods in the supply chain mainly for volatile markets and pandemic situations.	Create a responsible for supply chain network to define decoupling points and improve material and information flow.	•Agile supply chain network designer (including information and connectivity)	Supply chain designer	•Delivery / Levelling performance •Expedited transports •Lead time •Inventory

The first proposal is directly related with the third Lean Thinking Principle: flow creation (Womack & Jones, 1996). The analysis revealed that there are many layout factors, such as production pools and its location, that constraint product flow and consequently the pull system implementation. Due to that, a benefit evaluation for each situation, taken into account criteria such as inventory, lead time, cost, and other qualitative criteria, is proposed. The decision cannot be taken based only on cost impact but also on different criteria that impact in the whole value stream. To make this evaluation, different tools are identified to support the decision making afterwards.

Plant layouts are also a factor that JIT philosophy has taken into account. JIT supports cellular layouts, also known as U-shape cells, in contrast with strait line layouts, in order to have flow-oriented layouts as far as possible. Layouts should be arranged to smooth the production flow with focus on one-piece flow, avoiding inventory between processes and having more flexibility. For that, multi-functional operators are required to operate in different machines. However, it cannot always be implemented, so functional division of processes still exists (Hopp & Spearman, 2000; Monden, 1998).

Another proposal is related to the selection of the production control system. Although the company argues in favour of the pull system, it would be interesting if the company evaluated its applicability to each case and during the planning project phase, which might change depending on its strategy. Maybe hybrid ones are possible in some cases. Based on previous comparison and analysis of production control systems, some important criteria were defined and presented in Table 5. However, one of the most important concepts for pull implementation is the levelled production, so it should be a starting point.

To make production control clearer and more transparent for everyone, it is proposed to define the process with everyone that intervenes in it. Moreover, it is recommended to review production planning function since the existent function for the final assembly line is more related with customer contact than production itself. There are many people interfering with the process on a daily basis, so the process should be clearly defined. Production planners should have enough knowledge and training to do it.

PCS process is complex and tends to increase in complexity as the company grows up. Additionally, the amount of IT tools that arose in the last years bring data digitalization and transparency; however, the integration of every process that impacts the production control system is still missing. Therefore, one recommendation is the implementation of the production planning and control central IT tool that it has been developed by Bosch. The development of this IT tool shows the difficulties felt by Bosch in several locations concerning PCS.

Concerning continuous improvement of the project's purpose, the model recommends having a transparent target definition in a way that the project's team understands the impact of each measure. With that, team and management recognize the importance of continuous improvement activities and its impact on the value stream. Additionally, a frequent operational KPI follow up should be an input to trigger continuous improvement projects or improvement ideas from the shop floor levels.

The last proposal is related with a difficulty found in customer fluctuations, categorized as external. This was mentioned as a big problem for pull implementation. However, there is no indicator that shows the fluctuation behaviour and its impact on the PCS. Due to that, it is proposed to create that role in order to improve customer interface, understand customer production planning process, understand reasons of fluctuation, and negotiate with customers different methods to avoid creating a bullwhip effect that impacts the production's stability. This proposal is closely related with agile methods that support a strong collaboration in the supply chain networking, mainly in volatile markets. Additionally, the creation of a supply chain designer to evaluate and design the supply chain network and get advantages from suppliers and customer collaboration is proposed.

Furthermore, the model aims to implement a hybrid approach that consists in finding a decoupling point between Lean and agile approaches considering demand and product characteristics. One possible decoupling could be the finished goods and finished goods already packed, or even to work in collaboration with existent logistics service providers. This proposal is made due to some difficulties in creating levelling regarding the number of parts per pallet presented in section 5.2.2.4. If palletization according to customer's orders was performed in the external logistics provider, some instability would be avoided in the production area, which is a reason to create a decoupling point at the end of the process. This proposal should be analysed for each product and evaluated similarly to the proposal regarding PCS criteria selection. In summary, customer and supplier interfaces are relevant factors for production planning and control that affects directly inventory levels and delivery performance.

6.2.4 Dimension "People"

People involvement is a crucial part of the model's implementation. Since the beginning of the TPS model's creation that people and teamwork are considered the main agents of the continuous improvement process in the TPS house (Liker & Morgan, 2006).

In Table 35, every proposal for model implementation related to people is described. People dimension is focused on people skills' development and involvement in Lean. For that, people should have required competences and knowledge to understand Lean methods and tools. Those competences should be acquired by different methods, such as training, coaching sessions, and benchmark activities that promote sharing experience. Having an Obeya room, where people can brainstorm and work for a project, encourages and increases teamwork's spirit and cooperation. This is in line with the model of organizational knowledge creation presented by Nonaka et al. (1998) and described in section 2.2.5.

Table 35 – Model proposals for People dimension (1/2)

#	Proposal	How	Tool	Who	KPI
P1	Identify and promote employees' competences for the function.	Qualification matrix executed by the employees and manager.	Qualification matrix	All managers and employees	•Qualification achievement •Results continuous improvement projects/ activities
P2	Training sessions in Lean tools	Based on qualification matrix, address Lean tools training	Training, coaching sessions, benchmarking activities	Value stream leaders & managers	•Qualification achievement •Results continuous improvement projects/ activities
P3	Training sessions in project management	Based on qualification matrix, address Lean project management training and teamwork	Training, coaching sessions, benchmarking activities	Value stream/ product leaders & managers	•Qualification achievement •Results continuous improvement projects/ activities
P4	Practical sessions for experience sharing	Create sessions for experimental learning in Lean tools using for instance simulation games and share feelings and know how.	•Learning factory •Experience data base •Lessons learn •*Obeya* room	All managers and employees	•Qualification achievement •Results continuous improvement projects/ activities

#	Proposal	How	Tool	Who	KPI
P5	Objectives defined for continuous improvement activities and capacity allocated	Leaders define periodic targets (e.g., annual or by demand)	Periodic meeting with leaders	Value stream leaders & managers	Employee's satisfaction
P6	Participation in coaching sessions	Check the needs of coaching session and employees should require when they need.	Learning follow up	All managers and employees	•Qualification achievement •Results continuous improvement projects/ activities
P7	Employee's involvement on continuous improvement and part of the strategy definition.	Create methods and tools for employee's involvement. Promote employee's involvement.	•Suggestion boxes •Brainstorming Workshop with employees	All managers and employees	•Suggestion boxes adherence and implementation •Employee's satisfaction
P8	Define integration strategy for new employees	Create an integration plan according to qualification matrix.	Integration plan (including training, coaching sessions and continuous improvement project execution)	All manager	Qualification achievement
P9	Promote employee's feedback	Give opportunity to the employees to share improvement ideas and process feedback	•Employee's Survey •Feedback focus group	All managers and employees	Employee's satisfaction

Additionally, it is proposed a learning factory, as explained in section 2.2.5, as a method for getting knowledge. There are many types of application scenarios, such as industrial, academic, remote learning, changeability research, consultancy application, and demonstration (Abele et al., 2015). Since knowledge was one of the most important factors for Lean and pull implementation, this method of learning might be helpful and facilitate the acquisition of Lean skills and competences without the risk and pressure of applying tools in a wrong way.

Additionally, employees should have clear and defined objectives to understand task purpose, be prepared, and plan their activities taking into account that continuous improvement is part of their job.

Employees' feedback must be part of the company's culture, as it can be seen as part of the improvement process. Managers should therefore promote activities that encourage idea creation in an open environment that also motivates employees.

6.3 Criteria for production control system selection

In this section, the relation between the LOOP model previously described and the selection of production control systems in Lean and agile environment is presented. Although the model has already showed some features that include some elements of PCS and the model dimensions, this relation is explained in detail here. This relation intends to answer the research question "*Which are the conditions needed for a decision-making process related to the production control systems in Lean Production environment?".* Figure 79 represents the relation between the production control system selection and the LOOP model.

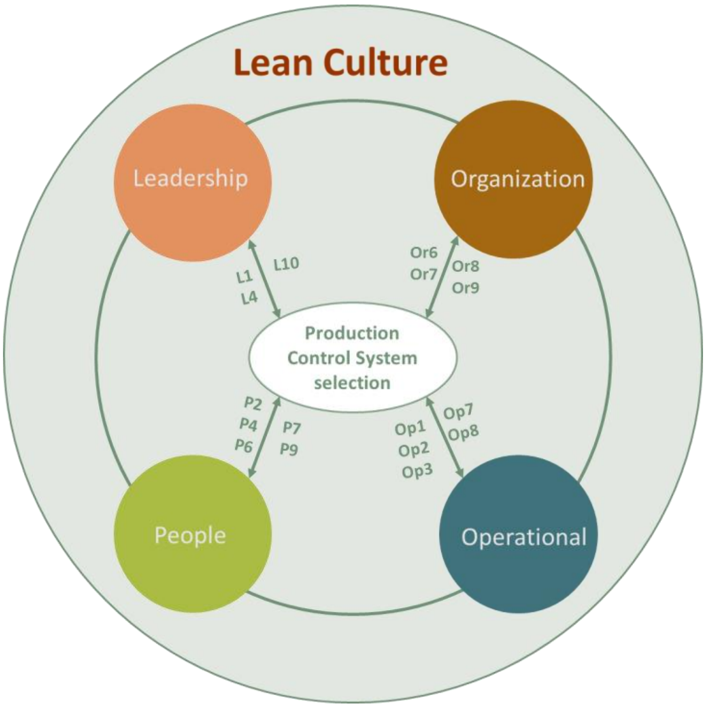


Figure 79 – Production control system selection according to LOOP

Each dimension of LOOP plays a special role in the production control system selection. In each dimension, there are specific proposals of the model presented before that directly impacts the PCS. Therefore, those proposals are clearly visible in Figure 79, which intends to focus this point. The culture proposed in the LOOP model is still valid since this model fits the Lean environment even when process is related with PCS. The influence of each model's dimension is presented next.

The PCS selection is dependent on leadership proposals:

- L1 – Clear strategy definition deployed by top management. Cause-effect relation;
- L4 – Define KPI targets per value stream/ Product (they should not contradict KPI outside V.S.);
- L10 – Lean Leadership system elements in whole organization. Idea is not differentiating Lean to indirect areas and Lean to production systems. Lean is a culture.

In the leadership dimension, proposals are closely related with the company's strategy and KPI definition, which influence production planning and control systems. KPIs, such as inventory levels and resources capacity, might influence the decisions. Furthermore, leadership style is also very important, as explained before. Therefore, even in PCS management, the lean leadership elements should be included.

PCS selection is also dependent on organization proposals

- Or6 - Assure communication and define interactions between different value streams and areas outside value stream organization;
- Or7 - Assure standards fulfilment in each value stream;
- Or8 - Design production planning and control function;
- Or9 - Develop supplier and customer's relationship to better control inventory levels and allows agile reaction.

In the organization dimension, the proposals that directly influence the decision about the PCS selection are related with communication between each area that interfere with the process. For that, standards and clear communication channels should exist. The function of production planning and control should be clearly defined, as well as the areas of influence on the process and their dependencies. Another important element of PCS management is the relation with the suppliers and the customers to achieve better fulfilment performance and react agilely.

The following proposal refer to operational ones:

- Op1 - Evaluate pros and cons of having one-piece-flow instead of pre-assemblies and production pools;
- Op2 - Production planning and Control process defined and standardized for everyone know;
- OP3 - Evaluate production control criteria;
- Op7 - Customer fluctuations analysis to negotiate with customer possible agreements and adapt supply chain. Improve customer interface;
- Op8) - Implement a hybrid lean and agile process: agile methods in the supply chain mainly for volatile markets and pandemic situations.

In the operational dimension, some proposals are important for the decisions taken, such as the evaluation of different alternatives related to having one-piece-flow or production pools. This point is very important in the planning phase, since it influences the number of inventory points and the production control points as well. In this sense, the process should be standard for everyone to know. An important part of the selection is the criteria, such as demand nature, product diversity, product quantities, among others, as defined in Table 5 of section 2.4.4. Additionally, it can be reinforced with information presented in Table 2, Table 3, and Table 4 of section 2.4.4.

