Universidade do Minho
Escola de Engenharia

Process Optimization in Logistics based on Bosch concepts for Continuous Improvement

Joana Oliveira Nascimento

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Dissertação de Mestrado
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Trabalho efetuado sob a orientação e coorientação de
Professora Doutora Senhorinha F. C. F. Teixeira
Professora Doutora Ana Cecília D. Ferreira Ribeiro

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Direitos de Autor e Condições de Utilização do Trabalho por Terceiros

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Thank you,

Joana

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.

OPTIMIZAÇÃO DE PROCESSOS NA LOGÍSTICA UTILIZANDO CONCEITOS BOSCH PARA MELHORIA CONTÍNUA

Resumo

Este projeto de dissertação foi desenvolvido no âmbito do Mestrado Integrado em Engenharia e Gestão Industrial da Universidade do Minho, focado na otimização dos processos na logística com base em conceitos da Bosch para a melhoria contínua na Bosch Car Multimedia Portugal, S.A. A metodologia seguida que permitiu o desenvolvimento da dissertação foi a Action-Research. Realizou-se uma revisão da literatura existente explorando conceitos relacionados com melhoria contínua e evolução das filosofias Lean para sua aplicação na gestão da informação, inteligência de negócios e análise de dados. Apresentou-se a empresa e o departamento de logística onde o projeto foi desenvolvido, bem como a filosofia estabelecida e adotada na Bosch.

O projeto de dissertação teve início com a análise das atividades relacionadas com a gestão de encomendas de clientes e planeamento e controlo da produção, realizadas no subdepartamento de Planning and Fulfilment de Logística. Após a análise de diagnóstico, destacaram-se dois principais problemas: elevado tempo e esforço manual despendido em tarefas relacionadas com a recolha e transformação de dados para análise, e falta de agilidade e integração das informações necessárias à alocação de matéria-prima aos clientes devido à crise global de semicondutores. Desenvolveram-se assim duas ferramentas com o objetivo não só de agilizar o processo de tomada de decisões na equipa de planeamento, mas também fornecer instrumentos essenciais para a execução de suas tarefas diárias – Order Variation dashboard – uma dashboard desenvolvida para avaliar se as variações nas encomendas dos clientes se encontravam dentro dos limites contratualizados com a empresa; - e os ficheiros de Standard Allocation – ficheiros automatizados que permitem não só analisar e definir a cobertura de matéria-prima, mas também simular planos de produção.

O desenvolvimento destas ferramentas proporcionou não só poupanças de até 400 horas semanais no departamento, mas também contribuiu para a transformação digital e aumento da eficiência das atividades por meio da automatização.

Palavras-Chave

Automatização de Processos, Digitalização, Inteligência de Negócios, Integração de Dados, Logística

PROCESS OPTIMIZATION IN LOGISTICS BASED ON BOSCH CONCEPTS FOR CONTINUOUS IMPROVEMENT

ABSTRACT

This dissertation project was developed within the scope of the Integrated Master's in Industrial Management and Engineering at the University of Minho, with focus on the optimization of processes in logistics based on Bosch concepts for continuous improvement at Bosch Car Multimedia Portugal, S.A. The methodology followed that permit the development of the dissertation was Action-Research. A review of the existing literature was carried out exploring concepts related to continuous improvement and evolution of Lean philosophies for their application in information management, business intelligence and data analysis. The company and the logistics department where the project was developed were introduced, as well as the philosophy established and adopted at Bosch.

The dissertation project initiated with the analysis of activities related to customer orders management and production planning and control carried out in the Planning and Fulfilment subdepartment of Logistics. After the diagnostic analysis, 2 main challenges were highlighted: considerable amount of time and manual effort spent on tasks related to data collection and transformation for analysis and lack agility and integration of necessary information due to the global semiconductor crisis. Thus, two tools were developed with the objective of not only to streamline the decision-making process in the planning team, but also to provide essential tools for the execution of their daily tasks – Order Variation dashboard – a dashboard developed to assess whether variations in orders from customers were within the limits agreed with the company; - and Standard Allocation files – automated files that allow not only to analyse and define raw material coverage, but also to simulate production plans.

The development of these tools not only provided savings of up to 400 hours per week in the department, but also contributed to the digital transformation and increased efficiency of activities through automation.

KEYWORDS

Business Intelligence, Data Integration, Digitalization, Logistics, Process Automation

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List of Abbreviations and Acronyms

AE – Automotive Electronics

BA – Business Analytics

BI – Business Intelligence

BI4Logistics - Business Intelligence for Logistics

BOM – Bill of Materials

BPS – Bosch Production System

CD – Current Day

CM – Current Month

CPS – Cyber-Physical Systems

CW – Current Week

DA – Data Availability

DALI – Data Analytics Supply Chain

DPPCon - Demand and Production Planning Control

DR – Digitalization Rate

DU – Data Usage

EDI – Electronic Data Interchange

ERP – Enterprise Resource Planning

ICT – Information and Communication Technologies

IoS – Internet of Services

IoT – Internet of Things

IT – Information Technology

JIT – Just-in-Time

KPI – Key Performance Indicator

LOG – Plant Logistics

LOI – Logistic Projects, IT System, Processes and LOG Quality Department

LOP – Logistic Planning and Fulfilment Department

LOS – Interface Supplier Department

PC – Piece

RM-FP – Raw Material – Final Product

SAP – System Analysis Program Development

SW – Snapshot Week

TF – Task Force

TPS – Toyota Production System

W – Calendar Week

1. Introduction

The present work was developed in the scope of the curricular unit Dissertation of the Integrated Master's in Industrial Management and Engineering, to obtain a master's degree. The projects described in this dissertation were developed at Bosh Car Multimedia Portugal, S.A. in Braga.

1.1 Framework & Motivation

Over the years, the manufacturing industry has witnessed a steady increase in complexity and requirements, with digital transformation revolutionizing the industrial environment to an unprecedented degree, establishing a variety of new business potentials and opportunities for industries all over the world. Industry 4.0 and logistics 4.0 concepts imply the integration of new technologies and organizations (Dossou, 2019), with trends such as digitalization, big data, Internet of Things (IoT), Internet of Services (IoS) and Cyber-Physical Systems (CPS) becoming progressively more significant (Hofmann & Rüsch, 2017). The success of an industry essentially depends on how consistently and actively the digital transformation is shaped and how the use of new opportunities is made, making it possible for industries to improve quality, costs and delivery performance and thus increase customer satisfaction (Bosch, 2020)

This dissertation is focused on the optimization of tasks performed by planning teams within the logistics' department at Bosch Car Multimedia S.A. With focus on task effectiveness and efficiency through automation, its main goal is to achieve waste reduction, structure adjustment and capacity re-allocation to where it is most beneficial for profitable growth.

1.2 Objectives & Expected Results

The main purpose of this dissertation is to optimise time and manual effort spent on tasks like orders verification analysis, production planning, data searching, collection, cleaning and reporting.

The goals aimed to be achieved are:

- Identification of opportunities for process improvement through the study of activities currently practiced in the department and a waste survey;
- Analysis, review and documentation of the feasibility of the measures identified through the definition of requirements and assessment of available resources;
- Identification of new standards, documentation, and training to the work teams;

- Key performance indicators (KPIs) implementation and monitoring.

It is expected that the work will allow the streamlining of processes for faster decision-making, in addition to optimizing the daily tasks performed by the work teams, as well as promoting the digitization and automation of activities within the logistics' department.

1.3 Research Methodology

Adopting the classification proposed by Saunders, Lewis & Thornhill (2016), the present study, regarding its purpose, is classified as a Combined Study as it combines more than one purpose, these being Exploratory and Evaluative Studies. It combines the purpose of "gathering knowledge about a topic of interest" to "discovering how well something works".

Considering the proposed objectives and defined expected results, the selected strategy is Action-Research. It is defined by Adams, Khan, Raeside & White (2007) as a type of applied research that is characterized by the application of fact finding to practical problem solving in order to improve the quality of action, involving the collaboration and cooperation of researchers and practitioners. It is an approach to problem solving that involves cycles of intention, action, and review (Coghlan & Brydon-Miller, 2014).

Regarding the adopted methodology, it is divided into 5 phases presented below:

- **Phase 1. Diagnosis –** the project initiates with the study of operations and tasks carried out by the planners of the logistics department. This study aims to identify problematic tasks with waste, study the identified tasks and investigate whether possible opportunities for improvement exist within the scope of continuous improvement concepts, taking advantage of digitization resources and developing automatic tools;
- **Phase 2**. **Selection –** after identifying the tasks to be reviewed in this project, the requirements for the tools to be developed, necessary data and available resources are defined, in order to select the most appropriate to meet the proposed objectives and allow to streamline the tasks of planners and assist in decision making;
- **Phase 3**. **Execution –** the tools are designed using resources that users are already familiar with, such as Microsoft and Microsoft Office applications. Automatic, visual, and intuitive tools will be developed to allow users to perform their tasks more easily;
- **Phase 4**. **Testing –** the next phase consisted in the testing of the tools. These are then continuously tested by users in order to ensure their functioning, applicability and obtain feedback for possible enhancements;

- **Phase 5. Continuous Improvement** – with the feedback obtained from the testing phase, a new cycle of execution and implementation of improvements begins, with the extension of the coverage of the developed tools to their final version. It is in this final stage that the tools will be published and a new standard for their use will be developed.

1.4 Dissertation Structure

This dissertation is divided into 6 chapters:

- After presenting the main objectives and methodologies adopted, the second chapter reviews the existing literature on the themes surrounding this project, presenting relevant methodologies and frameworks;
- The third chapter presents the company where the dissertation project was developed, as well as the philosophies that drove it;
- The fourth chapter presents the diagnosis and initial situation of the analysed processes and identification and description of the identified problems;
- The fifth chapter describes the development and implementation of the proposed improvements, as well as a survey and analysis of the improvements achieved;
- This dissertation is concluded with the sixth chapter where a general balance of the project is made, conclusions and possibilities to continuously improve the work developed.

2. LITERATURE REVIEW

With the principle of continuous improvement in mind, philosophies such as the Toyota Production System (TPS) and Lean Thinking were developed, which will be presented in this chapter. This chapter will also address the evolution of these methodologies in different areas of organizations, namely the application and impact of Lean tools in logistics and information management within the supply chain. Afterward, it will focus on digitization and how companies make use of new technologies from Industry 4.0 to optimize their activities and Business Intelligence (BI) and Analytics tools to streamline processes for faster decision making. Finally, there will be a brief presentation of some logistics key performance indicators for supply chains and quantification of waste in information logistics.

2.1 Toyota Production System

The TPS (Ohno, 1988) was born after the World War II in Japan, when Taiichi Ohno started studying the mass-producing system in American and European auto industries and why it didn't work in Japan. Although mass-producing fewer types of cars reduced costs, a production system aimed at increasing lot sizes was not practical. Besides creating all kinds of waste, muda, such a production system was no longer suitable for the needs of Japanese customers. Thus, the fundamental purpose of the TPS was to produce several models in small quantities efficiently, while lowering costs and improving productivity by removing non-value-added activities from the moment the customer places an order to the moment the product in delivered.

The basis of the TPS is the absolute elimination of waste. The two pillars of the TPS are:

- Just-in-Time (JIT), connecting and synchronizing every link in the chain to produce so that each process receives the exact item needed, when necessary, and in the required quantity, avoiding excessive stock accumulations and approaching zero inventory;
- *Jidoka* – autonomation – or "automation with a human touch", developing a process to include inspection, preventing mass production of defective products, reduce the number of operators and increase production efficiency. Production is stopped when an abnormality is detected and not continue until the problem is solved.

The TPS relies on the elimination of waste. Completely eliminating these wastes can improve efficiency of the operations by a substantial margin. Seven key forms of waste are usually identified:

- **Overproduction** of unnecessary products;

- Unnecessary **waiting time** to begin the next task;
- Unnecessary **transportation** of material;
- **Over-processing** the product with extra steps;
- **Inventory** of material to be completed or finished products to be shipped;
- Unnecessary **movement** of people;
- **Defects** in the product.

Other fundamental ideas of the TPS rely on leveling production to reduce costs, establishing a production flow and a way to maintain a constant supply of raw materials, creating standard work procedures to help detect areas where process improvements can be made and promoting a teamwork mentality.

2.2 Lean Thinking

Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company pioneered the concept which Womack, Jones & Roos (1990) undertaking a detailed study of the Japanese techniques later reiterated and established within Toyota as “The Toyota Way” (Stone, 2012), named Lean Production. Influenced by the TPS, Lean Production combines the advantages of artisanal production whilst avoiding its high costs with the benefits of mass production, while increasing the flexibility of the latter.

The Lean philosophy aims to achieve increased efficiency through the elimination of waste, using the least amount of effort and optimizing material, human and capital resources to respond to customer needs (Womack & Jones, 1997). Automation and versatility are also ways to achieve greater flexibility and to promote continuous improvement, "continually declining costs, zero defects, zero inventories, and endless product variety." (Womack et al., 1990)

To the seven key forms of waste identified in the TPS, Womack & Jones (1997) added an eighth in the form of goods and services that do not meet customer’s needs, while other authors (Brito, Ramos, Carneiro & Gonçalves, 2019; Kosven, n.d.; Skhmot, 2017) identified intellect and skills underuse as the eighth waste.

Womack & Jones (1997) identified 5 Lean Principles, presented in Figure 1.

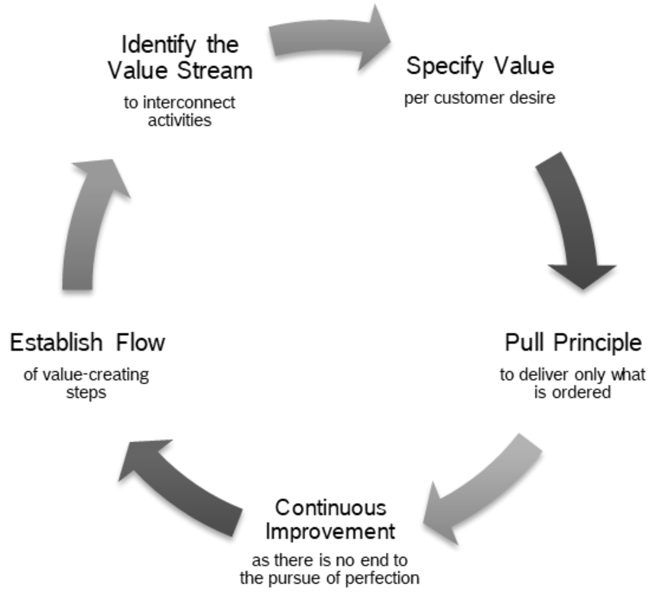

Figure 1 – The 5 Lean Principles.
Adapted from Womack & Jones (1997)

In the 90s, there was an evolution of Lean as a concept and expansion beyond its application in the automobile industry into the wider supply chain (Samuel, Found & Williams, 2015) as "any concept that provides customer value can be in line with a Lean strategy" (Hines, Holwe & Rich, 2004). Stone (2012) reviewed the evolution and application of Lean concepts beyond the shop floor application - product development, marketing, accounting, sales, and services, in addition to other areas of the enterprise. With focus on the guidelines and consequences of these applications, highlights the success of Lean transformations when aligned throughout the enterprise.

Samuel et al. (2015) argued the change of mentality regarding the Lean movement, from focusing on cost and waste reduction to value appropriation and the motivation to procure alternative approaches, concepts of quality or process improvements to enhance performance. More recently, Danese, Manfè & Romano (2018) emphasized the importance of integrating Lean implementations with the increased use of automation and information systems, particularly in the service sector. The authors review the benefits achieved with Lean practices on improved information flows, application of approppriate Information and Communication Technologies (ICT), information systems as Enterprise Resource Planning (ERP) and in decision support tools for Lean process development and supply management.