Another important factor for PCS selection is the analysis of customer fluctuations, since this is an important point for pull implementation. Besides that, it is always important to create a close relation with the customer to manage production order and inventory levels. Furthermore, it might be interesting to implement a hybrid lean/agile method in the supply chain to react to volatile markets.

The people proposals that interfere in the PCS are the following ones:

- P2 - Training sessions in Lean tools;
- P4 - Practical sessions for experience sharing;
- P6 - Participation in coaching sessions
- P7 - Employee's involvement on continuous improvement and part of the strategy definition;
- P9 - Promote employee's feedback.

In the people dimension, the focus is in the training topics, because they are still needed even in PCS. Lean tools should be part of those trainings, mainly pull topics. Therefore, training, practical sessions, and coaching could be part of the qualification process that might start in the integration of new employees. Furthermore, the continuous improvement activities related with PCS should also be part of the continuous improvement strategy and in which employees should be involved. Production control function should also have continuous improvement as part of its activities.

6.4 Model discussion

The conceptual model developed provides a valuable contribution to empirical knowledge of Lean Production and pull systems' implementation and overcomes some of the difficulties faced by several industries, especially in the case study where research was conducted.

Using a deductive approach to understand the main barriers of Lean implementation was an important phase to establish the relationship between Lean and those elements. The reflection about Lean Production coming back to its origins allowed the rethinking of the original concepts and main purpose of Lean, as well as the native culture in Japanese industries. This represents important insights to conduct the research and select the research instruments, such as the interviews. Additionally, understanding the relationship between Lean and existent production control systems led to the definition of criteria for production control system selection. The relation between different concepts allowed the collection of important data that supported the model development.

The data collection instruments used to conduct the case study also allowed the evaluation of alternative explanations that contributed to the model development, mainly for the defined proposals in each dimension. In this sense, the combination of both approaches, inductive and deductive, represents an advantage for the model development because they complement each other. The case study results and analysis, the theoretical background, and the theory development in particular, provided a strong support for the model validation.

The model was not implemented in the company, so it was not possible to access implementation results. The implementation and the analysis of the results would take plenty of time, which was not possible in the PhD time. Furthermore, the practical implementation of the model will depend on the company behaviour, which represents an uncertainty factor. However, despite not being part of the research objectives, the non-implementation represents a concern from the researcher's point of view. Accordingly, it is important to access the model framework, its main concepts, the proposals, and the possibility of its future empirical implementation. Therefore, an online survey was developed and performed in order to understand if the model could be well accepted by the companies, mainly by the organization where the case study was conducted.

The survey was developed in the Microsoft Forms platform that allows to easily send the survey to the participants and provides organized results. The survey was defined in three parts with eighteen questions describe in Table 36.

Table 36 – Description of the survey parts

Survey part	**Number of questions**	**Purpose**
First	Three	Sample characterisation
Second	Six	Main characteristics of the model assessment
Third	Nine	Dimensions and proposals assessment

In the last part, eight proposals were selected, two representatives of each dimension. Most of the questions had the possibility of answering according to the following scale: 1: Completely disagree; 2: Somewhat disagree; 3: Neither disagree, nor agree; 4: Somewhat agree; and 5: Completely agree. The survey is presented in Appendix 10.

The survey was provided to the same people who contributed for the interviews presented in section 5.3, since those people represent main drivers of continuous improvement process and pull system implementation. Additionally, it was important to access the opinion of the ones that contribute to the research development, also involving them in this phase. The survey's purpose was explained in an email sent to participants along with the survey's online link. The survey was voluntary and respected the confidentiality integrity. One limitation was related to the fact that most of the operational people had left the company a few months before, so it was not possible to include them. So, the survey was only sent to thirteen people, which represents a limitation. The answering rate was 62%. Unfortunately, no department head answered the survey (Table 40).

The results of the survey show that, in general, participants agreed that the proposed model gives answers to the difficulties of Lean and pull system implementation. Results are presented in detail in Appendix 11. The second part of the survey, where the model was presented, had a positive acceptance, scoring four and five, predominantly. As such, the results show that participants agreed with model dimensions and their relationship with Lean culture required for its implementation. In the third part, which explains the proposals, results were similar, with very positive scores in all questions. In question number seventeen, related with implementation of qualification matrixes in the people dimension, all participants answered, "Completely agree" (Table 45).

A different approach for PCS implementation in Lean environment is required. The main findings of the survey showed that participants agree with the proposed model. So, the recommendation is to apply the model and define a roadmap for the implementation. This might require an organizational transformation focused on the proposed model's dimension.

Although this survey is not representative from a statistical point of view, it was answered by the main managers involved in the topic. Managers are the ones that must be committed with implementation, as it was already mentioned, so their model acceptance is very important. In the future, the survey can be applied to other case studies.

6.5 Applicability of the model in other case studies

The outlined model presented in the previous sections was created based on research insights coming from two main sources: the diagnosis of the case study in the field and the literature review. Although the results of field are a particular case and cannot be generalised, the literature corroborates the results showing that other industries might have similar difficulties. The case study represents a multinational company with defined standards around the world, so there are many common features although each location has its own culture and specific procedures and processes. In this sense, LOOP model was created not only for this specific case. As a conceptual model, it aims to fit any company that intends to implement Lean and select a production control system.

Each model dimension is supported by general concepts capable to be applied independently of business area. Although there are specific proposals related to this case study, most of them can be easily applied in other companies. In some proposals, it is mentioned some internal tools or methods like "BPS assessment" in Organization dimension. In other companies, for sure, this tool does not exist. However, it can be used a similar one that assesses Lean implementation level. If there is not any method, in the beginning phase, the recommendation is tracking the main KPIs and checking the evolution of those indicators influenced by continuous improvement activities. Later, when the maturity is greater, a company can develop a structured method to deep analyse the whole system according to its reality. Regarding Lean leadership, it is noted that case study can use Lean wave tools to apply Lean leadership elements. Other companies can start training leaders for that culture and then use systematics and tools for waste reduction not only in the direct areas but in the whole organization.

In the Operational dimension, it is mentioned an internal software tool BMLP (Bosch Manufacturing and Logistics Platform) still under development that aims to integrate the whole production planning and control process. This proposal does not represent a limitation looking for other companies. Nowadays, there are several digital solutions in the market that might accomplish similar functionalities. Meanwhile, companies might start by clearly defining their processes and evaluating the digital solution that most fits their requirements, even with some tailoring. However, if some companies are not so deeply developed in digital tools, they can implement manual systems. An important aspect is to select the most suitable production control system according to the explanation in the section 6.3 and then found a digital tool to take advantages of the digital process. The most important is having transparent procedures that lead to continuous improvement.

The remaining proposals are general ones and can be tailored to other business. It does not mean that all of them must be applied at the same time. An implementation rollout should be created, and all dimensions should be considered as well as the proposals. In case of not being possible to implement any proposal, it should be analysed if it represents a blocker and find out an alternative. Each case is a single one and shall be treated individually depending on the business requirements. Besides the model dimensions, the organizational culture based on model elements has to be created and it takes some time.

In summary, the LOOP model was created based on some assumptions previously explained. Model proposals are directed for the case study where the research was developed, however most of them are easily applied in other industries. The specific ones can be adapted to each case.

7 Conclusions

In this chapter are presented the research conclusions and the main contribution to the field. Additionally, the research limitations are addressed as well as the future work.

7.1 General considerations

This thesis was motivated by the difficulties regarding the pull system implementation demonstrated by the company where the case study was developed. Furthermore, the author has developed some work regarding Lean Production in the last years, but there are still some challenges to overcome in the industry community. In the beginning of this research, the topic was apparently a technical problem. Over the course of the research development, it became clear the dependencies of other nature that influence the applicability of both concepts. Despite of being a big challenge to deal with areas such as organizational culture and leadership, it is necessary to address them because they have emerged as important and necessary concepts for improving the understanding of the phenomena under analysis. So, Lean implementation, its tools and methods that allow to achieve better performance by waste elimination require a holistic approach. Pull is one of the Lean principles and it is the PCS that best fits Lean thinking philosophy. Its implementation requires an organizational transformation in different areas. So, the technical point of view is not enough for a successful implementation. Those were the main findings of the conducted research. Furthermore, with more and more disruptive environments, it requires an agile PCS that suits the market requirements. Therefore, the correct selection of the PCS over the product life cycle leads to better performance of the production systems.

Existent research demonstrates that Lean Production requires leadership commitment for continuous improvement, a strong and close people involvement in the activities, a deep knowledge and training in the topic and an organizational culture oriented to Lean principles as well. Although the barriers to its implementation were already known in the literature, there was still a gap regarding the integration of pull System as a production control system and Lean Production. Due to this gap, two general research questions were addressed: "*Which are the conditions needed for a decision-making process related to the production control systems in Lean Production environment?*" and "*Why is the pull systems implementation still challenging for Lean companies?".*

As observed throughout this study, to answer the first question is mandatory to have a clear understanding about production control systems features and its applicability. In section 2.4.4, a study regarding the existent main production control systems was carried out. Furthermore, criteria for its application were identified like the demand nature, product diversity and quantities, process characteristics, main purpose, and production orders behaviour. Kanban system is still the one that best fit the original pull system however there are hybrid ones that might fit some business. Criteria identified should be considered for the selection process, however there are other important elements for the PCS selection. Furthermore, it is still important to adapt production control systems to the situation and be agile in this process. It means that is not always possible to keep the same strategy during the whole product life cycle. In addition, its adaptation is also applicable to response to the market requirements and changes, mainly in the current disruptive supply chains, as observed during Covid-19 crisis. So, as a conclusion, the selection of production control system is based on the criteria defined and should be adapted to the circumstances. However, it was understood in this study that those criteria are not enough to implement production control system in Lean environment. According to that, LOOP model presents a framework that includes all dimensions and the relevant proposals of the model for the PCS selection (section 6.3).

In this sense, the second question raised in this research tries to understand the possible relation between both concepts. In fact, the outcome of this research highlights the importance of Lean being an organizational philosophy based on waste reduction to create value, keeping a continuous improvement mindset in the whole organization. Lean Production cannot be only seen as a set of tools for performance improvement. There are some barriers described in this study that contribute for some companies not being able to implement Lean successfully. Consequently, pull system implementation, which is part of Lean principles and strategies, is also affect, by the lack of Lean culture and another relevant basis. Companies try to implement pull without having Lean Production consolidated.

By providing an answer to these questions, a conceptual model was developed that enables to cover a gap in the literature. This model designated by LOOP was developed based in the relation of different concepts existent in the literature and supported by the case study outcomes. LOOP provides a holistic perspective of four dimensions: Leadership, Organization, Operational and People considered essential when Lean Production is implemented. Those dimensions have the same level of importance and close relation between each other.

Leadership plays an important role when talking about Lean, managers should be committed with culture and continuous improvement activities. Without their support, implementation will not work successfully. The organization dimension highlights the importance of collaboration between teams. The traditional silos based in the functional organizational structures might represent a barrier for Lean and mainly pull implementation because production control systems involve cooperation between different areas of a company. Recently, different types of organization structures have been presented as an alternative of traditional ones.

The operational dimension identifies the needs of evaluating production control system criteria and adapting them to the requirements, evaluation of production lines configuration that impacts on material flow and consequently in the third Lean principle: creating flow. Additionally, the importance of creating close relations with suppliers and customers also shows a positive impact for pull system.

People dimension highlights the importance of People in the process. People represents the most important value in the organizations and mainly in the Lean implementation. They must be involved in the activities; they should know what Lean means and for that training and qualification contribute positively for the implementation. Continuous improvement is part of their job rather than part-time as commonly seen.

Besides these dimensions, the Lean culture is a base for the model. Lean culture is a fundamental element for continuous improvement mindset. Leaders play an important role spreading out this culture and leading with Lean culture values, mainly looking for People as the most important value of the company. LOOP model brings up a different approach of pull system implementation that was not noted before. The integrative perspective of each dimension which shows the importance of being in the same level and due to that feature, the model only works if each of them is considered.

Considering the results obtained in this research and taking in mind the case study questions "*Why is Lean Production implementation challenging?"* and *"Why has the pull system implementation been failed?"*, there are some challenges that the company must overcome, even after some years of experience in Lean. The answer of these two questions is related to each other and can be combined because it is clear that when Lean culture is not consolidated, pull system implementation will consequently suffer with same deficits. The results support the idea that leadership has an essential role, they should clearly define the strategy and be focus on the activities.

Furthermore, leaders should be committed with continuous improvement projects which should have a cause-effect relation. Results show a deficit in knowledge regarding Lean and pull concepts, so employees do not understand the benefits of such concepts. So, the implementation becomes much more difficult. In addition, functional organizational structure revealed to be a barrier for the implementation of both concepts due to contradicted departmental goals and lack of cooperation between each other.

The findings also demonstrated that the complexity of some processes, the material flow inside company and lack of IT tools that support PCS are a strong barrier for pull. Furthermore, external factors such as customer fluctuations also influence the success of the implementation. These findings are in line with literature as presented before, however they reinforce the existent literature in this field.

In addition, another question was raised in the case study "*Which are the most suitable production control system in this case study? Is the pull system?"*. In relation to this question, it was understood that the company has the main criteria that fulfil pull strategy. Most of the product families have a MTS demand nature and quantities are high, at least for the most representative variants. It means that levelled principle supported by TPS must be applicable to smooth the production and remove the external fluctuations from the production.

Furthermore, processes have to be decoupled via supermarkets. However, this strategy is not applicable for all products because there are MTO strategies due to lower quantities and exotic features. The criteria should be checked before and apply the strategy that most fits each product. The adaptation to the current situation and product features during the product life cycle provides an agility increasingly required nowadays. Although different PCS strategies might be chosen, a close relation with customers and suppliers should be disseminated to better react to the supply chain vulnerabilities.

LOOP model presents a set of proposals in each dimension which represents a value contribution for the practical implementation. Proposals provide important insights and orientations to be developed in different areas. Those proposals are general ones that can be applied in diverse businesses, although some tools referred are used in the case study because they represent a benefit for other industries. The conceptual model and proposals considered answer the objectives of this research and provide a different perspective of Lean and pull implementation based on integrative approach of important dimensions that revealed to be crucial to this topic.

7.2 Contributions to the field

The contribution to the field provided by this work refers to the approach it presents, integrating different concepts such as Lean Production, pull System and other production control systems, barriers to the implementation, organizational culture, and other relevant paradigms.

Those concepts have been explored in the literature which strongly suggested that leadership, people, organizational culture and structure, and technical elements were identified as key elements in the implementation of Lean Production. Until this research, there was no holistic perspective joining all concepts concerning the problems regarding Lean implementation. Furthermore, besides Lean Production, it was also included the production control system underlying Lean environment. The integration of this concept also represents a novelty of this research.

The results and conclusions attained in this work offer important contributions to the existent knowledge in the Lean and pull topics. This research showed that implementation of Lean Production tools in organizations requires additional elements besides the technical ones as traditionally referred. The LOOP model brings up an integrated framework of four dimensions: leadership, organizational, operational and people that support organizations on understanding the relevant elements for a successful implementation. Furthermore, the model provides a clear message regarding Lean culture as a mandatory element.

This research also explored the difficulties faced on pull system implementation that co-exists with Lean difficulties. That leads to explore production control systems in the literature and requirements for its implementation. This point also represents an important contribution to the field since for the first time, to the author's knowledge, both concepts, Lean and pull, are integrated in this sense. The findings allowed to define criteria for production control system selection. By knowing this, organizations can better select or even adapt their systems.

Finally, regarding to the method, the case study used in this research represents a relevant organization with wide experience in Lean topics, being one of the most representative company in this area in Portugal, and part of an equally representative firm worldwide. Therefore, it represents an important contribution for the empirical knowledge although some limitations are reported in the next section.

7.3 Limitations and future work

This research project shows there are still some misunderstandings about the success of Lean Production philosophy in the industry world. In fact, it reinforces the idea that Lean is much more than an implementation of a set of tools. LOOP model presents a holistic framework of different dimensions which are important contributors for a successful implementation. With these findings, this research creates a new understanding of the relationships between these dimensions and the importance of Lean culture.

However, this research presents some limitations that should be mentioned. The first one goes to the organization studied. Since only one case study was studied, this study cannot be generalized. Results are considered indicative and may contribute to new knowledge by pointing out specific issues that can be considered determinant factors in similar situations. Although the findings cannot be generalized, they are in line with literature and, additionally, the model presents an integrated perspective of the different dimensions for the implementation of both concepts: Lean and pull.

Nevertheless, it is important to note that such company is a multinational company that follows standard procedures and guidelines. Therefore, this study might represent similar results from other companies of the group around the world. In fact, the case study provided important evidence for the conclusions. The deep and wide analysis of the case study and the fact of being representative of many similar companies allowed a significant level of confidence in the development of the theory. However, enlarging the number of case studies within Bosch group represents a future research opportunity, mainly to understand the culture role.

The second limitation it is related with the fact that LOOP model was not completely validated and implemented, and this represents a limitation of the work. The model was validated with theory development. Anyway, the author recognized the importance of being validated even partially. In this sense, the survey did not seek to reach any statistical conclusions, but it represents a relevant outlook for future work. So, as a future work, it would represent a valuable contribution for the empirical knowledge if LOOP model was validated in other case studies or even implemented.

The impact of each dimension of the LOOP model in the production control systems selection also represents a potential research development topic. So as a future work, it is proposed to assess the need of having a weight factor for each proposal. With that, it might be possible to evaluate the impact of each dimension on the PCS selection.

Additionally, the approach used in the LOOP model regarding production control system selection suggests the possibility of other study object. It means that the model might be applicable in other situations besides the PCS topic. The model is general and includes a set of proposals in each dimension that might be useful to evaluate and apply in other topics. So, the model demonstrates that it is capable to be tailored and flexible.

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Appendices

Appendix 1 – Lean Production tools

Table 37 – Description of some Lean Production tools

Tool	Description
5S	5S is a Japanese acronym of six steps: seiri, seiton, seiso, seiketsu, and shitsuke which mean sort, set in order, cleanliness, standardization, and sustainability. 5S is a methodology with purpose to eliminate wastes of movements and over movements (Monden, 1998).
Kanban	Information system that controls the material flow and workload in the production system (Monden, 1998).
TPM	Total Productive Maintenance (TPM) is management system focused on preventive maintenance that promotes equipment efficiency (Nakajima, 1988).
OEE	Overall Equipment Effectiveness (OEE) is an equipment efficiency KPI presented inside of the TPM (Nakajima, 1988).
SMED	Single Minute Exchange of Die (SMED) is a technique to minimize change over times (Shingo, 1985)
VSM	Value Stream Mapping (VSM) is a technique with standard symbols that represents material and information flow of the entire product chain, from the suppliers to the customers in order to promote improvement activities once that value-adding and non-value-adding activities are visible (Rother & Shook, 1999).
Visual Management	Visual management is a practice of placing important information visible to all, which becomes easier to understand the message behind (Ohno, 1988).
Heijunka	*Heijunka* or levelling is a method of smoothing production quantities in order to diminish as much as possible the quantity variance (Monden, 1998).
Pokayoke	*Pokayoke* systems are mechanisms to avoid defective work, closely related with autonomation concept created by TPS (Monden, 1998).
A3 report	One pager report that structure the problem solving processes according PDCA cycle (Sobek II & Smalley, 2008).
Standard work	Standard work is a set of operations usually described in the standard operations routine sheets which specify the stand operation routines and their cycle time (Monden, 1998)..

Appendix 2 – Interview Guideline Interviews

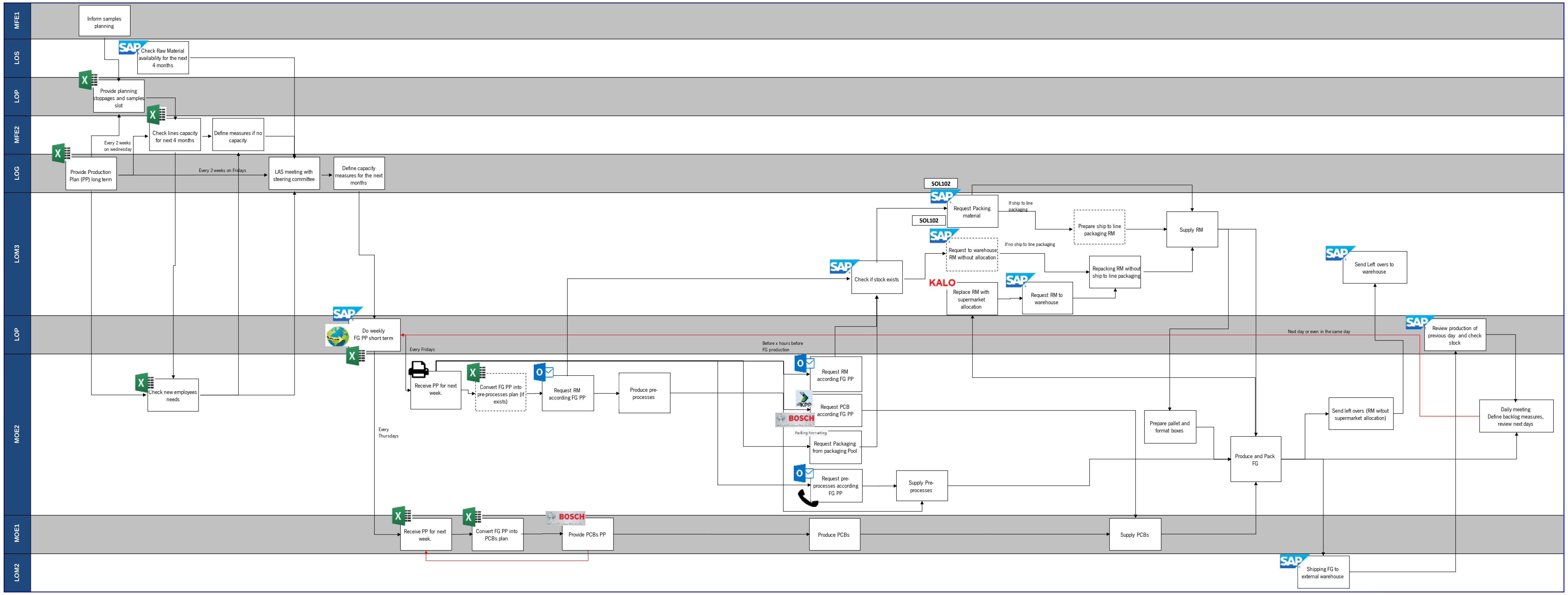
Table 38 – Interview Guideline 1/3

Who	Topic	Content/ Question	Goal	Thesis Phase
All	Lean Production	Bosch is based on a production system: the Bosch Production System, similar to the system created at Toyota, lean production related. For such implementation there are BPS principles and elements that support on it. What are the biggest challenges in having a lean company? Have you found obstacles in implementing these principles and elements?	To know the difficulties of having a Lean company. To know how the mindset is changed and how the Lean culture is created.	Understand the main constraints that are linked to the Lean Production implementation
M	Lean Production	BPS maturity level is measured in a range from 1 to 4. Level 1 represents the implementation of BPS essentials. Level 2 represents an improvable organization, Level 3 represents a self-learning organization, and Level 4 represents a lean company. In BPS assessment 2018, the factory maturity level is about 1.6 in average for the 3 existing value streams. What do you think about it?	Identify the main reasons to have lower maturity.	
M	Lean Production and Organizational	Is there any relationship between the outcome of the BPS Assessment and your annual objectives?	Identify the relation between the BPS assessment (how Lean is the company) and the employees goals. Is the result important for the management?	
M	Lean Production	In the BPS assessment, TPM is the only topic that has maturity level 3 in execution and 4 in concept. For example, the “Standardized shipping process” has level 1 in execution and concept. What is your opinion about it? What is different related to TPM success?	To know why there is only one topic with better results. What is done differently to the other topics?	
M	Lean Production	In the Balanced Scorecard 2019, there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. What is the strategy to achieve this goal?	To Know the strategy of improving BPS maturity. To know the road map implementation.	
O	Lean Production And Organizational	In the Balanced Scorecard 2019, there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. Have you been participating in any activity for the strategy implementation?	To know if the employees know the plant strategy and if they are involved in.	
All	Continuous Improvement	CIP projects are the procedure that Bosch has created that supports continuous improvement process. In 2016, 205 projects were opened and 50 were closed. In 2017, 157 projects were opened and 44 were closed. In 2018, 234 projects were opened and 38 were closed. What are the main factors that contribute to the projects closure? Which is the reason to close some projects and others not?CC	Identify the root causes of continuous improvement process not to be stable and not working.	
M	Continuous Improvement And Organizational	In the balanced scorecard 2018, there was a strategic initiative to implement a continuous improvement benchmarking systematic. For that, CIP cycles increased from 2 to 4, i.e. the project closing period changed from 6 months to 3. However, the closing percentage of projects decreased (from 28% - 2017 to 20.7% - 2018).	Identify the root causes of continuous improvement process not to be stable and not working. Why is projects duration changed if it was	