Stone (2012) and Hines et al (2004) debated on the difficulty to use Lean in various contexts of process improvement methodologies and misunderstanding as to where to apply Lean due to the variety of definitions. Hines et al. (2004) found "the distinction of Lean thinking at the strategic level, and Lean production at the operational level is crucial to understanding Lean as a whole in order to apply the right tools and strategies to provide customer value". Whereas Lean production is mainly associated with "the shop-floor tools" application "following Toyota's examples" (Hines et al., 2004), Lean thinking is a wider-ranging philosophy applicable to all systems and processes of the supply chain "in order to identify critical areas of improvement and ultimately bring about such improvements" (Hicks, 2007).

2.2.1 Lean Office in Logistics

The Lean logistics paradigm appeared with the focus on logistics non-value added activities, as logistics operations are characterized by the high level of manual control which ultimately impact the cost of operations (Pejić, Lerher, Jereb & Lisec, 2016). As noted by Jones, Hines & Rich (1997), it is necessary to evaluate the whole sequence of the supply chain, "from the customer order right back to the order given to the raw materials producer, and forward through all successive firms making and delivering the product to the customer", in order to identify possibilities for improvement and eliminate waste.

In administrative areas, the processes that add value to a product or service depend immensely, amongst other factors, on the overall flow of information and employee knowledge (Monteiro, Alves & Carvalho, 2017). The application of Lean principles in this areas is denoted as Lean office and embraces "the improvement of administrative processes and information flows" (Freitas & Freitas, 2020).

Sabur & Simatupang (2015) applied the Lean principles in activities concerning information flows, scheduling, production planning and order processing presented by Selvaraju et al. (2012) (as cited in Sabur & Simatupang, 2015) to improve customer response time. Monteiro, Pacheco, Dinis-Carvalho & Paiva (2015) improved lead times, process tasks, space organization and standardization of work implementing Lean office in the public sector, by eliminating non-value adding activities and automating tasks that were performed manually to increase efficiency in data search and daily problem-solving requirements. With the application of tools such as 5S, Poka-Yoke mechanisms, Standard Work, Visual Management and Kaizen, Monteiro et al. (2017) achieved reductions in process lead time resulted by better organization and work time management. The application of these Lean office tools "allowed to achieve greater transparency of the processes", providing "the clear identification of the tasks and responsibilities (...) throughout the process, thus facilitating the definition of priorities in the tasks to be performed".

2.2.2 Lean Information Management

In modern days' offices, it is vital to coordinate the development of information management capabilities and optimization of information flows, with emphasis on the advantages of electronic technologies and resources, guaranteeing information quality, reducing the use of paper with digitalization and increasing the use of information systems (Freitas & Freitas, 2020).

Hicks (2007) proposed a framework based on the proposition that "Lean thinking can also be applied to information management" (Figure 2), as the elimination of waste in the organization, visualization and representation of data adds value to the information and improves its flow through exchange, sharing and collaboration. Highlighted improvements on efficiency, productivity and quality of information and information management process, supporting "organizations in undertaking its core activities and sustaining its long-term competitiveness."

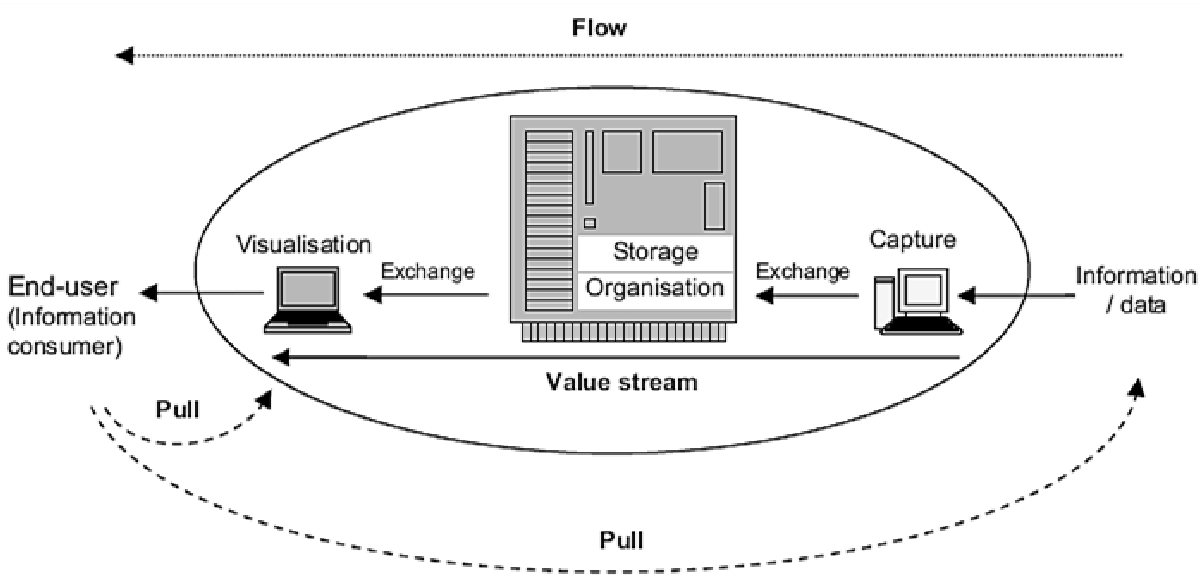

Figure 2 – The value-flow model applied to information management.
(Hicks, 2007)

In his framework, Hicks (2007) identified four main causes of waste related to the management of information, which comprise of missing or lack of information due to broken or unavailable processes, failure to identify or interconnect information due to incompatibilities in the process, generating and maintaining excessive information, making more difficult to identify essential information, and inaccuracy of the information, making corrective actions and verifications impossible. These causes identify four categories of waste (Annex 1):

- **Failure Demand** comprises extra resources and activities like generate or acquire new information, necessary to overcome missing information;
- **Flow Demand** includes the time and resources spent on the identification of the necessary information elements;
- **Flow Excess** as the time and effort necessary to manage excessive information;
- **Flawed Flow** covers the necessary steps to correct of verify information, as well as the unnecessary activities resulting from its use.

In a study to implement Lean information management at an automotive company, Bevilacqua, Ciarapica & Paciarotti (2015) proved "the usefulness of the waste classification model proposed by Hicks in waste detection and analysis" combined with the flexibility and low cost of visual solution implementations "provides complete interconnection and interoperability" within the company, as well as reduction of delays and streamlined scheduling. Other input by Bevilacqua et al. (2015), addressed the globality of applications of the implemented approach, as it can be adopted and benefit other production areas outside the automotive sector.

Freitas & Freitas (2020) identified key principles for managing information to optimize the information flow, which cover concepts related to the identification and gathering of the needed information, adequate storage, and standardization of the information for ease of access, quality assurance of information and information management and technological infrastructures for the processing and dissemination of the digital information within the organization.

The focus on improving the flow of information and implementation of a Lean approach to information management proves to be crucial to increase the competitiveness, as allows organizations to achieve improvements over a short period of time with low resource investment (Bevilacqua et al., 2015).

2.2.3 Lean Thinking in Digital Transformation & Industry 4.0

After mechanization, electricity and IT stimulated three major industrial revolutions, IoT and IoS boosted a fourth industrial revolution, Industry 4.0 (I4.0), resulting "in new ways of creating value and novel business models (…) with increased resource productivity and efficiency, creating value opportunities through new services and a high-wage economy that is still competitive" (Kagermann, Wolfgang & Helbig, 2013). Although the integration of Lean and digital transformation is relatively new, it is believed the improvements made in the field of digital transformation concerning I4.0 are "a main positive driver for development within the structure of Lean production systems" (Schumacher, Bildstein & Bauernhansl, 2020).

According to Bittencourt, Alves & Leão (2019), the implementation of I4.0 is facilitated by Lean Thinking as "it simplifies processes and eliminates waste in a way that it is not repeated, reduces the possibility of compromising scarce resources, and increases the transparency of work processes/organization." The same authors highlighted the importance of controlling and optimizing a process before automating it, as "the automation of an inefficient process does not make it efficient."

Hermann, Pentek & Otto (2016) and Santos, Oliveira e Sá, Andrade, Vale Lima, Costa, Martinho & Galvão (2017) identified important guidelines for I4.0 implementations, which focus on interconnection and interoperability of systems, people and information in CPS, information transparency and real-time operation capability allowing continuous data acquisition and processing, decentralization for better decision making and virtual and physical assistance, focusing on service orientation and modularity to provide greater flexibility and agility to CPS.

To guarantee a successful digital transformation and harmonization with Lean elements, it is necessary to deeply understand digital technologies and its effects on the optimization and waste reduction of information flows, allowing the adaptation and exploitation of "synergies in the sense of value-added oriented processes" (Hoellthaler, Meister, Braunreuther & Reinhart, 2020). Santos et al. (2017) and Wee, Kelly, Cattel & Breunig (2015) identified a set of enabling technologies for I4.0 in the field of data, computational power and connectivity, analytics and intelligence, human-machine interaction and digital to physical conversion such as big data/open data, IoT, cloud technology, digitalization and automation, advanced analytics, mobile and augmented reality, additive manufacturing and advanced robotics. Wee et al. (2015) also noted that cloud technology, digitalization of knowledge work, big data and advanced analytics have the greatest impact on software, process industry and logistics sectors.

Hoellthaler et al (2020) proposed a framework to classify and characterize digital technologies within technological fields of ICT, identification technologies and automation technologies, which application allowed for more efficient information flows, declining trial and error rates and improving overall process speed thus increasing efficiency. In his study, Hoellthaler et al (2020) expected the proposed framework to offer "starting points and potential levers to improve information processes in the context of information logistics" and incentivize "to use digital technologies accordingly".

2.3 Business Intelligence & Business Analytics

Good information management competences to integrate, transform and access business data are fundamental to distinctive analytical capabilities. As Davenport & Harris (2007) noted, "it's better to know

(…) than to believe or think or feel" as "most companies can benefit from more analytical decision making."

BI is characterized as the technologies and processes that advantage the extensive use of data to comprehend and analyse the performance of organizations, as Business Analytics (BA) makes the use of statistical and quantitative analysis with explanatory and predictive models possible to achieve greater efficiency and drive smarter decision making and better business actions (Davenport & Harris, 2007). Analytical applications range from a variety of tools and systems, including simple data analytics, manipulation and visualization tools as Excel and Power BI, as complex deep learning algorithms and predictive analysis, applicable in a wide range of techniques to assist organizations in forecasting, simulation and optimization to streamline and improve decision making (Krishnamoorthi & Mathew, 2018).

The same authors studied the synergies and impact of analytics resources on business performance (Figure 3) and provided fundamental insights for BA practices in organizations.

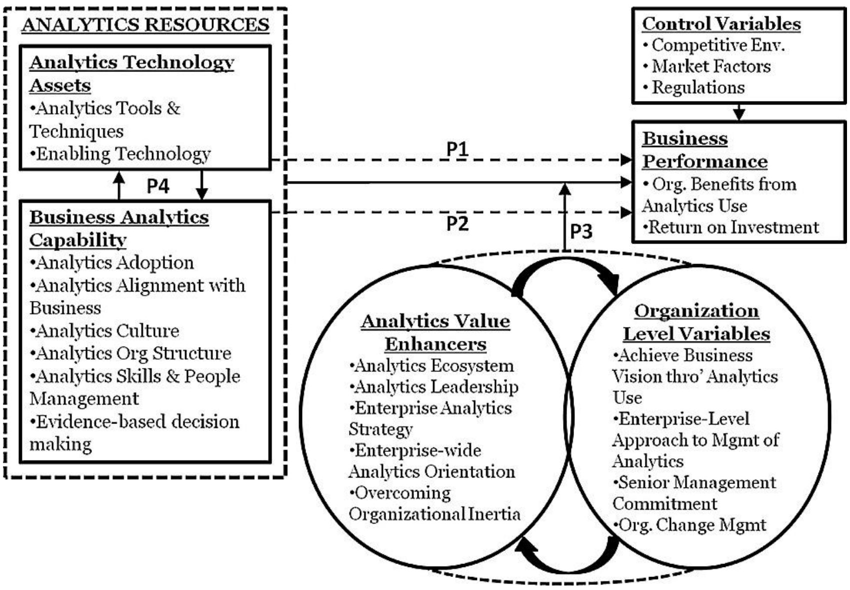

Figure 3 – Synergies and impact of analytics resources on business performance.
(Krishnamoorthi & Mathew, 2018)

Silva, Cortez, Pereira & Pilastri (2021) added that, although BA has proven useful in the optimization of resources and detect customer needs, still are few the number of research application studies within this topic.

Data quality is an essential characteristic that determines the reliability of data for decision making in organizations. Specifically, guaranteeing high-quality dependable data is a competitive advantage for all industries (Salem & Abdo, 2016).

2.3.1 Data Analytics & Big Data Analytics

Developments within I4.0 provided multiple new sources of information, with continuous data being generated by several sources like sensors, controllers and smart manufacturing systems which, taken advantage of the increased volume, variety and velocity of information, allows the possibility for enhancements within sustainable innovation (Santos et al., 2017). Through data analytics, extracting useful information from raw data allows for the discovery of patterns and relationships from rough data, thus improving process understanding, support decisions and reduce the time spent analysing data (Li, Zhang, Zhao, Pu, Chen & Liu, 2021; Santos et al., 2017). Whereas the emphasis of BI is in the measurement of past and current business performance (Davenport & Harris, 2007), the development of big data applications is focused on "exploration, discovery and prediction" (Debortoli, Müller & vom Brocke, 2014).

Within the field of big data analytics, Santos et al., (2017) studied the application of "a Big Data system aimed to validate a Big Data Analytics architecture" and it's improvements on analytical capabilities, supporting decision making, providing the possibility for faster and more streamlined data analysis and JIT response to possible problems.

2.3.2 Data Visualization

There are several ways to view and present data. Information processing can be strongly supported by Visual Analytical Tools that combine automated and interactive modelling (Cimini, Lagorio, Romero, Cavalieri & Stahre, 2020). Combining different databases with different visual layouts that leads to unique visual interfaces enables gathering more information in a shorter time (Nazemi & Burkhardt, 2019), revealing how important it is to focus on detecting and repairing data inconsistency problems.

Through dashboards, managers and planners can receive useful information that is customizable, easy to use and presented almost in real time, proving crucial "understanding the characteristics of dashboards that promote use and lead to individual and organizational performance gains" (Reinking, Arnold & Sutton, 2020). Additionally, dashboards can be as narrow or broad as needed, allowing organizations to create multiple dashboards to better organize their analytics. Designing a dashboard must be different from other visualisation systems. For instances, the information must be accessible and easily comprehended by the users, avoiding any distracting functionalities. Displaying data in tabular form is superior to graphs, allowing for greater detail and broader analysis. However, graphs reduce the information overload when compared to tables (Tokola, Gröger, Järvenpää & Niemi, 2016).

Contemporary information systems such as production and logistic dashboards provide vast amounts of information and, in those large volumes, frequently the user cannot find appropriate and important information on demand (Nadoveza & Kiritsis, 2013).

Dossou (2019) studied these concepts with the purpose of improving a company's supply chain. In this study, the author stated that "each user should have its dashboard integrating data required for taking good decisions", developing a framework of different dashboard types for the different purposes they should serve (Figure 4).