Who	Topic	Content/ Question	Goal	Thesis Phase
		What do you think about this?	not stable? Process does not work independent of the project period.	
VSMan	Continuous Improvement And Organizational	BPS assessment evaluates the three areas: Source make and delivery. As Value stream manager, do you interfere in all areas? Which is your role in the source and in the delivery? Have you already been a project owner in those areas? Do you think there are any relation between value stream manager role and CIP results? Would it be different with another organizational structure? Which one do you think that would work?	To know the value stream manager role. How is value stream manager involved in all value stream? How does this impact on the CIP? Identify the organizational structure as problem for continuous improvement process. To know if VSMan recognize organizational structure as a problem to implement Lean.	
M	Continuous Improvement And Organizational	BPS assessment evaluates the three areas: Source make and delivery. Does Value stream manager interfere with all areas? What do you think of the value stream manager role? Do you think there are any relation between value stream manager role and CIP results? Would it be different with another organizational structure? Which one do you think that would work? Is it part of the strategy?	How is value stream manager involved in all value stream? How does this impact on the CIP? Identify the organizational structure as problem for continuous improvement process. To know if management recognize organizational structure as a problem to implement Lean.	
M	Continuous Improvement And Organizational	In 2018, BPS assessor recommended to improve the visualization of employee involvement in CIP. How is it being done?	Identify the strategy of employees involvement in the continuous improvement process. Does the suggestion box make part of this strategy?	
All	Pull System	In BPS assessment, the pull principle implementation level is zero, i.e. not implemented. There have been several attempts at implementation over the last few years. In your opinion, what are the main factors that block the pull system implementation in the factory?	Identify the constraints and root causes of pull implementation failure.	
M	Pull System Strategy	In the last years, it was created a focus group for the implementation of Pull & Leveling at the factory. What is the factory strategy for pull implementation? What is the goal for the next BPS assessment? What is the goal for the pull principle maturity level?	To know the company strategy and road map for the pull implementation.	Identify the root causes for the pull implementation failure in Bosch Car Multimedia
All	Pull System	There are projects for example GM / CTP and PSA it was possible to implement at least some elements. However, there are others such as the Audi, CC and Renault that were not possible. What do you think about this?	Identify differences between projects that influences in the implementation.	
O	Pull System And Lean production	Pull & Leveling project was a high focus project in the company, in the GM/ CTP product family. What do you think about the project? Have you ever participated in this kind of project before? Was it a successful project? Which were the main barriers?	Identify the pull implementation main problems from the operational point of view. What are the difficulties? What did they feel during the project?	

Who	Topic	Content/ Question	Goal	Thesis Phase
			Know the team knowledge in Lean concepts. Are the employees link to the projects based on their skills?	
M	Training Organizational	Training is an important topic in lean implementation. The employee training level in lean content, such as training in BPS basisc, Pull & Leveling, lean logistics and others is about 30% (April 2019). Does this value seem reasonable to you? Is it enough? Were they useful? Has there been a consequence? Is the any strategy to increase the results once that the company intends to be benchmark? Do you think those results impact on the continuous improvement projects?.	To know the training strategy and how the employees are involved. To know the relation between training and CIP.	
M	Training Organizational	Is there any relation between projects and training? Do people, who participate in continuous improvement projects, have training for that? How are project team selected? Is there any qualification matrix?	To know if there is any qualification matrix and CIP projects. Are people qualified to participate in those projects? How the project team are created?	
All	Lean Production	There are some BPS elements such as Value Stream Planning, standardized work, 5S, TPM that are implemented and whose system is maintained. Which is the reason to not implement other elements? What should it be done to accomplish?	What is the difference between some elements implemented and others not implemented? Which are the reasons?	Understand the requirements to implement a pull system in the company
All	Pull System	In your opinion, what would it have to change in order to implement pull at the Braga plant?	Identify the changes needed for the pull implementation.	

Appendix 3 – Production Control System Diagram



Appendix 4 – Interview Questions

Table 39 – Interview questions (1/2)

Nº	Who	Content/ Question
1	All	Bosch is based on a production system: the Bosch Production System, similar to the system created at Toyota, lean production related. For such implementation there are BPS principles and elements that support on it. What are the biggest challenges in having a lean company? Have you found obstacles in implementing these principles and elements?
2	All	CIP projects are the procedure that Bosch has created that supports continuous improvement process. In 2016, 205 projects were opened and 50 were closed. In 2017, 157 projects were opened and 44 were closed. In 2018, 234 projects were opened and 38 were closed. What are the main factors that contribute to the projects closure? Which is the reason to close some projects and others not?
3	All	In BPS assessment, the pull principle implementation level is zero, i.e. not implemented. There have been several attempts at implementation over the last few years. In your opinion, what are the main factors that block the pull system implementation in the factory?
4	All	There are projects for example GM / CTP and PSA it was possible to implement at least some elements. However, there are others such as the Audi, CC and Renault that were not possible. What do you think about this?
5	All	There are some BPS elements such as Value Stream Planning, standardized work, 5S, TPM that are implemented and whose system is maintained. Which is the reason to not implement other elements? What should it be done to accomplish?
6	All	In your opinion, what would it have to change in order to implement pull at the Braga plant?
7	O	In the Balanced Scorecard 2019 there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. What is the strategy to achieve this goal?
8	O	Pull & Leveling project was a high focus project in the company, in the GM/ CTP product family. What do you think about the project? Have you ever participated in this kind of project before? Was it a successful project? Which were the main barriers?
9	VSMan	BPS assessment evaluates the three areas: Source make and delivery. As Value stream manager, do you interfere in all areas? Which is your role in the source and in the delivery? Have you already been a project owner in those areas? Do you think there are any relation between value stream manager role and CIP results? Would it be different with another organizational structure? Which one do you think that would work?
10	M	BPS maturity level is measured in a range from 1 to 4. Level 1 represents the implementation of BPS essentials. Level 2 represents an improvable organization, Level 3 represents a self-learning organization, and Level 4 represents a lean company. In BPS assessment 2018, the factory maturity level is about 1.6 in average for the 3 existing value streams. What do you think about it?
11	M	Is there any relationship between the outcome of the BPS Assessment and your annual objectives?
12	M	In the BPS assessment, TPM is the only topic that has maturity level 3 in execution and 4 in concept. For example, the "Standardized shipping process" has level 1 in execution and concept. What is your opinion about it? What is different related to TPM success?
13	M	In the Balanced Scorecard 2019, there is a strategy focus topic that aims to develop Braga plant as Benchmark plant related to BPS. Have you been participating in any activity for the strategy implementation?
14	M	In the balanced scorecard 2018, there was a strategic initiative to implement a continuous improvement benchmarking systematic. For that, CIP cycles increased from 2 to 4, ie the project closing period changed from 6 months to 3. However, the closing percentage of projects decreased (from 28% - 2017 to 20.7% - 2018). What do you think about this?
15	M	BPS assessment evaluates the three areas: Source make and delivery. Does Value stream manager interfere with all areas? What do you think of the value stream manager role? Do you think there are any relation between value stream manager role and CIP results?

Nº	Who	Content/ Question
		Would it be different with another organizational structure? Which one do you think that would work? Is it part of the strategy?
16	M	In 2018, BPS assessor recommended to improve the visualization of employee involvement in CIP. How is it being done?
17	M	In the last years, it was created a focus group for the implementation of Pull & Leveling at the factory. What is the factory strategy for pull implementation? What is the goal for the next BPS assessment? What is the goal for the pull principle maturity level?
18	M	Training is an important topic in lean implementation. The employee training level in lean content, such as training in BPS basisc, Pull & Leveling, lean logistics and others is about 30% (April 2019). Does this value seem reasonable to you? Is it enough? Were they useful? Has there been a consequence? Is the any strategy to increase the results once that the company intends to be benchmark? Do you think those results impact on the continuous improvement projects?.
19	M	Is there any relation between projects and training? Do people, who participate in continuous improvement projects, have training for that? There are some cases that people do not have training in the topic. How are project team selected? Is there any qualification matrix?

Appendix 5 – Research Participants Contact

"Good morning,

In the context of my PhD designated "Production Control System for Lean and Agile Processes" integrated in the Advanced Engineering Systems for Industry (AESI) doctoral program at the University of Minho, I would like to invite you to participate in an interview that is part of the data collection phase. from the project. Your participation is very important for the development of this work.

This interview aims to understand, in more detail, the main difficulties of implementing a production system with lean methodology as well as restrictions on the application of production control systems with the pull principle.

For a better analysis and data processing, an authorization, the attached form, will be requested to record the interview, which **guarantee all the interviewee rights**. This is normal interview procedure. The interview is **confidential, and all data will also be treated confidentially**. This form will be available for you to sign at the beginning of the interview. If you do not consent to the recording, please let me know in advance.

This research work **is not related to my work as Bosch employee, it is related with my research as a PhD student** at the University of Minho, therefore, it is totally independent of my tasks at Bosch.

This interview will take approximately **x h** and it will take place in the room xx, which have confidentially characteristics, so the interviewee feels completely comfortable. If you want to do it elsewhere, I'm open to your proposals.

After the meeting acceptance, I will send you the questions that belong to the interview guideline 3 days before the interview date.

I am available for any questions or doubts.

Thank you very much for your attention.

Ariana Araújo"

Appendix 6 – Informed Consent

Project: "Production Control Systems for Lean and Agile Processes", Doctoral Program in Advanced Engineering Systems for Industry (AESI), Ariana Araújo

Dear Sir. [participant name]

The present research project, integrated in the Advanced Engineering Systems Course for Industry at the University of Minho, supervised by Professor Anabela Alves and Professor Fernando Romero, aims to: know the main constraints related to the implementation of lean systems; identify the main reasons that lead to the implementation of pull systems failure; define requirements and strategies to implement production control systems in lean environments and define criteria for implementing production control systems that best suit the company.

The interview is an essential data collection method selected in this project to understand in more detail the main difficulties of implementing a production system with lean methodology as well as restrictions on the application of production control systems with the pull principle. So, I would like to ask your permission to carry out the interview, whose topics are attached, and to authorize me to record it. All information collected in this interview will be considered confidential information and its treatment, including reporting and analysis, will be done in a way that guarantees its anonymity. The information collected in this interview will be used exclusively in the doctoral project and will never be transmitted to third parties. In any case, and within the proper framework, it will be respected the Regulation (EU) 2016/679 from the European Parliament and of the Council of 27 April 2016 concerning the protection of individuals with regard to the processing of data, as well as the Code of Ethical Conduct of the University of Minho, from the Ethics Committee of the University of Minho, of July 2012.

Thank you very much for your attention.

With my best regards,

Ariana Araújo

I declare that I have become aware of and agree with the conditions set out above and that I consent to the interview recording.

________________________ de 2019

____

(signature)

Appendix 7 – Organizational Chart

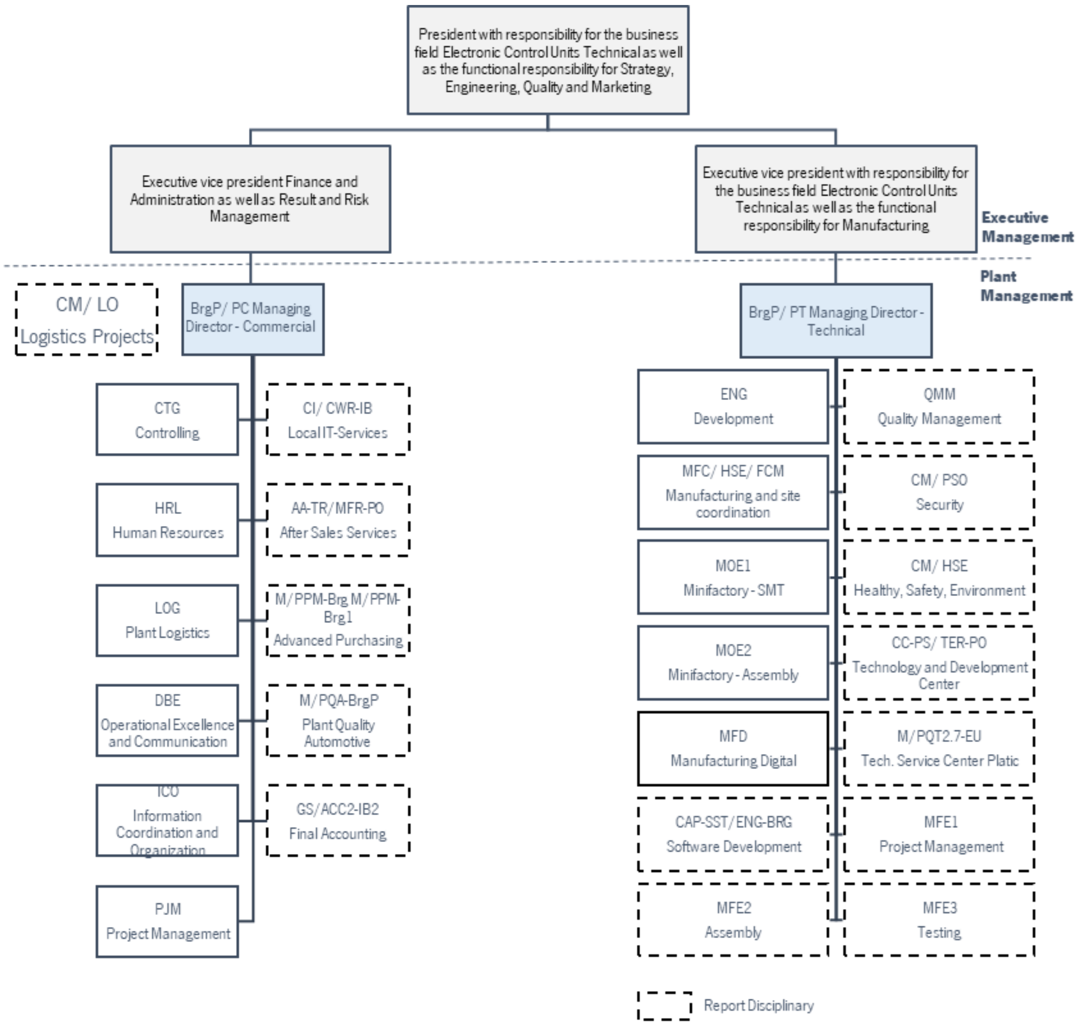


Figure 80 – Organizational Chart – Communication with executive management, First and second Levels of the Commercial and Technical Area

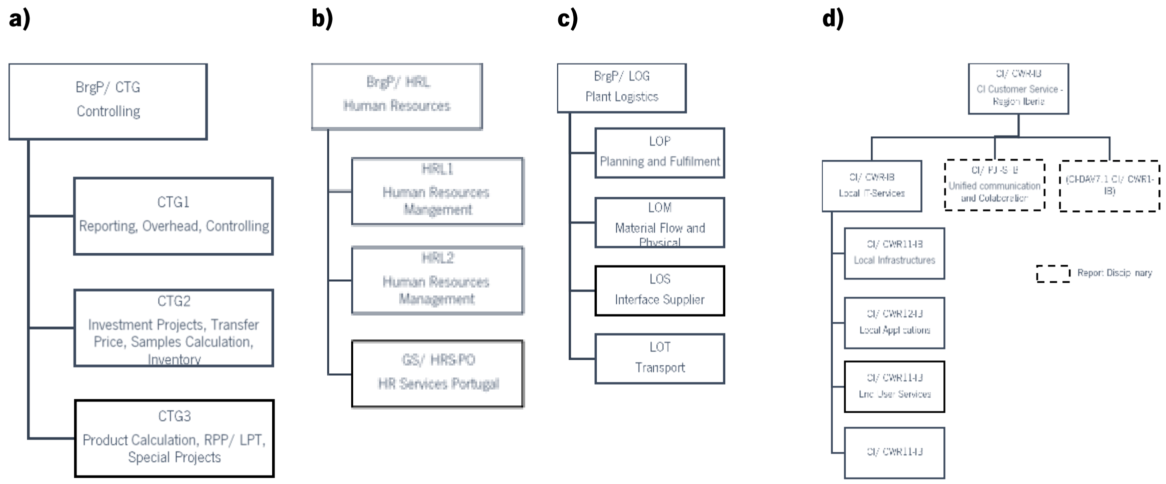


Figure 81 – Organizational Chart – Second and third Levels of Commercial Area a) Controlling b) Human Resources c) Logistics d) IT Services

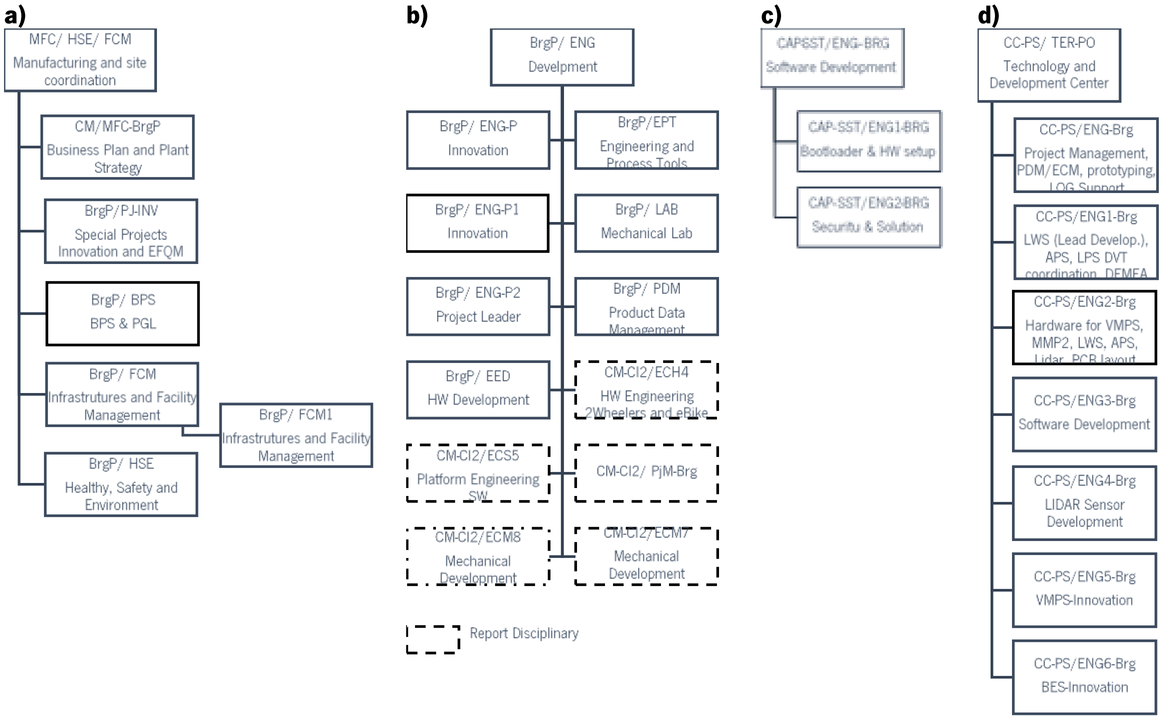


Figure 82 – Organizational Chart 1/ 3– Second and third Levels of Technical Area a) Manufacturing and site coordination b) Development c) Software Development d) CC Business

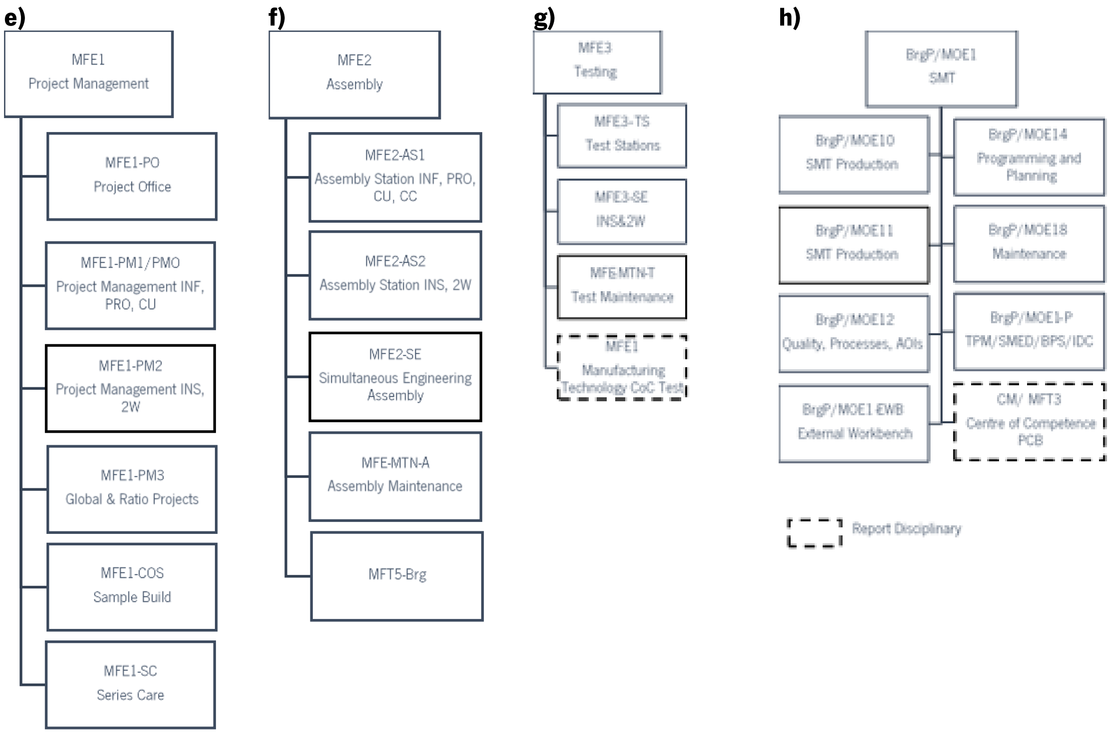


Figure 83 – Organizational Chart 2/3 – Second and third Levels of Technical Area e) Project Management f) Assembly g) Testing h) Production SMT