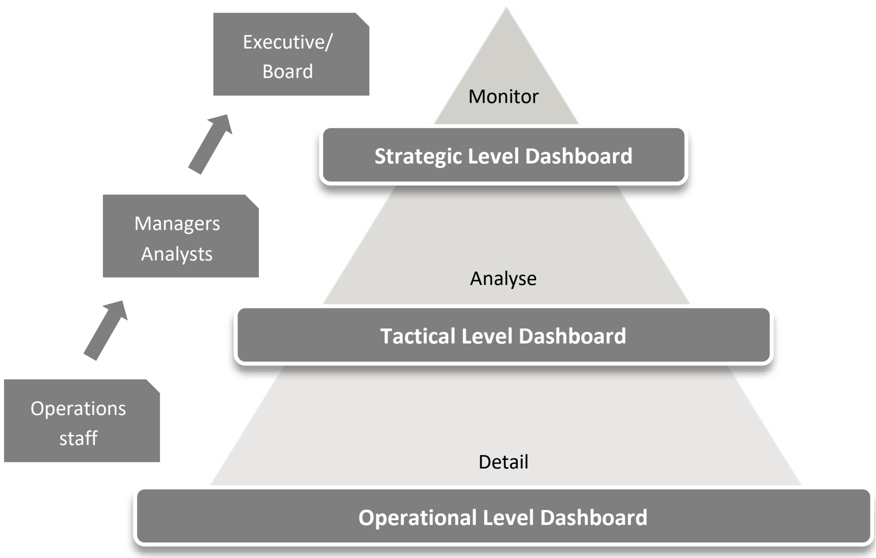

Figure 4 – Structure of dashboards.
Adapted from Dossou (2019)

Dashboards' structure must cover the three decision levels in an organization (Figure 4) and integrate criteria measures useful for each different level. At the operational level, dashboards must define specific operational indicators and measures. At the tactical level, these measures must be aggregated to provide an analysis on the overall system and provide the results for supporting in the decision-making process at the strategic level (Dossou, 2019).

2.4 Key Performance Indicators

Business monitoring or control is a critical activity to access business performance, enabling organizations to evaluate operations, discover problems and aiding "decision makers to take corrective actions sooner better than later" (Badawy, El-Aziz, Idress, Hefny & Hossam 2016). This monitoring is supported by an information system that gives information about several KPIs. Carvalho, Duarte & Machado (2011) identified cause and effects relationships between various performance measures and supply chain attributes, and how it can impact costs, flexibility, innovation, integration, and several key indicators of the supply chain (Annexes 2 and 3).

When addressing information management in organizations, it is possible to quantify wastes and problems related to operations in logistics with specific KPIs. Meudt, Metternich & Abele (2017) and Hartmann, Meudt, Seifermann & Metternich (2018) presented three model indicators:

- **Digitalization Rate (DR)** (defined by equation 1) indicates how much of the information is acquired automatically and digitally captured without human interaction and paper storage. Low DR indicates the existence of wastes in data generation, transformation, processing, or storage;

$$DR\ (\%) = \frac{\Sigma\ Automatically\ Acquired\ and\ Digitally\ Captured\ Data}{\Sigma\ Total\ Captured\ Data} \quad (1)$$

- **Data Availability (DA)** (defined by equation 2) assesses the availability of information, relating the amount of information collected from a value stream to all the information desired. High DA provides a background for continuous improvement processes and improved decision making;

$$DA\ (\%) = \frac{\Sigma\ Captured\ Information}{\Sigma\ Desired\ Information} \quad (2)$$

- **Data Usage (DU)** (defined by equation 3) evaluates the utilization and usefulness of the information collected, as stored data without a defined usage is considered waste. Low DU may indicate unnecessary data collection or storage, as well as non KPI-driven management.

$$DU\ (\%) = \frac{\Sigma\ Used\ Information}{\Sigma\ Captured\ Information} \qquad (3)$$

These KPIs objectivise problem causes in information logistics and the usage of information, by providing a percentage value of a standard set of data points which are collected in processes and aiming that every planed and collected data should be used for continuous improvement processes or decision making (Meudt et al., 2017).

3. THE COMPANY

The projects that served as the basis for the formulation of this dissertation were developed within the logistics department of Bosch Car Multimedia, S.A., the Bosch unit in Braga that belongs to the Automotive Electronics (AE) division, and it is the largest of the Group in Portugal.

This chapter will introduce a brief history of the Bosch Group, business sectors and their divisions. Thereafter, the Braga unit will be presented, detailing the main products, customers, and organizational structure of the area where the projects were developed. The chapter ends with the presentation of the methodology adopted by the company, Bosch Production System (BPS), an adaptation of the TPS whose objective aims to keep Bosch a competitive leader in future production systems.

3.1 Bosch Group

Today's globally operating company began in Stuttgart in 1886. Robert Bosch founded the "Workshop for Precision Mechanics and Electrical Engineering", characterized by its innovative strength and social commitment. By 1990, the Bosch company had taken the first steps onto the global market, with subsidiaries in two of the largest European sales markets for automobiles, United Kingdom and France. The 1960s through to the 1980s were marked by transformation at Bosch, turning it into a diversified group with self-managed divisions, a global company, and the market leader in AE. More recently, IoT and IoS opened many new lines of business for Bosch, aiming cover everything from automated driving to smart homes and autonomous communication between factory machinery.

Today the Bosch Group is a leading global supplier of technology and services. Its operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. It employs nearly 395,000 associates worldwide, with 440 subsidiaries and regional companies in over 60 countries, sales, and service partners in 150 countries and regions around the globe, with generated sales of 71.5 billion euros in 2020 (Figure 5).

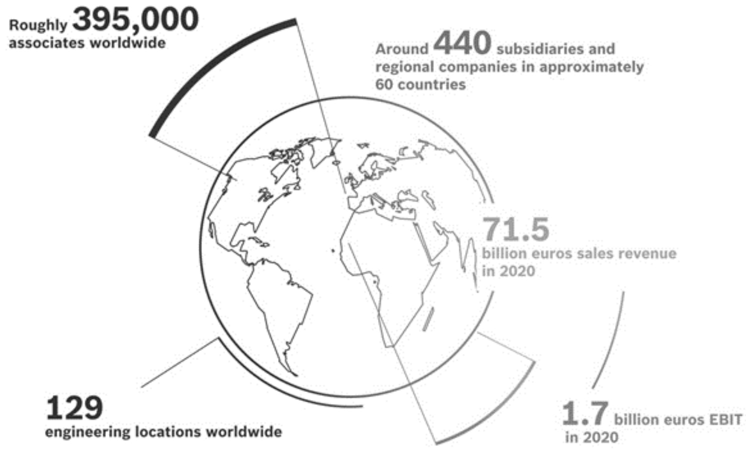

Figure 5 – Sales revenue, associates, locations — key figures and brands at a glance.
(Company | Bosch Global, n.d.)

Bosch in Portugal

In 1911, Gustavo Cudell established the first Bosch sales office in Portugal. Today its represented by Bosch Termotecnologia, in Aveiro, Bosch Car Multimedia Portugal, in Braga, and Bosch Security Systems, in Ovar. In these locations the company develops and manufactures hot water solutions, automotive multimedia and security and communication systems, respectively, most of which are exported to international markets. With more than 5,500 employees, Bosch is one of the largest industrial employers in Portugal and generated, in the last years, several millions of euros in internal sales.

3.2 Bosch Car Multimedia, S.A.

The Bosch unit in Braga, this work was developed, belongs to the AE division and it is the Group's largest in Portugal. Focused on the development and production of multimedia solutions and automotive sensors, this Bosch location also hosts teams from other divisions in the Mobility area, such as Cross-Domain Computing Solutions, Chassis Systems and Automotive Aftermarket.

3.2.1 Customers & Products

Bosch Car Multimedia Portugal provides a large portfolio of customers from all over the world. The Bosch unit in Braga is responsible for the development and manufacture of navigation systems, state-of-the-art infotainment, instrumentation systems and clusters, steering angle sensors and control unit, and instrumentation clusters for two-wheel vehicles (Figure 6).

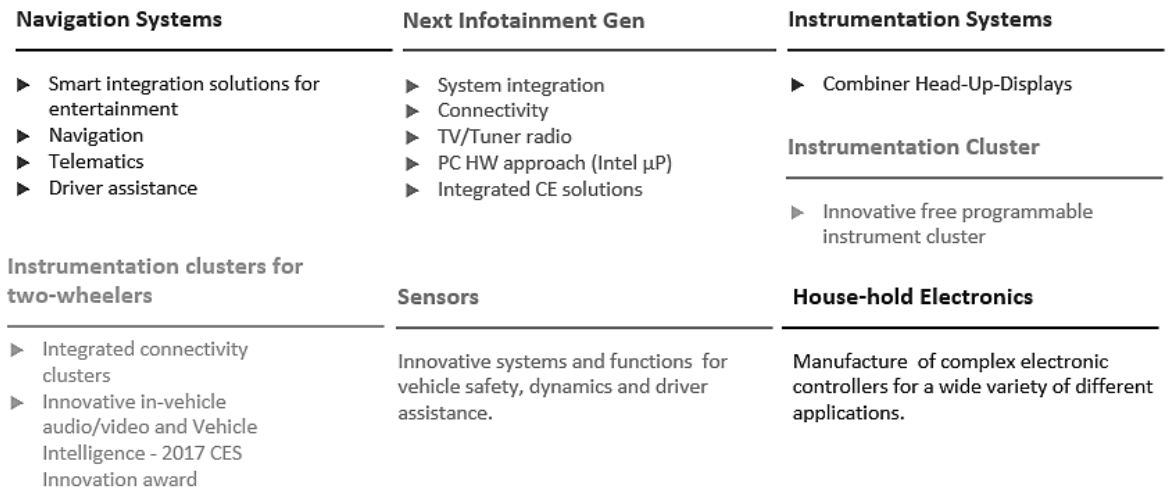

Figure 6 – Current Product Portfolio.
(Bosch Internal Documentation)

3.2.2 Organizational Structure

The internal organization of Bosch Car Multimedia, S.A. is divided into two main areas: Commercial Area (Figure 7) and Technical Area (Figure 8).

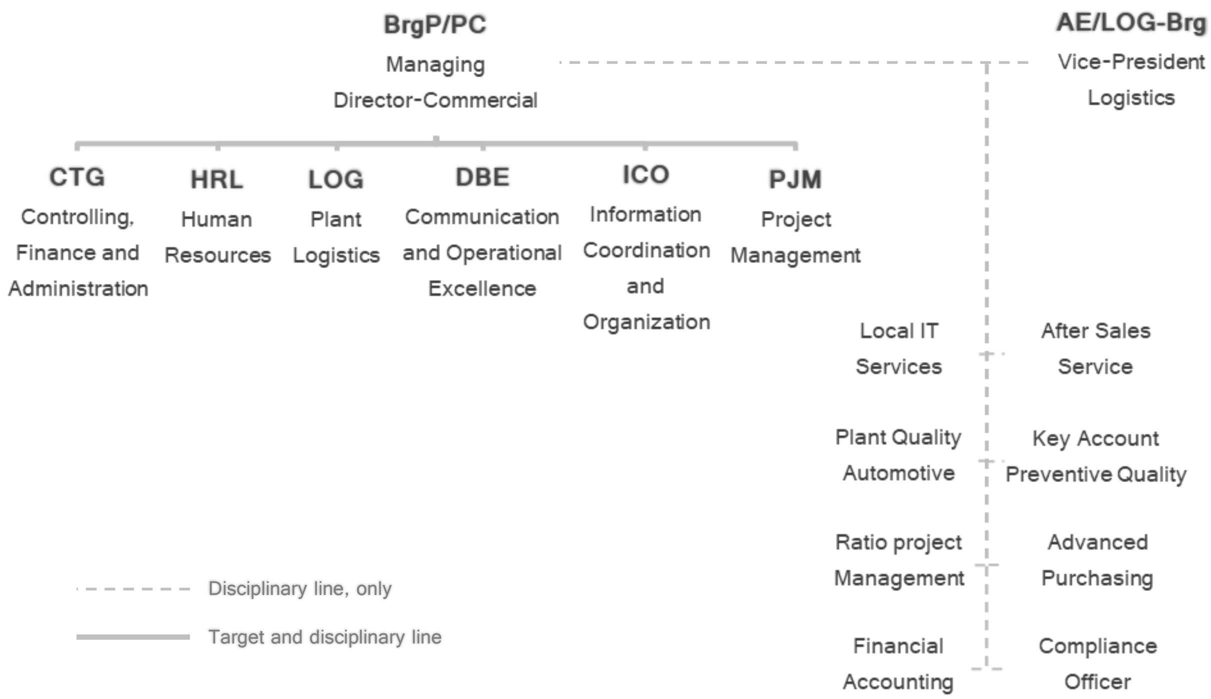

Figure 7 – Commercial Area Organization in Braga.

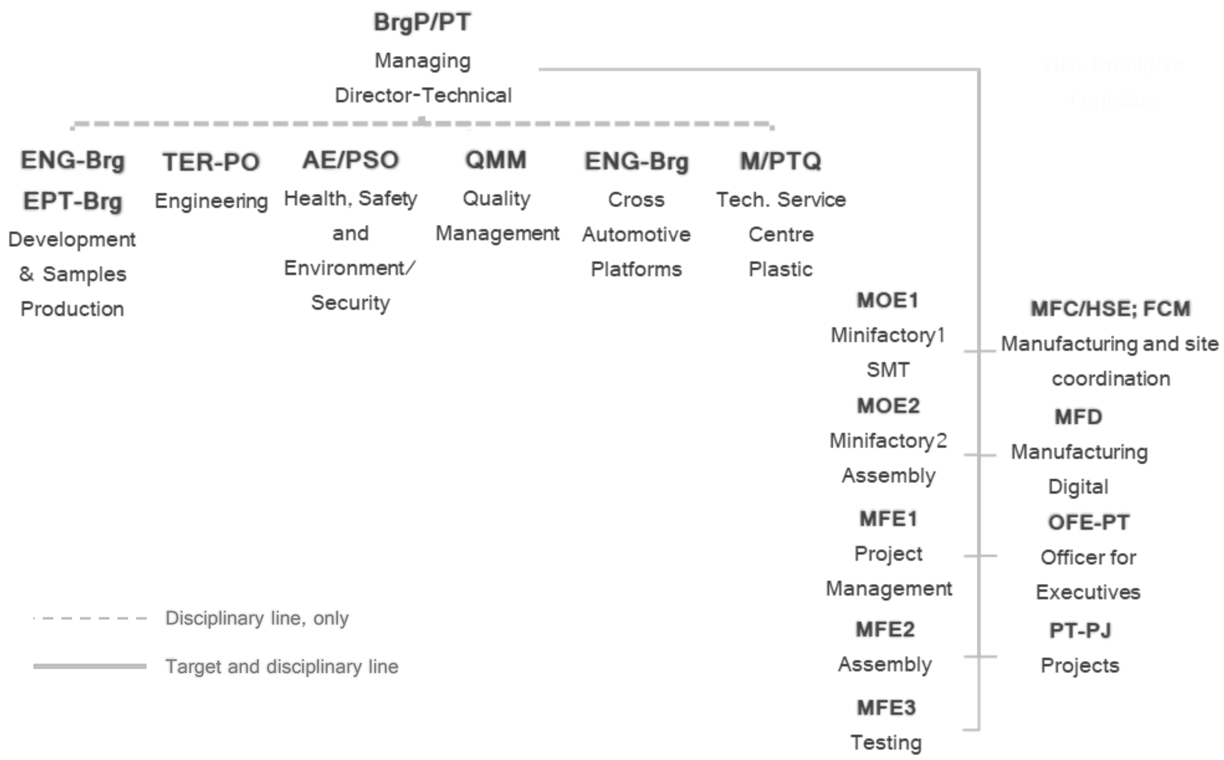

Figure 8 – Technical Area Organization in Braga

Within the Plant Logistics (LOG) Department (Figure 9), division where the work was developed, there are also subdivisions according to the functions performed within the supply chain, all working together to optimize and manage the supply chain of Bosch in Braga.