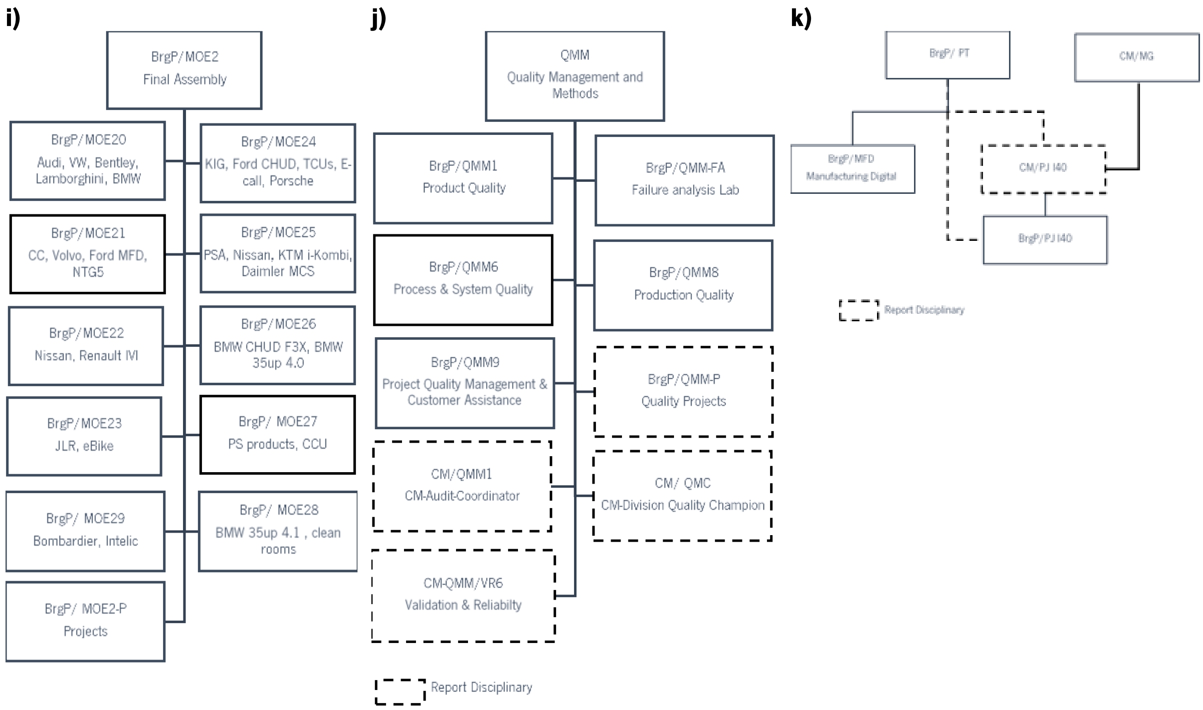
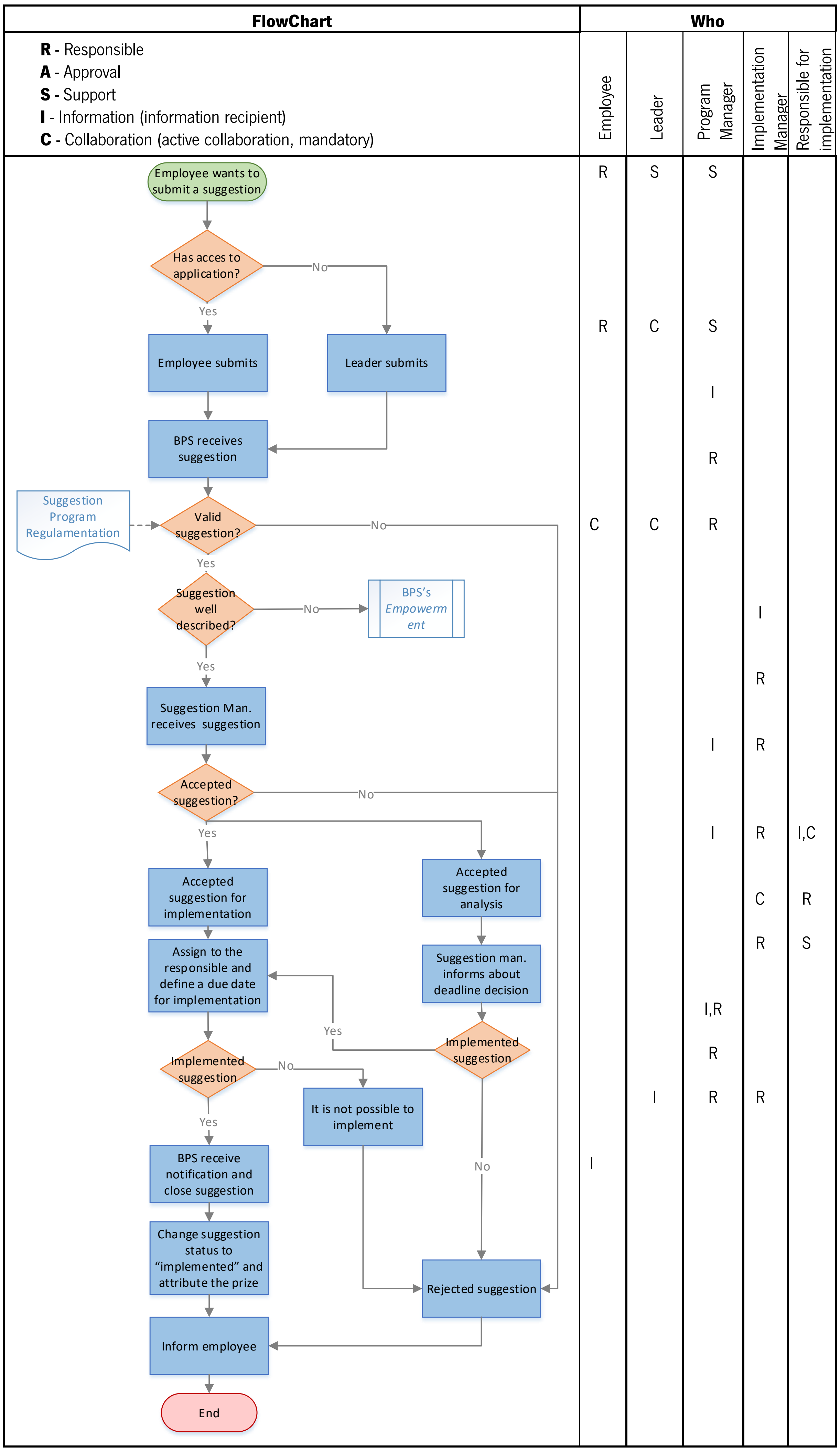


Figure 84 – Organizational Chart 3/ 3 – Second and third Levels of Technical Area i) Production Assembly j) Quality k) Manufacturing Digital

Appendix 8 – Suggestion Program Flow Chart



Appendix 9 – Value Stream Mapping

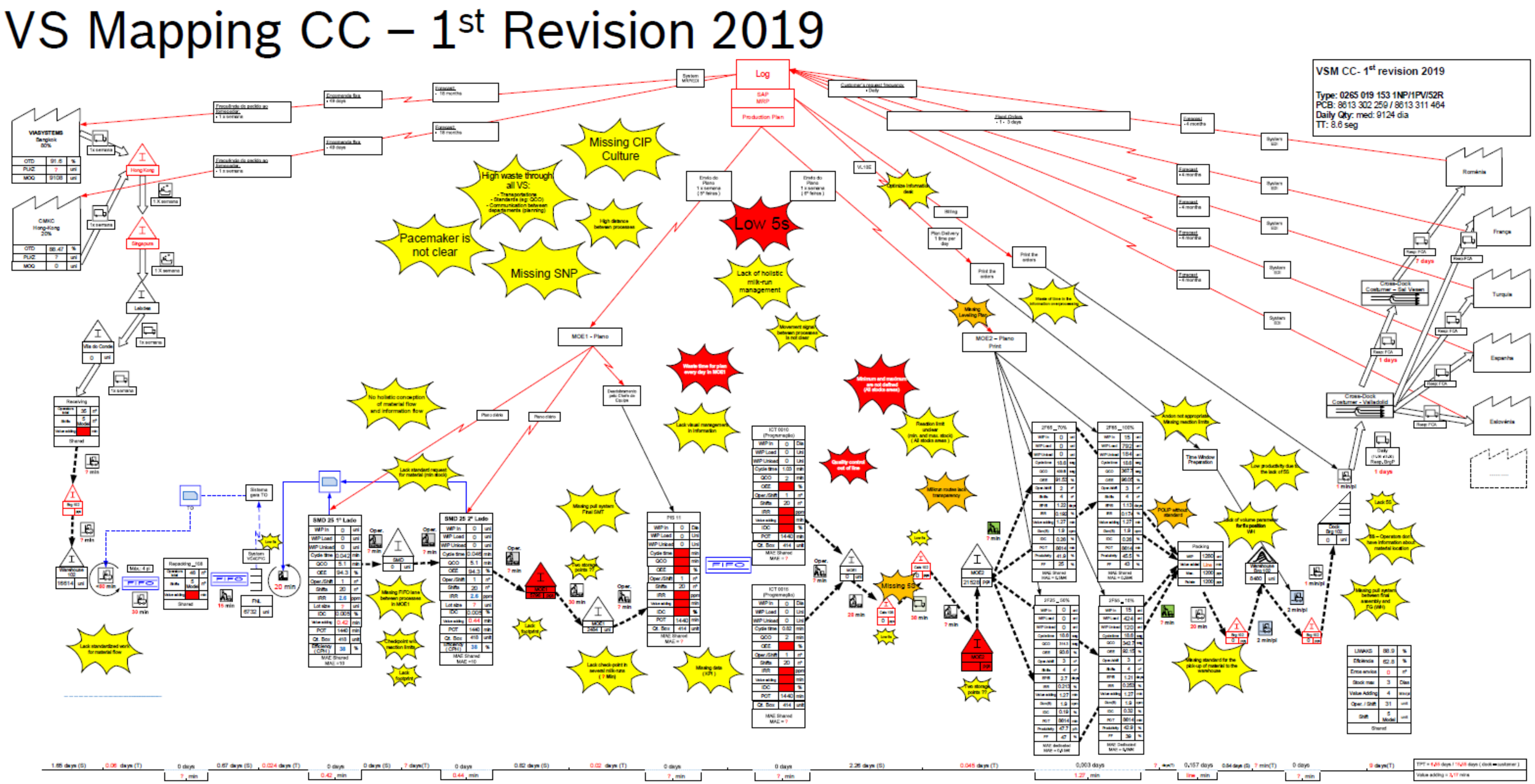


Figure 85 – Value Stream Mapping CC 1st revision 2019

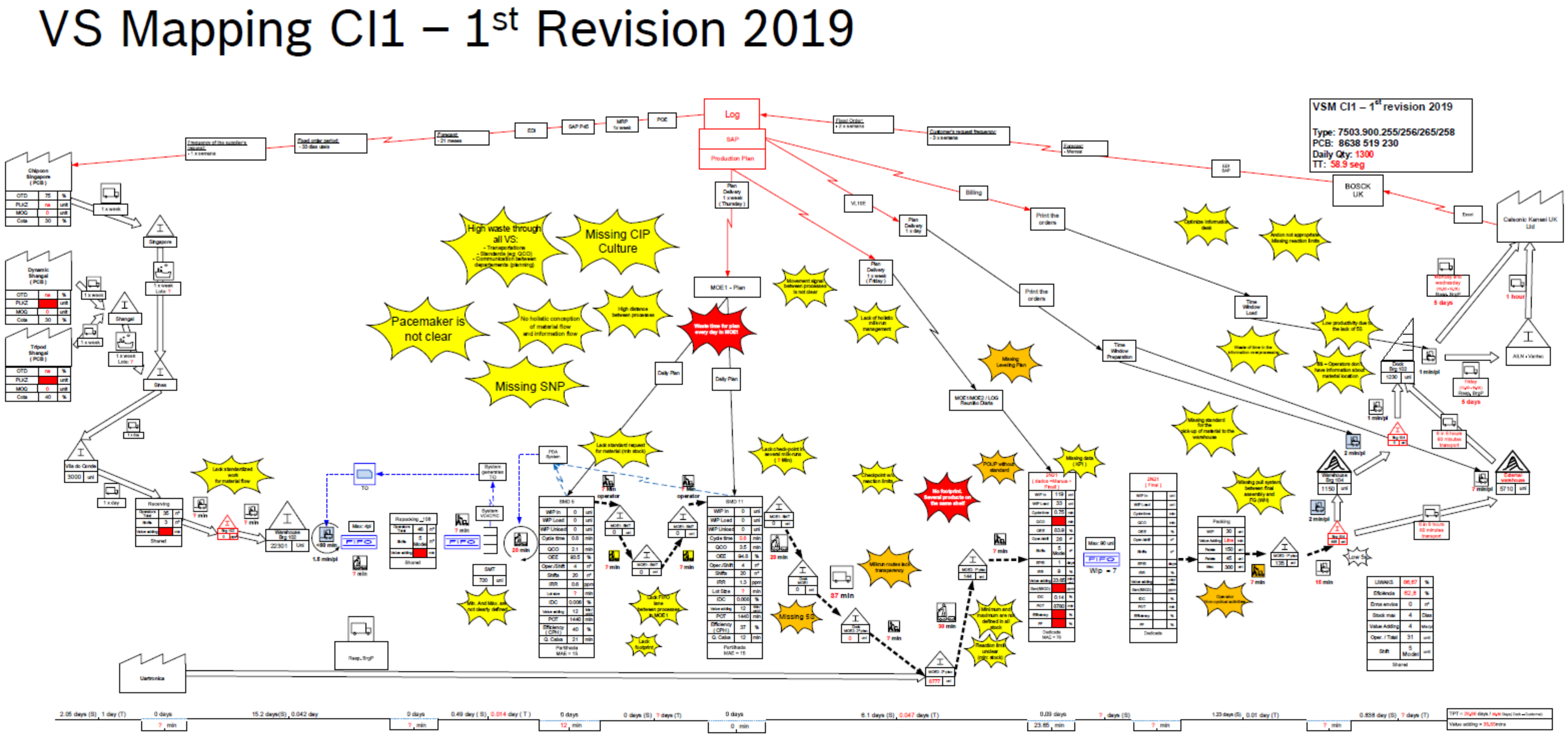


Figure 86 – Value Stream Mapping CI1 1st revision 2019

VS Mapping CI2 – 1st Revision 2019

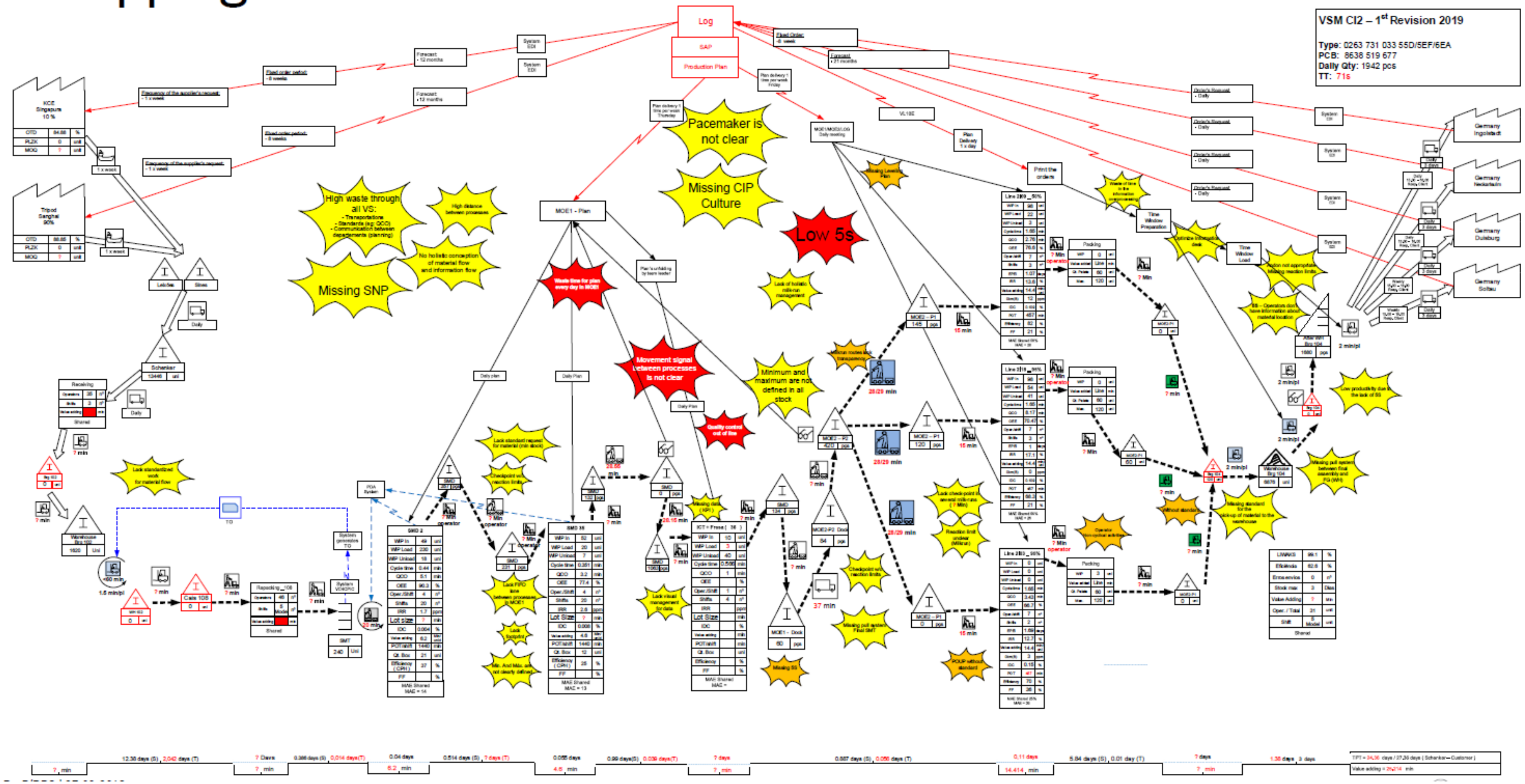


Figure 87 – Value Stream Mapping CI2 1st revision 2019

Appendix 10 – Model Survey

Evaluation of a Lean Production Conceptual Model

This questionnaire intends to validation partially the conceptual model developed within the scope of the AESI (Advanced Engineering Systems for Industry) doctoral program whose topic is "Production Control Systems for Lean and Agile Processes".

Your participation is very important and we thank you in advance for your cooperation in this research process.

We appreciate that the answers reflect your opinion. This questionnaire is divided into 4 sections, including a sample characterization and a acknowledgment section. The average time taken to answer is 5 minutes.

This research work is not related to my work as Bosch employee, but with my work as a PhD student at the University of Minho, being therefore totally independent of my tasks at Bosch.

All information collected by the questionnaires is confidential and will be used exclusively for academic purposes. In case of any doubt about the investigation, do not hesitate to contact the researcher Ariana Araújo, through the e-mail ariana.araujo@pt.bosch.com.

Characterization

1

Gender *

- ◯ Female
- ◯ Male

2

Hierarchical levelin your function *

- ◯ Operational
- ◯ Section Head
- ◯ Department Head
- ◯ Administration

Intervention

3

Years of service in the company *

◯ <5

◯ 5 e <10

◯ 10 e <15

◯ >=15

General Evaluation of the Model

The conceptual model developed (LOOP) assumes a holistic view of four fundamental dimensions for the application of Lean methodologies and production control systems according to Pull principles. According to this model, the four dimensions: Leadership, Organization, Operational and People have the same degree of importance and must be addressed together for a successful implementation. Additionally, this model is based on an organizational culture based on Lean principles, fundamental for the dimensions to work in a cohesive way.

In this section the model will be presented in a generic way. You can give your opinion on a scale from 1 to 5 in which: 1: Strongly disagree; 2: Partially disagree; 3: Neither agree nor disagree; 4: I partially agree; 5: I totally agree or, 1: Does not interfere; 2: Interferes little; 3: Indifferent; 4: Interferes moderately; 5: Totally interferes.

4

On a scale from 1 to 5, do you consider that the 4 dimensions proposed by the conceptual model (Leadership, Organization, Operational, People), are suitable for a correct implementation of Lean Production methodologies? *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

5

Do you think that some dimension is missing? *

- ◯ Yes
- ◯ No

6

If you answered yes to the previous question, please give an example:

Introduza a sua resposta

7

The proposed conceptual model is based on 4 dimensions (Leadership, Organization, Operational, People) interconnected and dependent on each other, which means that one cannot work without the other. This criterion is essential for the implementation of Lean Production methodologies according to the model. On a scalefrom 1 to 5, how would you rate this connection and interdependence? *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

8

On a scale from 1 to 5, do you consider that the proposed conceptual model is suitable for the implementation of a Pull system? *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

9

The Lean culture is at the base of the proposed model. On a scale of 1 to 5, how important do you consider culture in implementing Lean methodologies? *

	1	2	3	4	5	
Does not interfere	◯	◯	◯	◯	◯	Totally interferes

Evaluation of the model dimensions

In this section you will be presented with some of the measures proposed by the model in each of its dimensions.

Similar to the previous section, you can give your opinion on a scale from 1 to 5 in which: 1: I totally disagree; 2: Partially disagree; 3: Neither agree nor disagree; 4: I partially agree; 5: I totally agree.

10

On a scale from 1 to 5, how do you rate the following measure proposed by the Leadership dimension: "The definition of the company's strategy must be clearly defined. This must be communicated at different levels hierarchical through initiatives that explain the contribution of each area for the company's strategy". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

11

On a scale from 1 to 5, how do you evaluate the following measure proposed by the Leadership dimension: "Active participation of managers in continuous improvement activities, guiding teams to achieve results". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

12

On a scale from 1 to 5, how do you rate the following measure proposed by the Organization dimension: "Recommendation for the application of organizational structure organizational product-oriented". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

13

On a scale from 1 to 5, how do you rate the following measure proposed by the Organization dimension: "Design the production planning and control function, identifying the main intervention areas, the main roles, defining tasks and the respective responsible". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

14

On a scale from 1 to 5, how do you rate the following measure proposed by the Operational dimension: "Creation of responsibility for analyzing long and short-term fluctuations of the customer that allows improving the interface with the customer and making decisions with regard to production planning ". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

15

On a scale from 1 to 5, how do you rate the following measure proposed by the Operational dimension: "In planning production lines, consider the pros and cons of having pre-assemblies (functional pools) or one-piece-flow approach through integrated criteria assessment such as: inventory, space, transportation, lead time, cost, risks of quality, ergonomics and safety". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

16

On a scale from 1 to 5, how do you rate the following measure proposed by the People dimension: "Promotion of sessions for experimental knowledge sharing through the games, simulations or the implementation of the learning factory concept". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

17

On a scale from 1 to 5, how do you rate the following measure proposed by the People dimension: "Creation of qualification matrix for all employees (direct and indirect). This matrix should work as basis for the integration of new employees and for the definition of a training matrix". *

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

18

The proposed model is based on the assumption of a Lean culture based on several elements. On a scale from 1 to 5, how do you rate the following statement: "For a successful Lean Production implementation, the elements described in the figure have to be part of the organizational culture". *

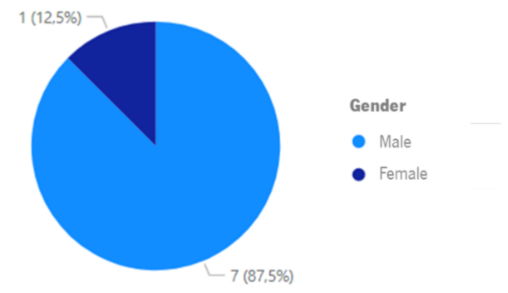
	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	I totally agree

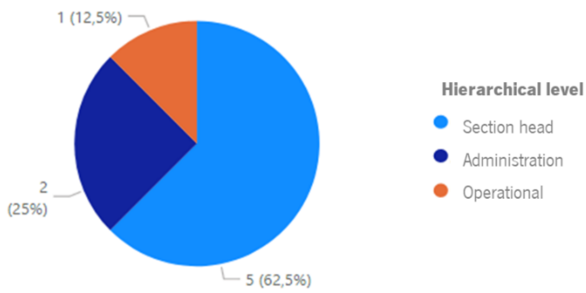
Secção 4 ...