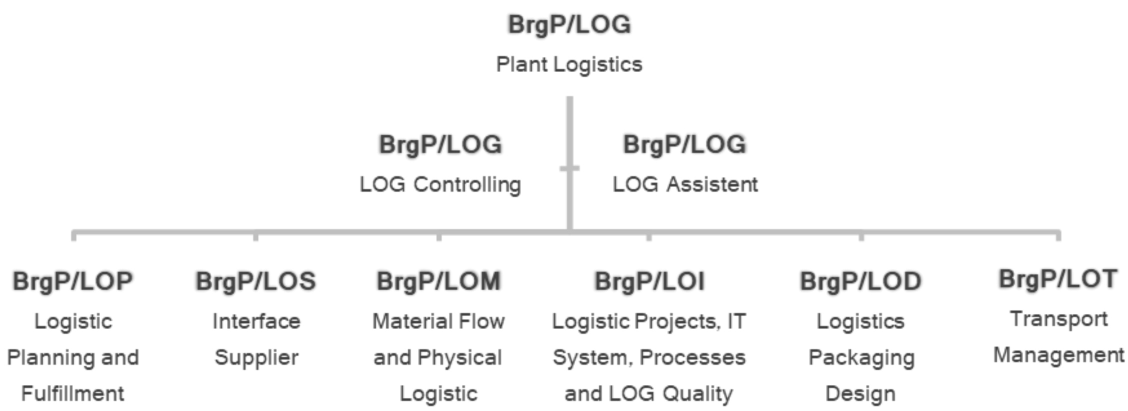

Figure 9 – Organizational scheme of the logistics department in Braga

The projects stated in this dissertation were developed within the scope of the activities of the Logistic Projects, Information Technology (IT) System, Processes and LOG Quality (LOI) subdivision. This team is responsible for Logistic Innovation, IT Systems, Processes, Logistics Service Provider management and LOG Quality, as well as supporting other teams within the logistics department. The tools described in this dissertation were designed with and for the Logistic Planning and Fulfilment (LOP) subdivision, in order to motivate and support the continuous improvement of its activities.

3.3 Bosch Production System

A fundamental prerequisite for success is the capability of meeting customer requirements faster, better and with lower expenses than the competition. In order to achieve this, originated in 2001 the BPS, designed to organize the supply chain and all supporting processes, improving them continuously. The fundamental objective of BPS is Lean and waste-free production with a fast and continuous material flow.

Nowadays, digitalization and connectivity spur the further development of BPS. Based on standards in the order fulfilment process and a data strategy, additional possibilities are created for further improvements that incorporate suppliers and customers. The continuous collection of more and different types of data forms the basis of IT-supported data analysis that further reduces waste in the supply chain.

The basics of BPS include fundamental notions such as added value and waste, through a waste-free order fulfilment process with a constant material flow as the ideal state of the value stream. The BPS principles, methods and rules serve as a guide for action and the BPS elements, implementation tools as guidelines for executing tasks and assuming responsibilities.

3.3.1 BPS Principles

Inspired by the TPS pillars, the BPS is based on eight principles which form the basis for actions and cooperation among the various functions in the design of a sustainable, waste-free and agile supply chain, including supporting the digital transformation of Bosch (Figure 10):

- **Pull principle –** produce and supply only what the customer wants;
- **Process orientation –** develop and optimize processes holistically;
- **Fault prevention –** avoid errors by means of preventive measures;
- **Flexibility –** adapt products and services quickly and effectively to current customer requirements;
- **Standardization –** standardize processes and implement best-in-class solutions;

- **Transparency** – design self-explanatory and straightforward procedures, where deviations from the target situation are immediately apparent;
- **Continuous improvement** – develop continuously and in a targeted way;
- **Personal responsibility** – know the tasks, competencies and responsibilities and carry them out actively and independently.

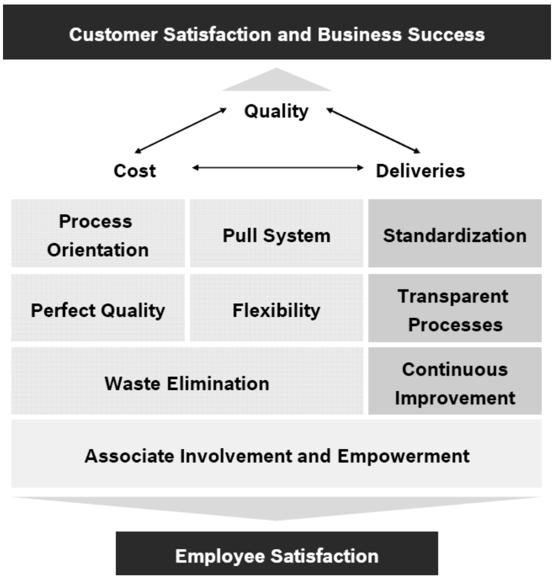

Figure 10 – Eight Principles of BPS.
(Bosch Internal Documentation)

3.3.2 BPS Elements

BPS elements are tools and methods used to implement the BPS principles: Value Stream Planning; Standardized Work; Leveling; Consumption Control; Project Flow Board and Critical Chain Project Management; 5S – Order and Cleanliness; Lean Line Design; Flow-oriented Layout; Quick Changeover; Ship-to-Line; Cyclic Material Supply; Total Productive Maintenance; Shopfloor Management Cycle; Poka Yoke.

3.3.3 BPS & Digitalization

The ICT field of innovation delivers key differentiating factors for Bosch products and services by driving the digital transformation of Bosch in all domains, aiming to increase the efficiency and quality in the development of systems and software through automation, virtualization, and data-driven intelligence as fundamental approaches to achieve these goals.

Bosch takes advantage of a variety of systems and software to support its activities, such as:

I. System Analysis Program Development (SAP)

SAP is an ERP software, an information system that connects processes and data from multiple departments of an organisation in a single system, enabling the automation and storage of all information of a business. This type of interconnection has two perspectives:

- functional perspective - as finance, accounting and logistics systems;
- systemic perspective - as transaction processing, information management and decision support systems.

II. Business Intelligence for Logistics (BI4Logistics)

As defined within Bosh, BI4Logistics supports BI services for analytical and data exploration scenarios in Bosch Mobility Solutions with focus on Logistics (Figure 11). The centralized processing and preparation of data assures a high maturity of logistics KPI.

The purpose and vision for this system is to use case-based development, offering easy access and minimizing the access time by giving the end user the ability to open and interact with high performance reports and enabling visualization of reporting results via dashboards with easy handling and interactive charts.

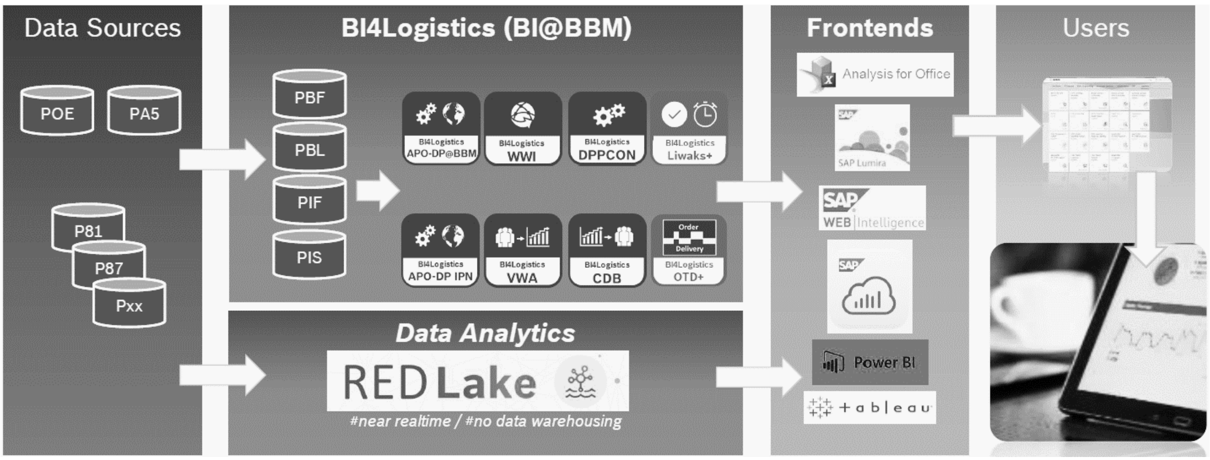

Figure 11 – BI4Llogistics architecture.
(Bosch Internal Documentation)

III. Demand and Production Planning Control (DPPCon)

DPPcon is a simple form of data warehouse integrated into the BI4Logistics system, where a daily data upload is made that contains daily, weekly and monthly data snapshots that provide standardized and use case-based reports (Figure 12).

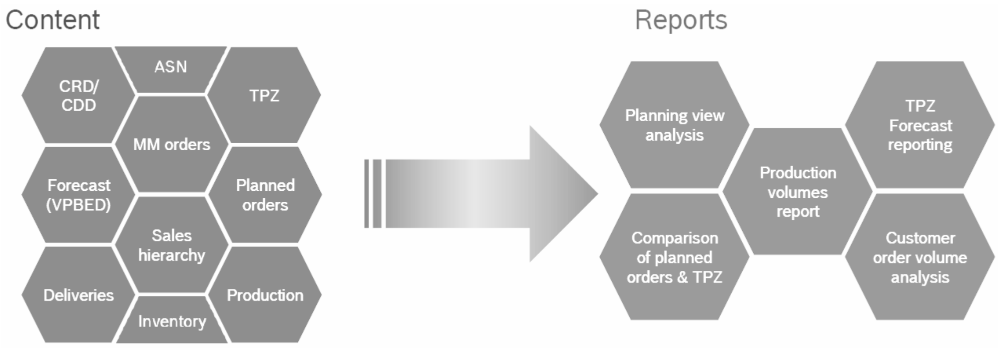

Figure 12 – DPPCon data content and reports.
(Bosch Internal Documentation)

IV. Data Analytics Supply Chain (DALI)

DALI is a system that contains a database and it's used in Bosch as a replica of SAP, where the data is refreshed almost at real time. It comprises information of several SAP and non-SAP systems to enable supply chain analysis based on real-time data and DALI applications (Figure 13).

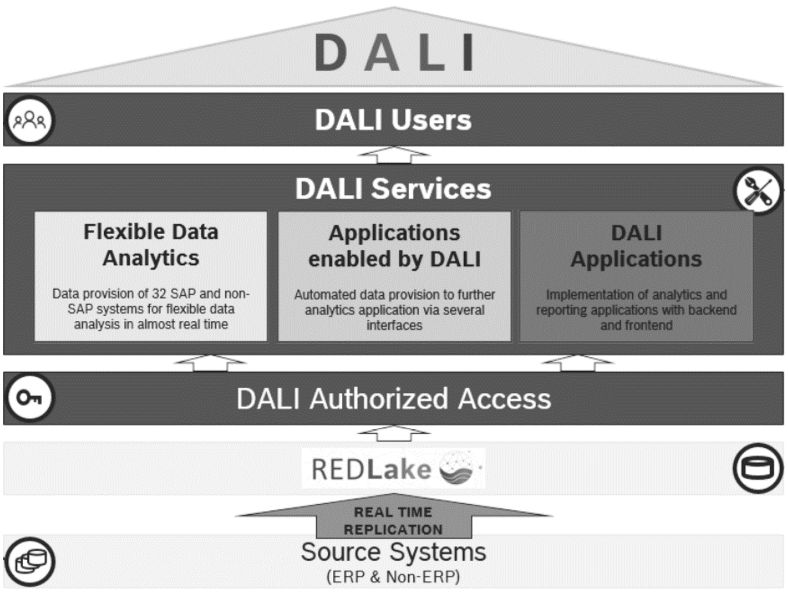

Figure 13 – DALI at a glance.
(Bosch Internal Documentation)

4. Analysis & Diagnosis

Within the scope of continuous improvement activities promoted by the BPS, several activities with waste and opportunities for improvement were identified, namely in the daily tasks of the LOP department planners.

Bosch, like other major technology and automotive industry companies, is facing the consequences of a global semiconductor components shortage. This electronic components' crisis, despite affecting the supply since 2018, was aggravated by the Covid-19 pandemic. Factory closures severely affected chip production for most suppliers which caused stock to drain while, in contrast, there was an increase in demand for electronic components such as computers, televisions and tablets with the widespread use of homeworking due to global lockdowns. The recurring crisis, along with catastrophes such as the floods in Taiwan, trade barriers between China and the United States of America and even the obstruction of the Suez Canal caused instability in the supply of raw materials and significantly increased lead times for semiconductors. The inability to respond to demand and uncertainty in the supply of raw materials has caused serious losses for the automotive industry, making it crucial to streamline the supply chain with longer term orders and respond more rapidly to any changes in forecasts.

In this section, the main wastes and problematic tasks in the daily activities of planners are identified, their main causes are explored and possibilities for improvement are presented, including supporting the tasks of planners who work incessantly to respond and mitigate the effects of the electrical component crisis at Bosch.

4.1 Process Overview

Tasks performed in the planning department consist of Customer Orders Management and Production Planning & Control. All activities related to the reception, acceptance, and management of orders from customers are part of the daily tasks of the planners in the LOP department (Figure 14), as well as production planning, leveling, and controlling, both in short and long term. It is also the responsibility of the planner to be in direct contact with the customer to ensure transparency in the supply chain.

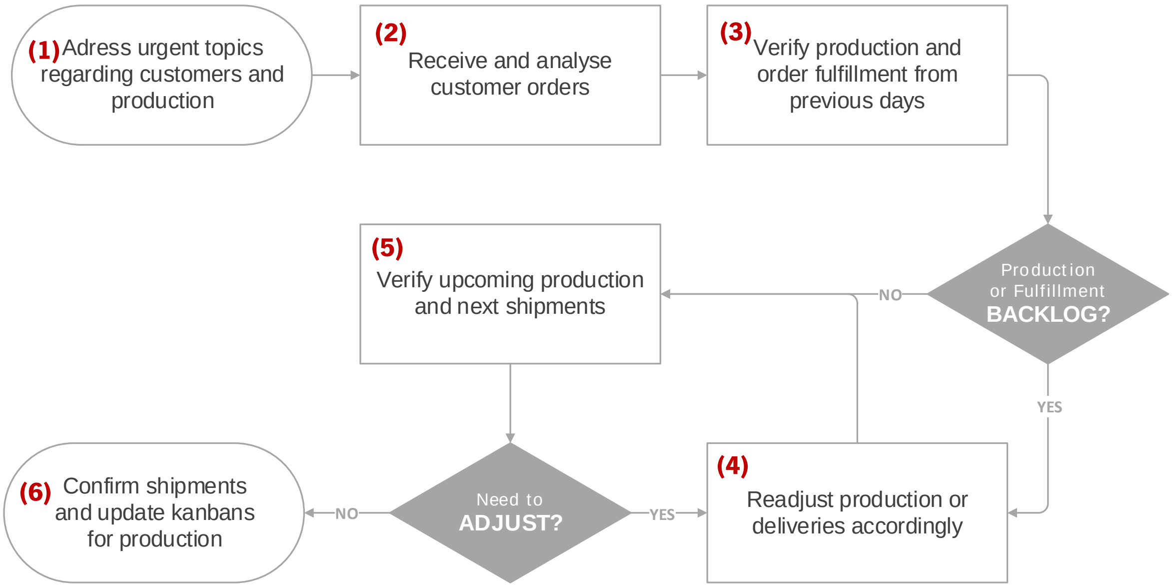

Figure 14 – Planners' daily activities.

Daily, the planner starts by checking SAP for errors in receiving customer orders, production line problems or fulfilment issues, and contacts the customer if further information is needed (1). Customer orders are transferred via Electronic Data Interchange (EDI) and planners need to receive and analyse them to plan according to the customer needs (2). The planner controls daily production and confirms with the line manager that orders are fulfilled, delays or problems in the production of a shift, if there is backlog and that raw material coverage is ensured (3). If required, the planner can adjust the production plan accordingly (4). It is also the daily responsibility of the LOP planner to validate production plans for the following days (5), confirm and communicate upcoming deliveries to customers and launch production orders (6).

Weekly, the planner is tasked with leveling production. To accomplish this, must check with the head of section the daily and weekly production capacity of the production lines and the coverage of raw material with the purchasing department, LOS. With these data collected, the leveling is made in external system and the resulting production plan is imported to SAP and sent to the production lines. Longer term production planning is done fortnightly. Planning is carried out for the current month and the next three months, and these plans will always be subject to change as necessary. This long-term planning is discussed and approved in a meeting once every two weeks between LOP, LOS, automatic insertion, and production engineering.

4.2 Problem Identification

As stated in chapter 2.2.2, there are several types of waste arising from inadequate principles of information management and the deficiency of use of digital and automated data analysis tools. These problems were identified in the activities of receiving and analysing customer orders, mainly to verify if there were variations in the ordered quantities and if they are allowed in the customer's contracts (Figure 15).

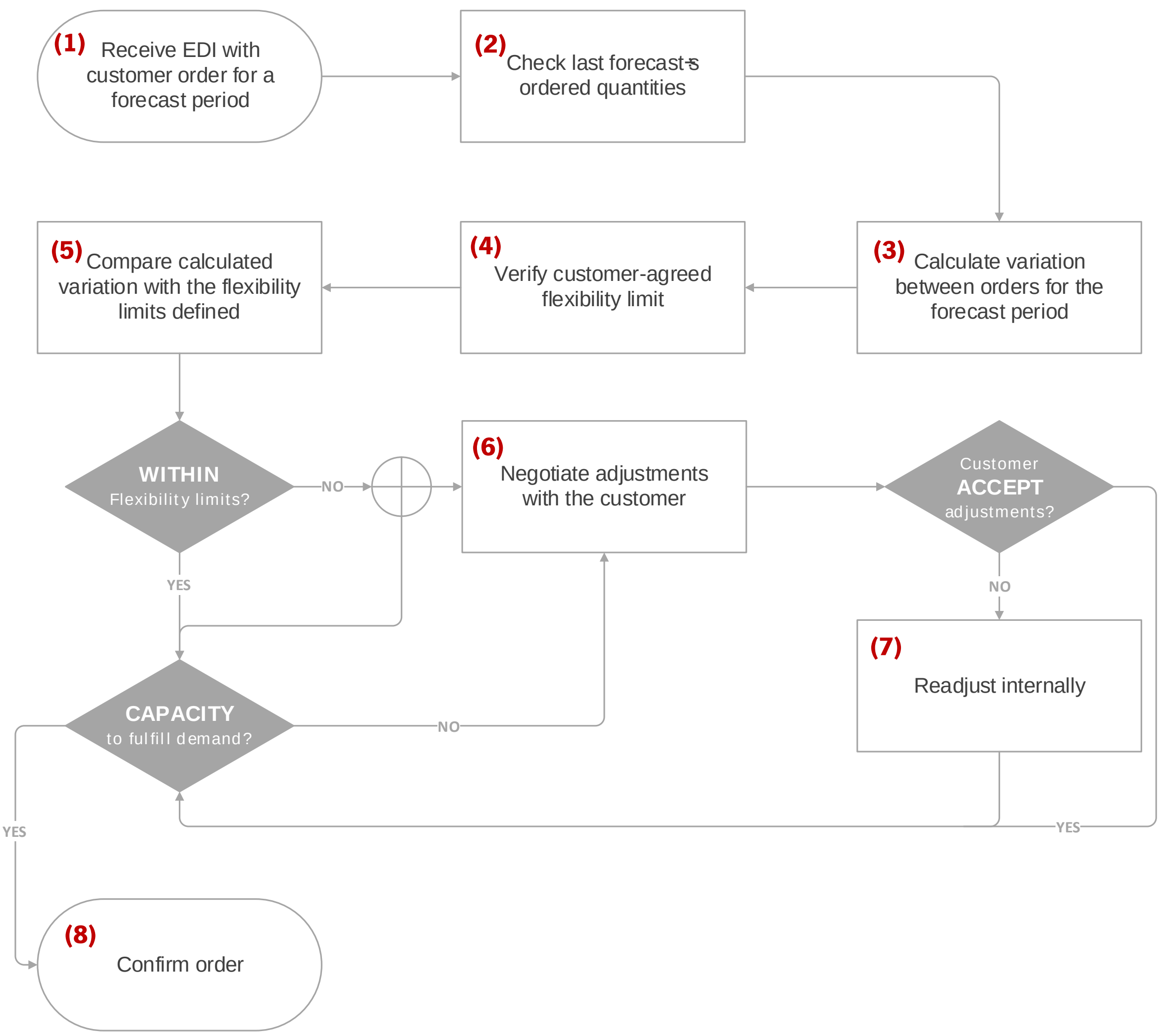

Figure 15 – Customer order variation analysis.

When examining new orders (1), the planners also check for any alteration in the demand quantity (2 and 3) and whether is within the variation limits fixed with the customer (4 and 5). The order is accepted if the variation is within the flexibility rules (8); if not, adjustments need to be made with the customer (6), as long as is within the reaction time, or in the production plans for the forecast period (7). This analysis is crucial to determine whether the plant has the capacity to fulfil the order, or it needs to renegotiate order quantity or reallocate production for the next forecast period. Currently, per planner, these tasks require about 3,5 hours per week or 42 minutes per day, with most of this time spent on collecting data, calculating variations, and selecting and adjusting the flexibility limits – around 30 minutes per day.

Numerous wastes are also identified when leveling production and in auxiliary tasks of collecting information to plan, adjust production plans, and communicate information to customers.

The planner accesses multiple different SAP systems and transactions to collect information on customer orders, production plans, backlog orders and final product inventory, to verify how many parts are in stock of each raw material, quantities received, and planned to be received: to confirm receipts plans and total raw material coverage, contacts the LOS planner responsible for the corresponding part, since LOS maintains direct contact with the supplier and can rapidly inform of any changes to the planned receipts in the system. Since the information is spread over the different systems and sources, the planner has to search and compile it in order to proceed with its analysis, which results in great waste of time and overall capacity of the planners.

4.2.1 Time & Manual Effort

The main problem identified is that planners waste too much time and manual effort on tasks like data searching, collection, and reporting.

When checking if orders variations are within the flexibility rules agreed with customer, this occurs because there is not a report, a dashboard nor a tool that automatically analyses order variances, so planners must calculate them manually. Furthermore, in order to know which flexibility rule should be applied to an order, planners must consult the different customer requirement matrixes and customer logistics manuals. These files are individual for each customer, and contain information on the contracts, mainly terms and conditions agreed with the customers. This analysis must be done within the reaction time permitted by the customers, which is not standard for every customer nor very long. As a consequence of not fulfilling this task on time, planners have to accept the order leading to capacity problems to fulfil the orders, as well as shortage of raw materials in orders with large increases in variations. On the other hand, there is a wasteful accumulation of stocks with large decreases in orders quantity.

When leveling production, this occurs because planners use a manually populated Excel file which determines the coverage of a particular raw material based on the final products that use the raw material. This file contains great quantity of data that is obtained through the various integrated systems and other departments. It requires being filtered, cleaned, and prepared to then being manually pasted in the final Excel file. In addition, there is information that is not being considered in the existing files but must be integrated, namely the usage of raw material in each final product and different raw material numbers can be substituted by one another, therefore should be analysed together.

4.2.2 New Allocation Rules

Another problem raised from the crisis of electrical components that results in the scarcity of raw materials. Consequently, production must be adjusted following the rules for allocation of raw materials to final products and customers.

Usually when planning and leveling production, raw material coverage is given for the total availability raw material and planned deliveries. Since shortage, the amount of raw material must be divided and allocated according to rules defined centrally and distributed by a Task Force (TF), a Bosch internal team created to respond to the electronic components' crisis, responsible for calculating and communicating the fair share allocation to all plants of AE within Bosch Group. This rule is adhered to all customers affected by missing or critical raw materials, which allows the allocation of parts to be fair and adapted to customer needs. Accordingly, the current files used to level production will have to be adapted to accommodate the new logic defined by the TF and allow not only visualization through final products affected by a raw material, but also which raw materials affect a final product.

5. Project Development & Implementation

These projects focus mainly on optimizing time and manual effort spent on tasks like data searching, collection, and reporting, essential to improve the analysis of customer orders, support in planning, adjusting, and leveling production and facilitate decision making within the Logistics Planning and Fulfilment department of Bosch Car Multimedia, S.A. It is also expected that the creation of the proposed tools will accomplish the standardization goal aimed within the BPS, help mitigate consequences of the electrical components' crisis and complement the planner's work.

This chapter will describe the development of the two projects studied in this dissertation. First, the development of an interactive dashboard to analyse variations in customer orders and compare with the flexibility rules agreed with the customer – Order Variation Dashboard. Secondly, the development of two automated template files that allow the visualization and simulation of production plans by raw material and project as well as critical raw material coverage.

5.1 Order Variation Dashboard

Currently, for analysis of order variations, it is necessary to generate several reports whose data sources have different origins. There is no common repository for all customers where flexibility rules are available, as well as a tool that consolidates the results for later analysis and action by planners.

To define what procedures should be structured to accomplish the automation objective, the most important aspect was to ascertain what type of tool would best support the planners in their analysis, what data should be taken into consideration and how that data should be displayed.

The purpose of the tool would be to compare current week's releases with snapshots of previous releases for a specific forecast period, clearly and visually indicating whether there is variation between the current release and the forecast release and whether this variation is permitted or restricted by the flexibility limits contractually defined with the customer. Furthermore, the tool should also be able to quantify the variation, as this information is necessary to report to the customer.

The team of planners was already acquainted with the use of dashboards, using them daily to support planning activities, examine stocks levels, coordinate production backlogs and occupation of production lines. Therefore, it was decided to develop a new dashboard sheet for the management of customers' orders and integrate it into the team's existing dashboard. This dashboard would be powered by reports that could also be consulted if planners needed a more detailed analysis, and it would report information regarding releases, forecasts, variations in quantities and flexibility rules associated with each customer.

The first step taken into the project development was to analyse the planners' daily activities and how the tasks were currently performed, then automate as possible these tasks. Three main actions were established:

- Automate order variation calculation;
- Analyse flexibility rules by customer;
- Develop Order Variation dashboard.

The first two actions identified consisted of the creation of the reports that would serve as the database for the dashboard and the third action is the development of the dashboard itself.

5.1.1 Automation of order variation calculation

To retrieve data relating to customer order volume analysis, standard data sources – SAP – and centralized manual data inputs were used. The report taken from DPPCon into Excel consists of weekly snapshots of the data available on the system for the different weeks of the calendar. It contains the parameters of each order and quantities ordered by Calendar Week (W) taking place in each Snapshot Week (SW).

Each order release is characterized with a set of predetermined parameters. Customers place an order for a final product which is associated to a project that can contain more than one final product. This means that each project can comprehend multiple products, but a product can only be associated with one project.

To automate the calculation of the variation of order releases, the first stage was to define which forecast period would be considered. The requirements for unit of time to be selected and the time horizons to be compared were defined by the dynamic variables within the report from DPPCon, and:

- The variation in releases would be calculated on a weekly basis as there are no significant daily variations;
- To allow for records comparison, the report would comprise information of releases from the snapshot of the current week (SW_n) up to six weeks prior (SW_{n-6});
- Only variations in percentage in releases between the snapshot of current week's releases (SW_n) and the two previous weeks (SW_{n-1} and SW_{n-2}), in a 60-week calendar horizon (W_{n-8} to W_{n+52}) would be considered.

For each calendar week, the variations of the ordered quantities (Q) are calculated with equations (4) to (6).

$$\Delta Q_{SW_{n,n-x}} = Q_{SW_n} - Q_{SW_{n-x}} , for\ x = \{1, 2, 3, 4, 5, 6\} \quad (4)$$

$$\Delta_{SW_{n,n-1}}(\%) = \left(Q_{SW_n}/Q_{SW_{n-1}}\right) - 1 \quad (5)$$

$$\Delta_{SW_{n,n-2}}\ (\%) = \left(Q_{SW_n}/Q_{SW_{n-2}}\right) - 1 \quad (6)$$

After identifying the parameters characterizing each release and the fields needed for the calculation, the order variation report was created. (Table 1).

Table 1 – Order variation calculation report.

Calendar Week	**Order Release Parameters**	**SW_{n-6}**	**...**	**SW_n**	$\boldsymbol{\Delta Q_{SW_{n,n-1}}}$	**...**	$\boldsymbol{\Delta Q_{SW_{n,n-6}}}$	$\boldsymbol{\Delta_{SW_{n,n-1}}}$	$\boldsymbol{\Delta_{SW_{n,n-2}}}$
W_{n-8}		PC	...	PC	PC	...	PC	%	%
...		...	...	...	...	...	...	...	...
W_{n+52}		PC	...	PC	PC	...	PC	%	%

The report comprises information of orders variations quantity, in pieces (PC) and percentage (%) per customer material, project, ship-to, plant and total volume with data retrieved from various integrated systems.

5.1.2 Flexibility rules analysis

Each customer group has agreed flexibility rules applied to all orders commissioned by that customer, consequently applied to the projects to which the products are associated, although there are projects associated with multiple customers with different rule sets. Following the completion of the orders variation report was the development of the flexibility rules report. It consisted of gathering the logistics analysis reports from the different customers, standardize the flexibility rules defined within the agreements and group customers and projects by standard. Four standard rules were identified (Figure 16): Increase/decrease *percentage limit set per week*; *Project specific* rules; *Maximum order quantity calculation tables*; *Must comply* to order quantity.

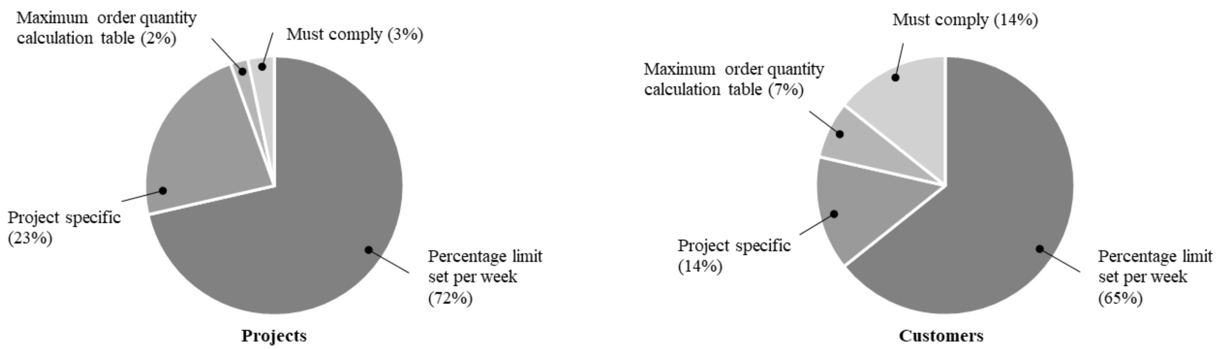

Figure 16 – Project and Customer distribution by standard.