Thank you for your collaboration

Appendix 11 – Summary of the survey results

Table 40 – Part1: Characterization of the study sample: Gender, Hierarchical Level, years of work





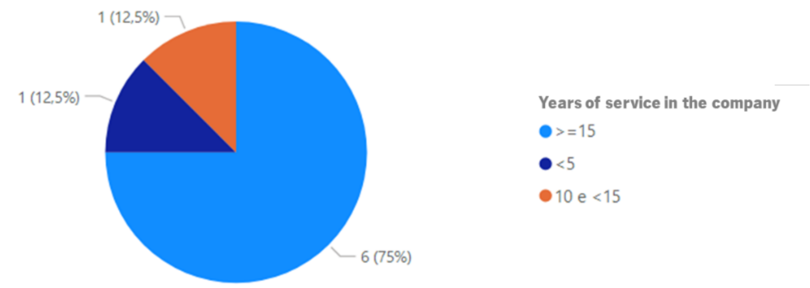
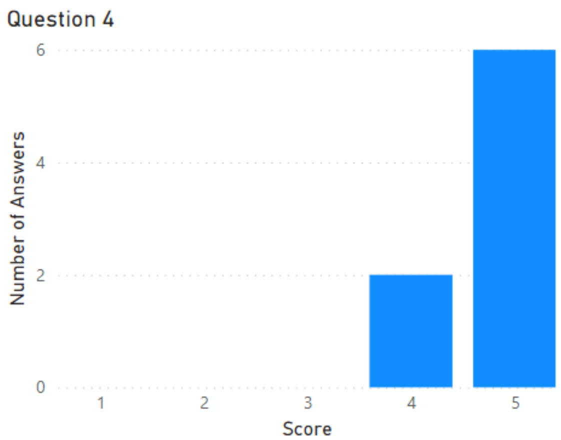
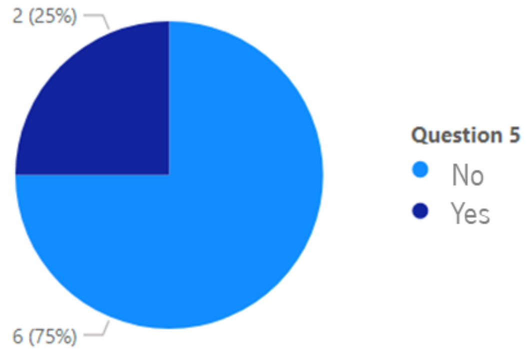


Table 41 – Part 2: General characteristics of the model (questions 4 to 9 and 18)

Do the LOOP model dimensions fit to Lean Production implementation methodologies?



Do you consider that misses any dimension?

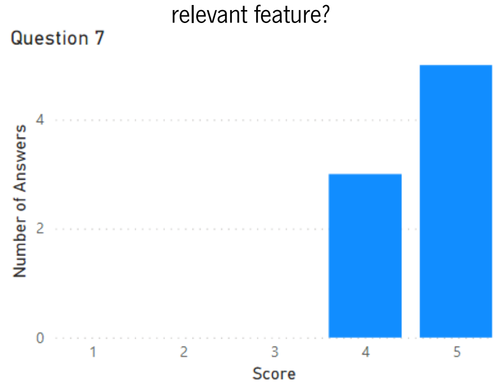


If you answered positively in the precious questions, please raise an example:

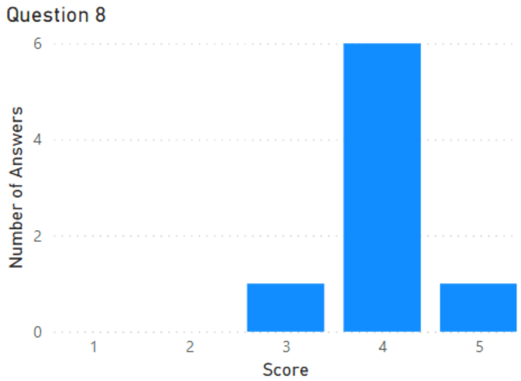
Question 6

- No, considering that knowledge is included in "People" dimension.
- Relationship with customer and supplier/ Developing People First / Lean Management (4 elements)
- Strategy

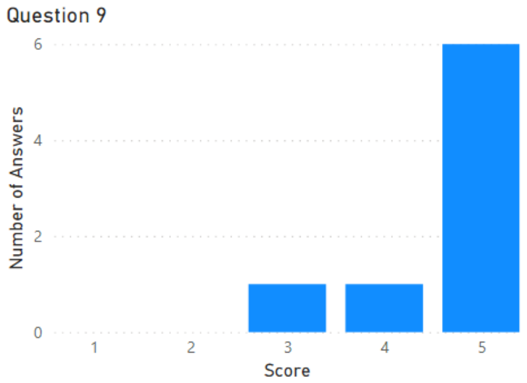
Do you consider the dependency of the model dimensions a relevant feature?



Do the LOOP model dimensions fit to pull implementation?



Do you consider the culture an important element of Lean Production implementation?



Do you agree with organizational culture elements whose model is based?

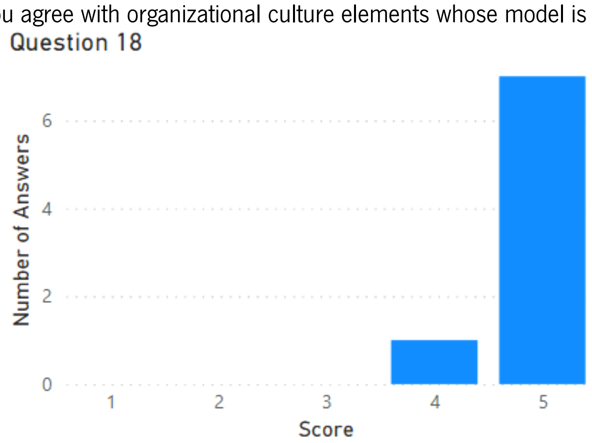
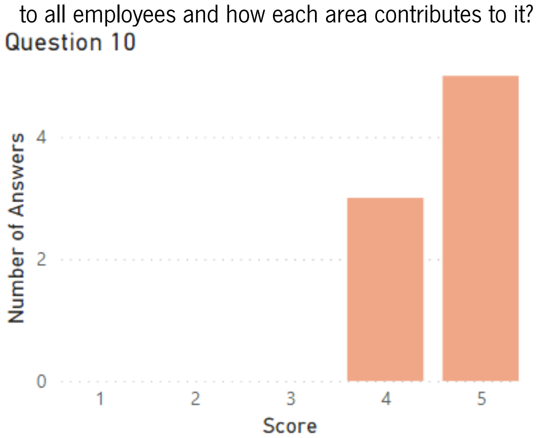


Table 42 – Part3: Leadership dimension (questions 10 to11)

Do you agree that company strategy should be communicated to all employees and how each area contributes to it?



Do you agree that managers should participate actively in the continuous improvement activities?

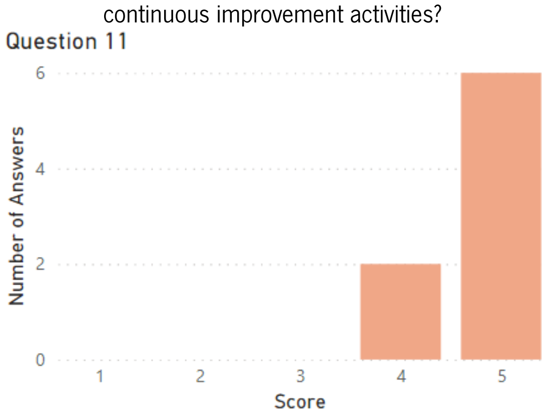


Table 43 – Part3: Organization dimension (questions 12 to13)

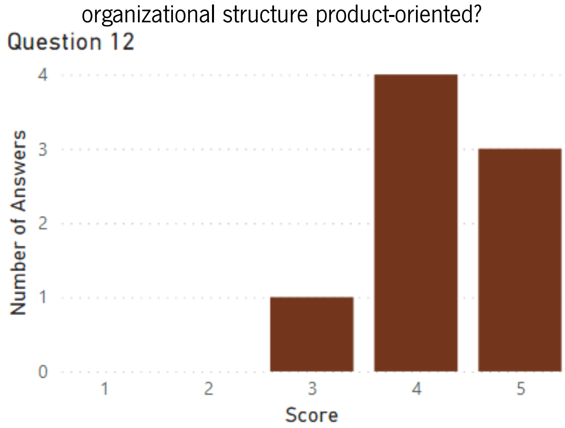
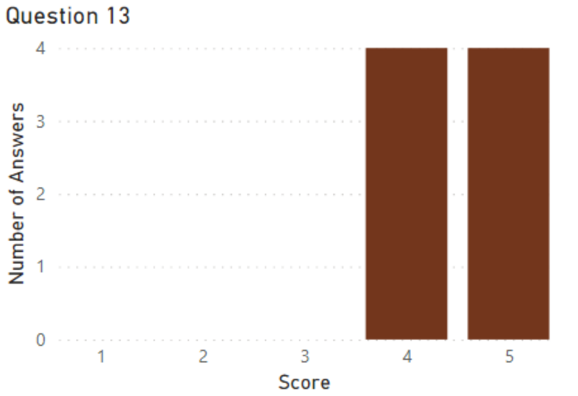
<table>
<tr><td>Do you agree with recommendation to implement an organizational structure product-oriented?

</td><td>Do you agree with the need of defining production planning and control function?

</td></tr>
</table>

Table 44 – Part3: Operational dimension (questions 14 to15)

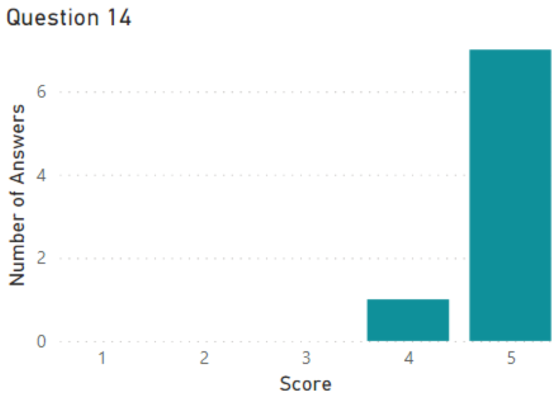
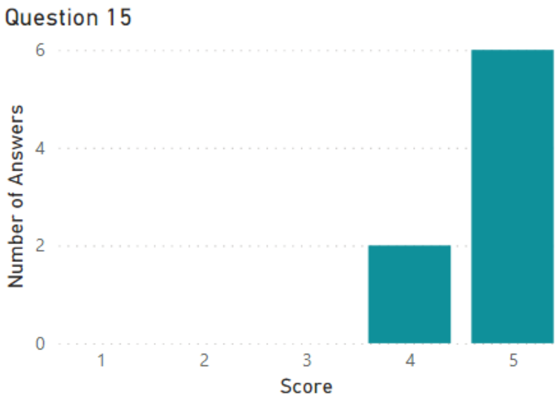
<table>
<tr><td>Do you agree with creation of a customer fluctuations role?

</td><td>Do you agree that during planning production lines phase, different criteria should be part of the decision taken?

</td></tr>
</table>

Table 45 – Part3: People dimension (questions 15 to16)

<table>
<tr><td>Do you agree sharing sessions through games, simulations or learning factory to increase people knowledge?

</td><td>Do you agree with qualification matrix creation for all employees?

</td></tr>
</table>