The development of the report and dashboard mostly includes the most significant standard, *percentage limit set per week* (72% of projects and 65% of customers), since there is no standard guideline for active projects with *specific rules* (23% of projects and 14% of customers) and customers with *must comply* rules (3% of projects and 14% of customers) are outside the scope of this analysis. For the *calculation tables* standard (2% of projects and 7% of customers), an adapted calculator (Figure 17) was developed, accessible through the dashboard. It returns, by entering specific parameters, what are the maximum daily, weekly, and monthly quantities allowed to order. The calculator is based on data tables and calculation instructions provided by customers.

CALCULATOR - *CALCULATION TABLES* STANDARD

INPUT FIELDS	
Last Periodic Forecast	17600
Number of Worked Days	20,5
Consumption Coefficient	1
Packaging Unit	100
Volume Constraint	1000
Average Daily Consumption (ADC)	**858,54**

Maximum Quantity in Flexibility Tables	**1070**
w/ consumption coefficient	**1070**
Maximum DAILY Consumption	**1000**
Maximum Quantity in Flexibility Tables	**4625**
w/ consumption coefficient	**4625**
Maximum WEEKLY Consumption	**4700**
Maximum Quantity in Flexibility Tables	**17958**
w/ consumption coefficient	**17958**
Maximum MONTHLY Consumption	**18500**

Figure 17 – Calculator developed for *calculation tables* standard.

Based on the periodic forecast, the average daily consumption of each product is compared with the flexibility tables provided by the customers in order to identify the maximum consumption quantities which, multiplying by the consumption coefficient provided, allows the calculation of the maximum order quantities for each period (daily, weekly or monthly).

The standard increase/decrease *percentage limit set per week* characterizes the limit as a percentage change defined in a predetermined time horizon, in weeks (Table 2). This standard is known in 9 customers and more than 60 projects of the plant.

Table 2 – Flexibility rule standard general example - *percentage limit set per week.*

	x%		y%				z%		
W	0	+1	+2	+3	+4	+5	+6	+7	+8
	-x%		-y%				-z%		

This example characterizes a flexibility rule defined on a 9-week horizon. W_0 is considered the week the order is released, and the rule is applied over the next 8 weeks. In this example, the first two weeks following the posting of the purchase order, W_0 and $W_{+1,}$ have allowable quantity changes of ±x%. The next four weeks, W_{+2}, W_{+3}, W_{+4}, and $W_{+5,}$ allow quantity changes of ±y% and the last three weeks of the horizon, W_{+6}, W_{+7}, and $W_{+8,}$ ±z% variation.

After identifying the fields characterizing the first flexibility rule standard, the flexibility rules report was created (Table 3). This Excel report aims to centralize the manual data inputs as well as serve as database to the dashboard.

Table 3 – Flexibility rules report.

Calendar Week	**Customer**	**Rule Description**	$\Delta_{SW_{n,n-2}}$ **Upper Limit**	$\Delta_{SW_{n,n-2}}$ **Lower Limit**	$\Delta_{SW_{n,n-1}}$ **Upper Limit**	$\Delta_{SW_{n,n-1}}$ **Lower Limit**
$\mathbf{W_{n-2}}$			%	%	-	-
$\mathbf{W_{n-1}}$			%	%	%	%
...			...	...	...	...
$\mathbf{W_{...}}$			-	-	%	%

The report comprises information of percentage limits (%) per customer group with data retrieved from the requirements matrixes of customers.

5.1.3 Dashboard development

After completing the Excel reports that would serve as the database for the dashboard, the final action was to design an easy, visual, and interactive dashboard in Power BI[1], with graph comparison between order variation percentage and flexibility limits defined. Since planners have access to all the information detailed in the reports, it would be unnecessary to repeat data in the dashboard, displaying only the information that would be relevant in the comparison between order variation and flexibility rules in the dashboard.

The developed dashboard (Appendix 1) contains two charts that represent variations in orders between snapshot weeks for the different calendar weeks and compares these variations with the limits set by the rules (Figure 18).

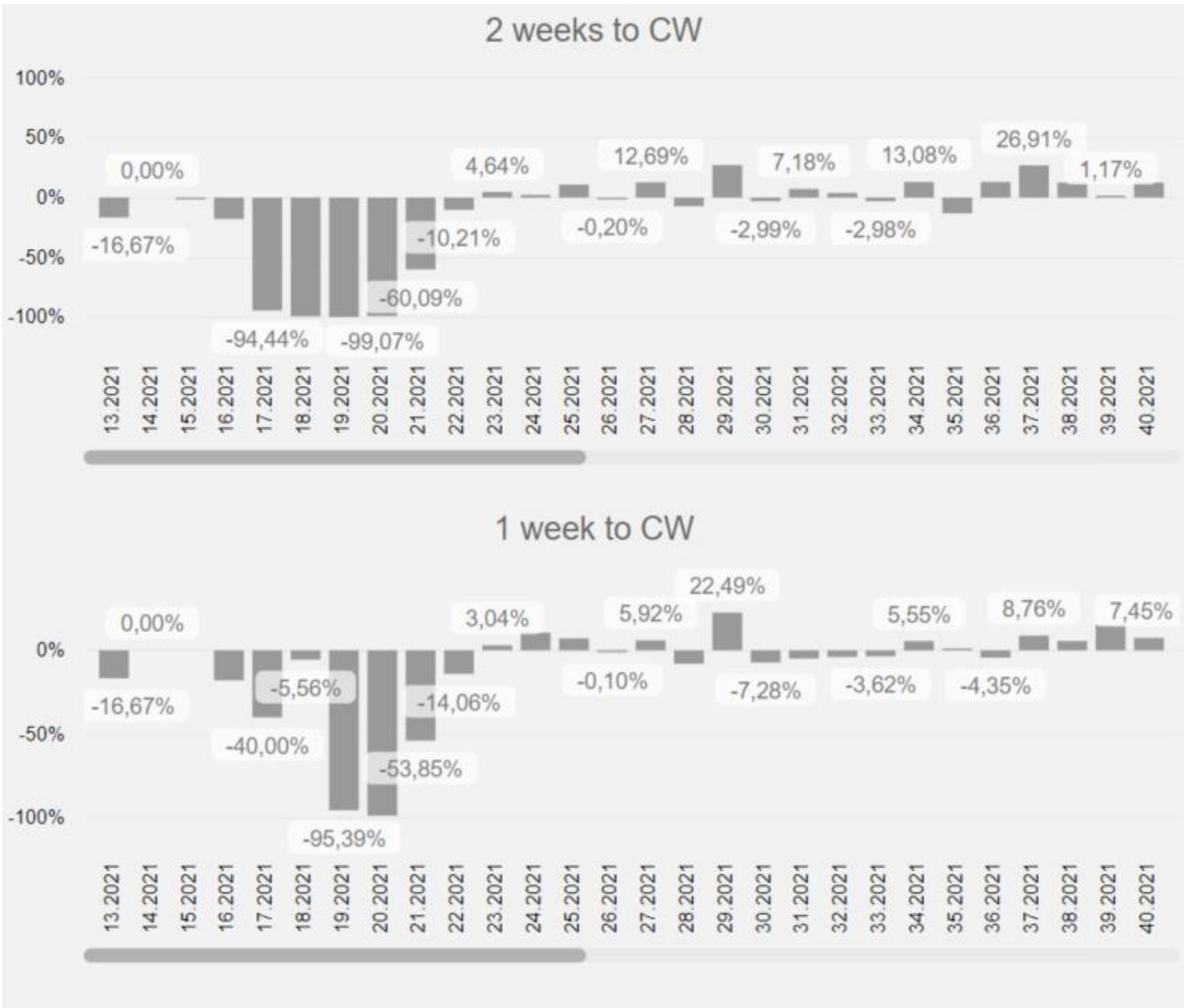

Figure 18 – Order Variation dashboard – variation (%) and comparison charts.

[1] Power BI is a Microsoft software that provides interactive visualizations and BI features, allowing users to create and customize their own dashboards and reports to take advantage of greater data insight.

It also contains a table with the quantities ordered each week (1) and another with variation quantities (2) (Figure 19).

(1) Releases

Calendar Week	SW15	SW16	SW17	SW18	SW19	SW20	SW21
13.2021	38	13	12	12	12	12	10
14.2021	898	159	51	51	51	51	51
15.2021	278.101	4.133	589	302	152	151	151
16.2021	335.456	199.198	4.336	137	134	134	110
17.2021	384.797	352.737	230.485	21.889	108	10	6
18.2021	377.911	347.987	334.107	221.711	4.918	36	34
19.2021	334.469	344.116	345.032	313.014	204.155	6.353	293

(2) Differences

Calendar Week	SW15 - SW21	SW16 - SW21	SW17 - SW21	SW18 - SW21	SW19 - SW21	SW20 - SW21
13.2021	-28	-3	-2	-2	-2	-2
14.2021	-847	-108	0	0	0	0
15.2021	-277.950	-3.982	-438	-151	-1	0
16.2021	-335.346	-199.088	-4.226	-27	-24	-24
17.2021	-384.791	-352.731	-230.479	-21.883	-102	-4
18.2021	-377.877	-347.953	-334.073	-221.677	-4.884	-2
19.2021	-334.176	-343.823	-344.739	-312.721	-203.862	-6.060

Figure 19 – Order Variation dashboard – variation (PC) and comparison tables.

The planner selects the parameters concerning the order to be analysed in the filters area (3) and selects the rule set corresponding to the customer for whom the order is placed (4) (Figure 20). Descriptive information of each selected rule set is also provided (5). The centralized master report (6) is accessible through the dashboard, where the data is refreshed weekly, as well as adding, modifying, or eliminating flexibility rules. The two reports created in the previous sections are available in the master report as well. It is also through the dashboard that planners access the calculator for orders analysed by the *calculation tables* standard (7).

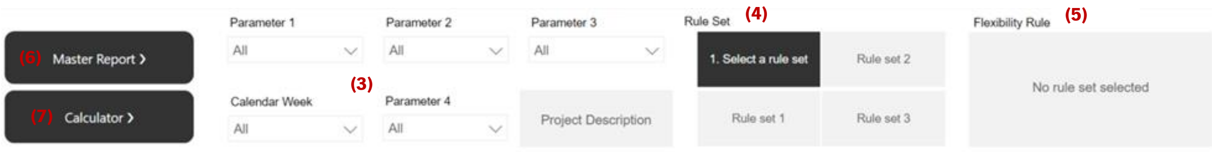

Figure 20 – Order Variation dashboard – filter and information area.

The dashboard represented in Figure 21 contains fictitious data reporting order releases for a product from weeks 13.2021 to 21.2022. In the current week of the analysis, 22.2021, the releases in the week's snapshot, SW_{21}, are compared with the snapshots of the previous two weeks, SW_{19} and SW_{20}. This variation is represented by the values of the columns in both charts. Line values represent the maximum percentage variations allowed.

When analysing calendar week 22.2021, it is observed that:

- In the snapshot for the week two weeks prior to the current week, SW_{19}, the ordered quantity for week 22.2021 was 7 186 PC, while in the current week's snapshot, SW_{21}, the ordered quantity is 5 196 PC. This decrease of 1 990 PC (equation 4) represents a variation of -27,69% (equation 6) in the ordered quantity that is outside the permitted limit of ±10% for that week.
- In the previous week's snapshot, SW_{20}, the order for week 22.2021 was 5 746 PC, and in the current week's snapshot, SW_{21}, 5 196 PC. This decrease of 550 PC (equation 4) represents a -9,57% (equation 5) variation that is within the permitted limit of ±10%.

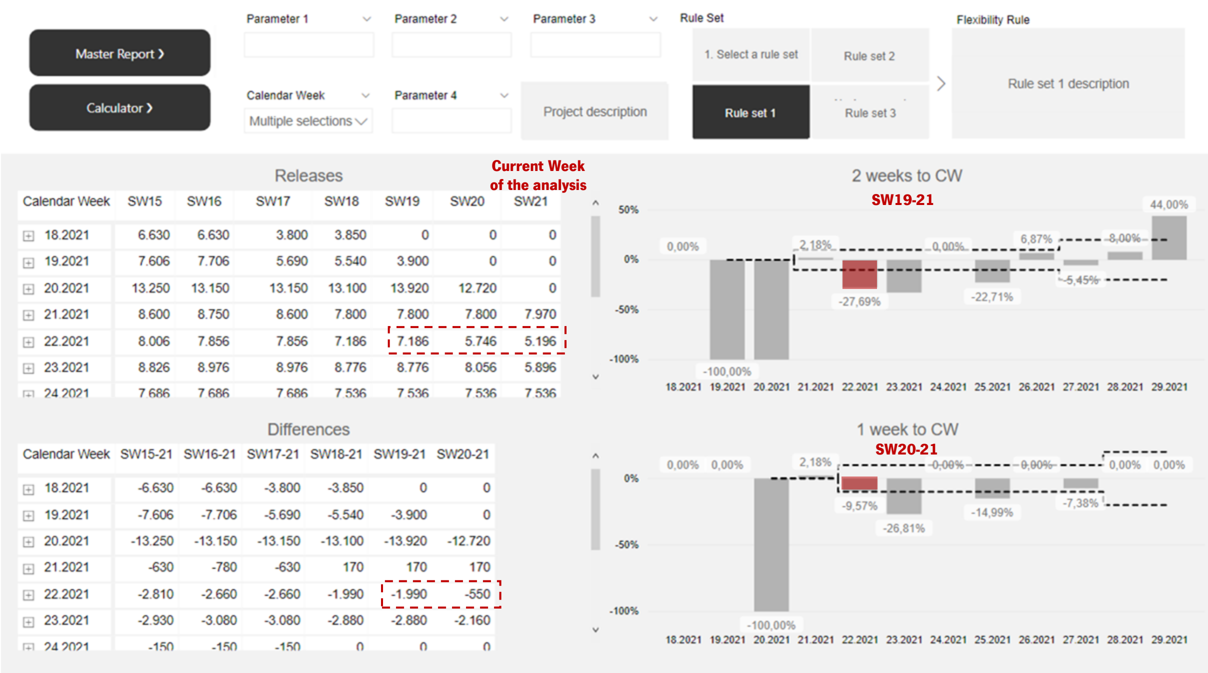

Figure 21 – Order Variation dashboard – Analysis example.

In this example, for the selected order parameters, *Rule set 1* was chosen, whose defined flexibility limits are described in table 4 and table 5. In the dashboard used by the planning team, *Rule set 1* is named after the customer with the agreed flexibility limits. For confidentiality purposes, it was renamed in this dissertation.

Table 4 – *Rule set 1* description for SW19.

	0%		10%						20%											
W	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	0%		-10%						-20%											

Table 5 – Rule set 1 description for SW20.

	0%		10%						20%											
W	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	0%		-10%						-20%											

Based on the information synthesized in the dashboard, the final decision always depends on the planner. In the example, for week 22.2021, it is observed that the reduction compared to the amount ordered two weeks before is greater than the one allowed by the flexibility limits, but the reduction compared to the previous week is allowed. This means that, according to the flexibility rules, the planner must inform the customer of the excess quantity and can reject the reduction that exceeds the allowed limits. However, depending on the circumstances in which the plant finds itself, the planner may not reject the order. Reliant on the quantity of product that is in stock, it may be in the planner's interest to reject the reduction and deliver the originally ordered quantity to the customer, avoiding keeping large accumulations of inventory. On the contrary and taking into consideration the crisis in electronic components that is affecting the industry, the reduction in the quantities ordered is beneficial for the planner, as it allows the relocation of critical raw materials to other orders and maintain the satisfaction of customer needs.

This design made it possible to achieve the main objective of this dashboard, comprehensible and easily interpreted by planners, providing an overview of customer orders, and helping planners' decision making. Ideally, the planner stops manually checking the comparison between orders variation and customer flexibility rules, automatically obtaining the information to report to the customer.

5.2 Standard Allocation Files

The existing manual Excel file has a similar structure to a Material Requirement Planning table and it determines the coverage of a particular raw material based on the final products that use the raw material (Figure 22). Each file displays a unique raw material and comprehends, for each project, information on customer demands, planned production orders, backlogs, stock of raw material, finished product inventory, coverage of raw material and finished product in addition to consumption and planned receipts of raw material, in days (CD) and in weeks (CW).

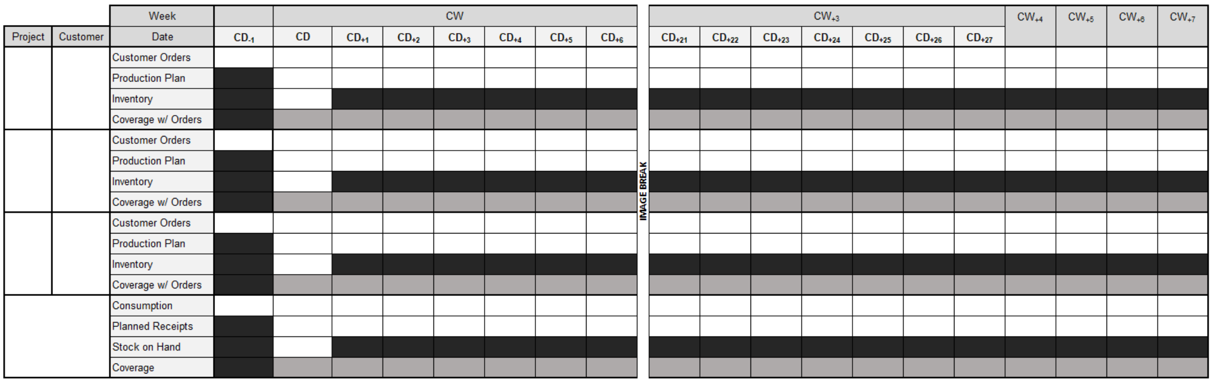

Figure 22 – Standard Allocation Files by Raw Material Template.

The file considers only a short-term time planning horizon of eight weeks: the first four weeks in days and the last four weeks on a weekly basis, as requested by the planning team. To line up with the shorter-term and longer-term production planning and forecasting functions, the first action taken was extending the horizon to cover sixteen weeks of planning, comprising of approximately four months: the first four weeks, approximately one month, in days and the next twelve weeks, approximately three months, on a weekly basis. The timeframe and time measures considered were defined internally by the LOP planneSrs' team, with the purpose of adapting the files to their needs. Although SAP contains a heuristic that automatically plans production based on orders and available inventory, within four months the production is manually adjusted by the planners. This allows for greater control over automatic system changes and regulate resource needs.

To populate the file, it is necessary to gather data relating to customer demands ($Q_{Ordered}$), production plans ($Q_{Planned}$) and quantities to be received ($Q_{Planned\ Receipts}$) within the defined timeframe, both on a daily and weekly basis. Considering the available quantities in stock (Q_{Stock}) of raw materials and final product, the coverage (C) for each day/week (n) is calculated with equations (7) to (10) and integrated in the templates (Appendix 2).

$$C_{Final\ Product_{CD}} = Q_{Stock} + Q_{Planned_{CD}} - Q_{Ordered_{CD}} - Q_{Backlog} \tag{7}$$

$$C_{Final\ Product_{CD+n}} = C_{Final\ Product_{CD+n-1}} + Q_{Planned_{CD+n}} - Q_{Ordered_{CD+n}}, n > 0 \tag{8}$$

$$C_{Raw\ Material_{CD}} = Q_{Stock} + Q_{Planned\ Receipts_{CD}} - Q_{Consumed_{CD}} \tag{9}$$

$$C_{Raw\ Material_{CD+n}} = C_{Raw\ Material_{CD+n-1}} + Q_{Planned\ Receipts_{CD+n}} - Q_{Consumed_{CD+n}},\ n > 0 \tag{10}$$

In the existing file, the planned quantity of final product to be produced ($Q_{Planned}$) is equal to the planned quantity of raw material to be consumed ($Q_{Consumed}$), as currently the usage of raw material in the final products is not considered, because of the high effort required to manually download that data. In addition, the existing file only allows for a view by raw material, it is also necessary to adapt the file making it possible to analyse the coverage by project, a set of final products.

Since the data sources for both files developed is the same, the next step, taken into the development of the project, consisted of collecting the different data sources, creating and organizing the data in reports and automate the writing of the file as much as possible. The next sections detail the development of reports with data that will feed the allocation files and its development and automation.

5.2.1 Information collection & consolidation

The data needed to analyse the coverage of raw material and final product is spread across several systems. In order to be able to use the data in the allocation files, it is first necessary to collect and organize it into reports, and then integrate the developed Excel reports for the filling of the files. When retrieving information from the system, it is necessary to select not only the information that is required, but also the identifiers that will also allow the data to be intersected between the multiple reports. To this end, unambiguous reports were created for the data to be retrieved by the formulas in the Standard Allocation Files and additional supplementary tables developed that allow for data aggregation.

I. Critical Raw Materials List & Planned Receipts

The foundation of allocation files is the identification of critical parts. The main criteria for inclusion in the list of critical parts is raw materials on severe shortages, with recurrent stoppages and likely to oblige the planning of an allocation share to several clients. In addition to critical parts identified by TF, materials that will not have receipts planned for the next two weeks are also considered in the list, criteria defined internally between the LOP and LOS planning teams.

This identification is made by the LOS planners, the department whose main function is the management of supplier orders. For each critical part identified, LOS must also provide information regarding the planned quantities to be received for the period considered by the allocation files. Considering this, the report for critical raw materials was created (Table 6).

Table 6 – Critical raw material & planned receipts report.

Critical Part	**Date Added**	**Vendor**	**LOS Responsible**	**CD_{-1}**	**...**	**CD_{+26}**	**CW_{+4}**	**...**	**CW_{+12}**
				PC	...	PC	PC	...	PC

The report contains the list of critical parts, identification of seller, LOS planner responsible and quantities planned to receive for each day/week of the time horizon considered. Filled out daily by LOS planners, allows LOP planners to know which raw materials are most affected by the crisis of electronic components and if it is necessary to make changes to the production already planned. Furthermore, it provides the list of raw materials, or critical parts, to be considered by the allocation files.

The values of this report will serve the raw material coverage calculation formulas ($C_{Raw\ Material}$) with the quantities of critical pieces planned to receive ($Q_{Planned\ Receipts}$) in the considered timeframe.

II. Bill of Materials (BOM)

After identifying the critical parts to be considered by the allocation files, it is necessary to know which final products of the factory are affected and in what quantity the raw material is used. For this purpose, the BOM is consulted for each final product, which gives the relationship between critical part, final product and usage quantity.

The BOMs are downloaded from SAP, exported into an Excel file and the output file is automatically cleaned and filtered for the raw materials in the critical parts list, creating the BOM report (Table 7).

Table 7 – BOM report.

Critical Part	**Final Product**	**Usage Quantity**

This report provides a unique combination of critical part, or raw material in the critical part list identified by LOS and final product, with corresponding quantities used, essential for converting quantities of final product to be produced ($Q_{Planned}$) into quantity consumed ($Q_{Consumed}$) of raw material (11).

$$Q_{Consumed_{CD}} = Q_{Planned\ CD} * Q_{Raw\ Material\ Usage} \tag{11}$$

III. Customer Demands, Production Plans & Inventory of Finished Products

Once the critical parts are identified and which final product are affected, it is necessary to know the quantity ordered of each product, for each project, for the considered timeframe, and the scheduling of the quantities to be produced, available and retrieved daily from SAP.

Since the allocation files consider different time measures, it is necessary to have a report for each time measure in the timeframe - daily, weekly and monthly. The snapshots reports contain information of quantities (PC) of EDI Orders and Production Plans for each final product of each project.

For the daily report (Table 8), a timeframe of four months was considered: the previous three months (CD_{-93}) are considered to carry out the review of orders in backlog, defined by the team leaders with the department's administration, and the current month, in days (CD_{+31}), for the daily visualization.

Table 8 – Daily snapshots report

Plant	Project	Final Product	Attribute	Q_{CD-93}	...	Q_{CD+31}
			EDI Order	PC	...	PC
			Production Plan	PC	...	PC

For the weekly report (Table 9), the entire four-month timeframe was considered, the current week (CW) and the following fifteen weeks (CW_{+15}). It allows not only to obtain the necessary data to complete the final allocation file, but also a more macro view of customer orders for the timeframe considered, as these reports will be available for consultation.

Table 9 – Weekly snapshots report.

Plant	Project	Final Product	Attribute	Q_{CW}	...	Q_{CW+15}
			EDI Order	PC	...	PC
			Production Plan	PC	...	PC

For the monthly report (Table 10), all previous timeframes were considered, that is, the previous three months (CM_{-3}), the current month (CM) and the following four months (CM_{+4}). The information on quantities in this report is not used directly in the allocation files. Instead, this report allows planners to get an overview of demands and production plans for the entire timeframe considered. Furthermore, this report contains all combinations of final products and corresponding projects with orders/production in the time horizon, which will be used in an auxiliary report.

Table 10 – Monthly snapshots report.

Plant	**Project**	**Final Product**	**Attribute**	Q_{CM-1}	Q_{CM}	…	Q_{CM+4}
			EDI Order	PC	PC	…	PC
			Production Plan	PC	PC	…	PC

Finally, a report for the final product inventory was also created with data retrieved automatically from SAP (Table 11).

Table 11 – Inventory snapshots report.

Plant	**Project**	**Final Product**	**Attribute**	Q_{CD}
			Inventory	PC

This report comprises information about the quantities (PC) of finished product inventory existing for the current day (CD).

IV. Stock of Raw Material & Received Quantities

Similar to the report created for quantities in stock of the final product, another report was also created (Table 12), through a query to DALI, to obtain the stocks of raw material available in the system when consulting the allocation files.

Table 12 – Raw material stock report.

Critical Part	**Stock on Hand**
	PC

This report contains quantities (PC) of raw material stock in real time available in the SAP system.

To avoid duplication of data, like planned receipts that have already been entered into the system and are being considered as raw material stock, a report was also created that allows planners to inspect in real time raw material receipts on the day of analysis (Table 13).

Table 13 – Raw material receipts report.

Critical Part	**Receipt Quantity**
	PC

This quantity received ($Q_{Received}$), if exists, will be subtracted from the quantity of raw material existing in the system, substituting equation (9) with equation (12).

$$C_{Raw\ Material_{CD}} = (Q_{Stock} - Q_{\ Received}) + Q_{Planned\ Receipts_{CD}} - Q_{Consumed_{CD}} \qquad (12)$$

V. Supplementary Reports

Finally, reports were created that serve as auxiliary keys for the connection between the different reports, as well as file automation.

The first supplementary report gathers information from two sources, the Monthly Snapshots Report and through a query to DALI, providing the unique relationship between final product and projects associated with it (Table 14).

Table 14 – Final product by project report.

Project	**Final Product**

This relationship allows not only to group the final products by project, but also link projects and raw materials on the Filtered BOM Report. It also allows the automation of the file providing the number of final products to be considered in each project, the number of projects affected by each critical part, and the number of unique raw material-final product (RM-FP) combinations in each project, fundamental for the automation logic in Visual Basic for Applications – VBA[2].

[2] VBA is the programming language of Excel and other Office programs. Allows the automation of repetitive tasks and to accelerate every-day tasks, additionally to adding new functionalities to Office applications.

Another supplementary report created concerns consolidated raw materials. There are raw materials that, despite having different identifying numbers, refer to the same material. This is because there are different suppliers supplying the same part and, therefore, the identification number is different depending on the origin. With the crisis in electronic components, it was decided that, depending on the deficiency of raw material deliveries from one supplier, the same raw material from another supplier could be used. This means that all consolidated parts would have to be analysed together. Since the Filtered BOM Report only contains information on a single raw material, it was necessary to create a report where the connection between raw materials that can be replaced by each other is made (Table 15).

Table 15 – Raw material consolidation report.

Critical Part	**Consolidated Part**

This supplementary report is manually filled by the LOP and LOS planners based on consolidated materials information, and it provides the list of consolidated raw materials that will be analysed together by the allocation files.

VI. Fair Share Allocation of Critical Parts

The fair share calculation logic originated during the electronic components' crisis. It is the logic applied to raw materials considered critical with insufficient coverage where undersupply is not avoidable, the main objective being to minimize the impact through allocation at plant level and fine allocation with the customer. Allocation is necessary to divide the available supply by customer, applying a *pro rata* logic. The calculation is based on the total quantity of customer demand on a specific date and contemplates production parameters such as lead time and scrap rate. An allocation share is calculated which, considering the total available amount of critical materials, provides the different plants with quantities of raw materials that will be made available to each customer, project and final product.

Through customer demand, the necessary amount of raw material for each customer ($Q_{Customer\ Needs}$) is obtained. Depending on the total needs of all customers ($Q_{Total\ Needs}$), a fair share percentage ($\%_{Fair\ Share}$) (13) is calculated which, through the total quantity of material available ($Q_{Raw\ Material}$), determines the amount of raw material to allocate to each customer ($Q_{Allocation}$) (14).

$$\%_{Fair\ Share} = (Q_{Customer\ Needs}/Q_{Total\ Needs}) * 100 \tag{13}$$

$$Q_{Allocation} = Q_{Raw\ Material} * \%_{Fair\ Share} \quad (14)$$

The fair share allocation file is developed by the TF and it is distributed to all plants in the AE division of the Bosch Group. It contains percentage of fair share and quantity of raw material to allocate per customer, project and final product of all plants affected by the raw materials classified as critical parts, for an eight-week timestamp.

The information regarding the quantity to allocate depends on the quantity of raw material that is expected to be received from the supplier in a certain period. If the quantity received from the supplier does not correspond to the forecasted quantity, adjustments will have to be made accordingly within the plant. For this purpose, the fair share percentage provided in the file is used. Moreover, since the fair share percentage will be used in the analysis of coverage by project, unnecessary data was removed from the file sent by the TF and a Fair Share Allocation Report (Table 16) by project was created to be used in the allocation files.

Table 16 – Fair Share Allocation report.

Critical Part	**Project**	**FS_{cw}**	…	**FS_{cw+7}**	…	**FS_{cw+15}**
		%	…	%	…	%
		%	…	%	…	%

This report contains fair share (%) per project for each critical part identified. Since the TF file only covers a period of eight weeks (CW to CW_{+7}). The weeks that are not covered are extrapolated from the last week to the following eight weeks (CW_{+8} to CW_{+15}).

5.2.2 Standard Allocation files development

Once the reports that would serve as a database for the allocation files were completed, the last step taken was querying the different reports to aggregate its data and the creation and automatic filling of the files, constructing them based on the existing template. The reports created in the previous sections will serve as the basis for the two templates created: allocation by raw material and allocation by project - shifting only the filtering parameter on the initial page: critical part (Appendix 2) and project (Appendix 3), respectively. The integration and filtering of data from the different reports are accomplished via unique keys which allow the aggregation of the reports that, through the execution of macros, are represented in dynamic and adaptable templates to provide an improved analysis to the planning team.

The aggregation, cleaning and filtering of data are made in Power Query[3] (Figure 23). For the raw material allocation files, the initial parameter, critical part, validates in the supplementary report the existence of consolidated raw materials. Once all parts are identified, they are filtered in the BOM report and this allows the identification of the final products that contains the identified critical part, its consolidated parts and usage quantity. Through other supplementary report, the projects to which the filtered final products are associated are obtained, thus filtering the daily, weekly and inventory snapshot reports. The remaining reports are filtered either by critical and consolidated part (Critical Raw Material & Planned Receipts, Raw Material Receipts Report and Raw Material Stock Report) or final products (Fair Share Allocation Report) through project.

For the allocation files by project, the initial parameter, project, is first crossed with the supplemental report. Then, after identifying the final products associated with the project, the BOM report is filtered, and the associated critical parts and usages are obtained. The remaining data integration follows the raw material allocation logic mentioned previously.

[3] Microsoft Power Query for Excel is an add-in that allows for the combination of data from multiple sources, shape it in order to prepare it for further analysis in tools like Excel and Power Pivot, or visualization in tools like Power BI.

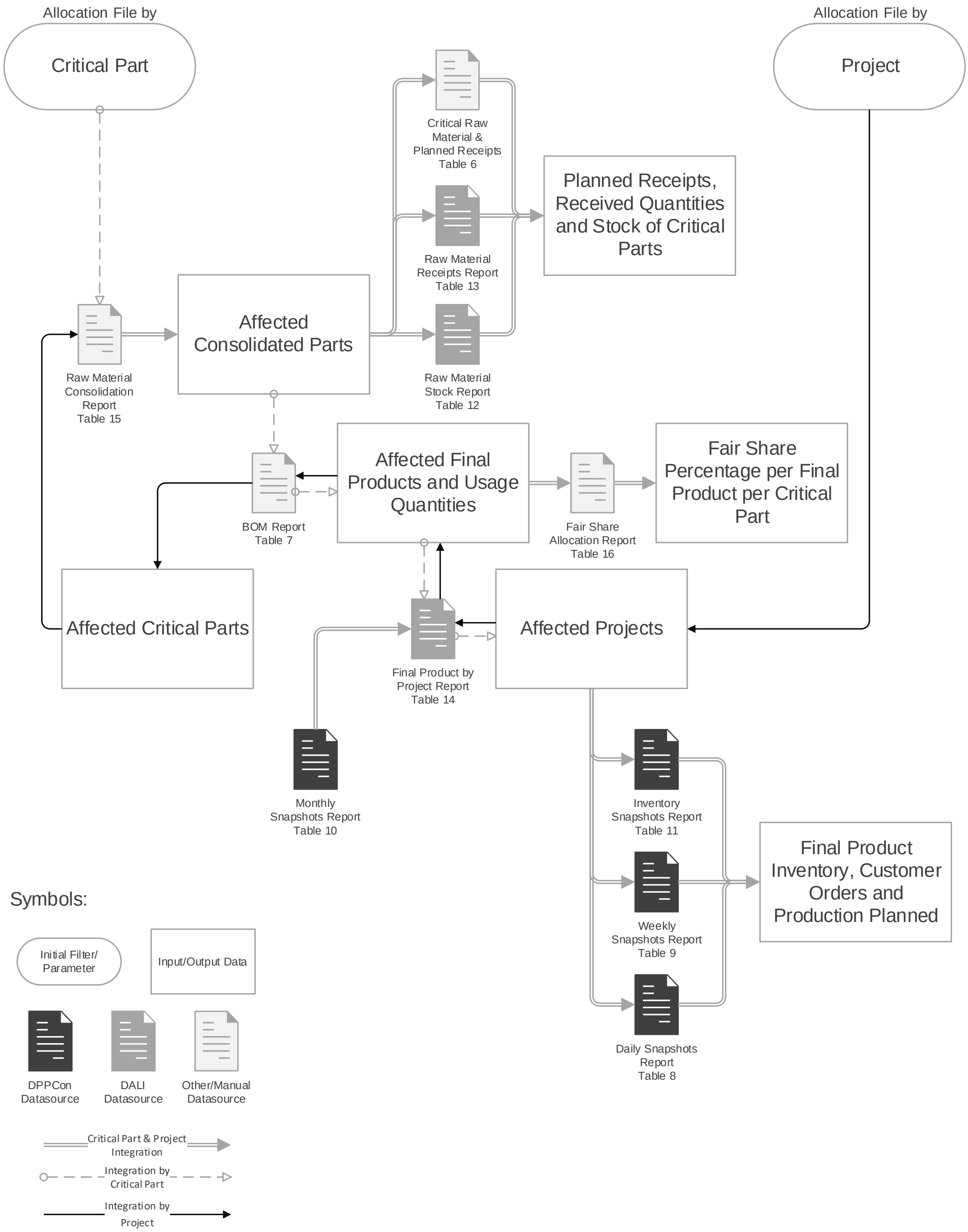

Figure 23 – Data integration.

Once the data is integrated, the manipulation and filling of the templates is done through simple macros in Excel and straightforward formulas in the worksheets. The developed macros allow the manipulation of the templates according to the projects, critical <parts or final products retrieved from

the integration of the data and name the ranges of the aggregated reports. The formulas, through the named ranges defined within the macros, retrieve the data, and allow the combination of information and calculation "in real time" in the manipulated templates.

In the raw allocation files by raw material, the lines corresponding to one project/customer are copied and pasted, via macro, according to the number of different projects affected by the critical part under study (Figure 24).

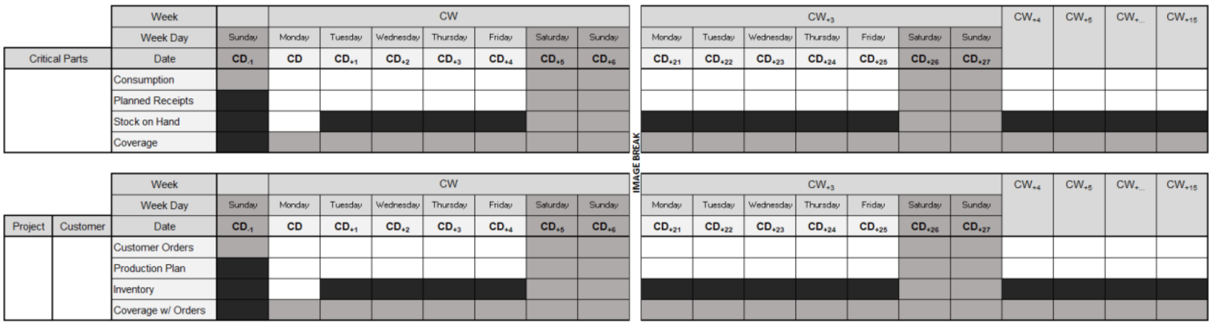

Figure 24 – Proposed Standard Allocation Files by Raw Material Template.

The main objective of aggregation and visualization by critical part is to obtain an overview of raw material coverage considering the different projects affected by it, thus allowing to report information to the customer in a clear and concise manner. It was defined among planners, team leaders and the department's administration that this visualization would only be informative, not being necessary to include the final products that would allow the files to simulate and manipulate production plans.

For the allocation files by project, it was defined that the ability to simulate production plans would be a requirement, being essential then to consider the final products since planning is done according to these. It was also defined that these files should provide an overview and a detailed view. In the macro view, it would be necessary to view aggregated raw materials and final products, regardless of whether all final products are affected by all critical parts and vice versa. By the logic of allocation files per project, the lines corresponding to each critical part are copied and pasted, via macro, according to the number of different raw materials that affect the project and the same logic applies to the lines corresponding to final products, multiplying according to the number of final products of each project affected by the identified critical parts (Figure 25).

		Week		CW							CW_{+3}							CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
		Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Project	Customer	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
		Customer Orders																			
		Production Plan																			
		Inventory																			
		Coverage w/ Orders																			

	Week		CW							CW_{+3}							CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Critical Parts	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
	Consumption																			
	Planned Receipts																			
	Stock on Hand																			
	Coverage																			

	Week		CW							CW_{+3}							CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
	Customer Orders																			
	Production Plan																			
	Inventory																			
	Coverage w/ Orders																			

Figure 25 – Proposed Standard Allocation Files by Project Template – Sheet Macro.

In the micro view, it would then be necessary to visualize all the existing combinations of RM-FP and the usage quantity of each raw material in each final product. By this logic, the lines corresponding to this ranges are copied and pasted according to the number of different RM-FP combinations existing in the project under study (Figure 26).

			Week		CW							CW_{+3}							CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
			Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Usage	Raw Material	Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
			Customer Orders																			
			Production Plan																			

Figure 26 – Proposed Standard Allocation Files by Project Template – Sheet Micro.

After executing the macros, the data is organized in the tables according to the formulas described in the previous sections (Appendixes 4 to 7). Conditional formatting is also applied to the tables to make files easier to examine, such as highlighting weekends and colouring days when coverage is negative. The planner can now get an overview and detailed view of raw material consumption, planned final product production and aggregate customer orders in an easier, faster, and more comprehensive manner than before and on demand.

The allocation file by raw material presented in Figure 27 contains fictitious data reporting the coverage of a critical raw material that affects 5 projects for different customers and contains data referring to aggregated customer orders and production plans for the final products associated with each of the projects affected by the identified critical part for the weeks 18.2021 to 35.2021.

	Week		CW_{18}							CW_{21}							CW_{22}	CW_{23}	CW_{24}	CW_{25}	CW_{26}	CW_{27}	CW_{28}	CW_	CW_{34}
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Critical Parts	Date	02/mai	03/mai	04/mai	05/mai	06/mai	07/mai	08/mai	09/mai	24/mai	25/mai	26/mai	27/mai	28/mai	29/mai	30/mai									
CRITICAL PART W	Consumption		1224	1152	1249	648	323	0	645	904	216	0	648	960	0	0	3094	688	956	3396	7010	7808	10912	...	7723
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	27500	11000	0	0	0	0	0	...	0
	Stock on Hand		91504																						
	Coverage		90280	89128	87879	87231	86908	86908	86263	72719	72503	72503	71855	70895	70895	70895	95301	105613	104657	101261	94251	86443	75531	...	7801

		Week		CW_{18}							CW_{21}							CW_{22}	CW_{23}	CW_{24}	CW_{25}	CW_{26}	CW_{27}	CW_{28}	CW_	CW_{34}
		Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Project	Customer	Date	02/mai	03/mai	04/mai	05/mai	06/mai	07/mai	08/mai	09/mai	24/mai	25/mai	26/mai	27/mai	28/mai	29/mai	30/mai									
PJ1	**Description of PJ1 for Customer A**	Customer Orders	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	320	510	420	370	330	...	0
		Production Plan		0	0	0	0	323	0	0	40	0	0	0	960	0	0	920	0	0	1680	1500	1240	800	...	1040
		Inventory		0																						
		Coverage w/ Orders		-37	-37	-37	-37	286	286	286	2066	2066	2066	2066	3026	3026	3026	3946	3946	3626	4796	5876	6746	7216	...	13266
PJ2	**Description of PJ2 for Customer A**	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
		Production Plan		216	0	0	0	0	0	0	432	0	0	0	0	0	0	432	72	0	648	576	648	0	...	648
		Inventory		0																						
		Coverage w/ Orders		216	216	216	216	216	216	216	1512	1512	1512	1512	1512	1512	1512	1944	2016	2016	2664	3240	3888	3888	...	8424
PJ3	**Description of PJ3 for Customer B**	Customer Orders	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230	216	0	0	0	864	0	...	1296
		Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	230	0	0	216	216	0	0	...	432
		Inventory		183																						
		Coverage w/ Orders		147	147	147	147	147	147	147	828	828	828	828	828	828	828	828	612	612	828	1044	180	180	...	180
PJ4	**Description of PJ4 for Customer C**	Customer Orders	65674	2520	5184	1224	252	0	0	0	1692	1332	378	684	221	0	0	18468	72	1496	3810	2934	12204	4284	...	12568
		Production Plan		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
		Inventory		1634																						
		Coverage w/ Orders		-65552	-69584	-69559	-69163	-69163	-69163	-68518	-69145	-70261	-70639	-70675	-70896	-70896	-70896	-87852	-87308	-87848	-90806	-89022	-95306	-89478	...	-90754
PJ5	**Description of PJ5 for Customer D**	Customer Orders	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	639	3105	4842	...	6287
		Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3960	5715	5085	...	6840
		Inventory		0																						
		Coverage w/ Orders		-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-20	-20	-20	3301	5911	6154	...	7800

Figure 27 – Proposed Standard Allocation Files by Critical Part – Analysis example.

Since the tables are too large to fit within one sheet, the data has been truncated and the example analysis will be done only for the data visible in the image. In this example, it is observed that the existing stock of Critical Part W can fully fulfil the consumption for the planned production which, in combination with the planned receipts of CW22 and CW23, guarantees the coverage of raw material until CW34, ending this period with a surplus of 7 801 PC of Critical Part W. When analysing the projects affected by Critical Part W, it is also possible to observe that the existing final product inventory quantities and planned production for the weeks in question is not sufficient to guarantee the total satisfaction of customer orders for all projects, mainly due to the large quantities of orders in backlog.

- For the project PJ1, the 37 PC in backlog will be answered in the CW of the analysis, CW18, as the planned production of 323 PC on May 7th will over-cover the ordered quantities in 286 PC.
- However, for the project PJ4, the backlog quantity of 65 674 PC will not be answered within the weeks in scope, not only because the ordered quantity keeps increasing, but the quantities planned to produce are not enough to fully cover the orders, ending this period with 90 754 PC under covered of final products associated to PJ4.

Faced with this scenario, the planner can then plan the next steps: re-plan the existing quantities in backlog of PJ4. Although the SAP heuristics may consider the backlog and re-plan production accordingly and automatically, there are still factors that are not considered. For instances, the coverage of other raw materials affecting the same finish good. To this end, the planner will then be able to consult the allocation files by project to not only ascertain whether this project is affected by other raw materials considered critical, but also to be able to simulate different production plans based on raw material coverage.

Similar to the allocation files by raw material, the allocation files by project represented in Figures 28 to 32, contains fictitious data regarding customer orders and production plans for PJ4, a project aggregating 15 final products affected by 9 raw material identified as critical parts. As seen in Figure 28, the totality of customer orders is not delivered, mainly due to the large quantities of orders in the backlog. In order to fully satisfy the customer, it is necessary to re-plan the production. It is also possible to ascertain the criticality of the raw materials associated with PJ4. Although most critical parts reach negative coverage during the weeks under review, Critical Part X is extremely critical to the plant as it has no quantities in stock or planned receipts in the weeks in scope, reaching under coverage in the CW of the analysis.

		Week		CW18							CW21							CW22	CW23	CW24	CW25	CW26	CW27	CW28	CW_	CW34
		Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Project	Customer	Date	02/mai	03/mai	04/mai	05/mai	06/mai	07/mai	08/mai	09/mai	24/mai	25/mai	26/mai	27/mai	28/mai	29/mai	30/mai									
PJ4	Description of PJ4 for Customer C	Customer Orders	65674	2520	5184	1224	252	0	0	0	1692	1332	378	684	221	0	0	18468	72	1496	3810	2934	12204	4284	...	12568
		Production Plan		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
		Inventory		1634																						
		Coverage w/ Orders		-65552	-69584	-69559	-69163	-69163	-69163	-68518	-69145	-70261	-70639	-70675	-70896	-70896	-70896	-87852	-87308	-87848	-90806	-89022	-95306	-89478	...	-90754

	Week		CW18							CW21							CW22	CW23	CW24	CW25	CW26	CW27	CW28	CW_	CW34
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Critical Parts	Date	02/mai	03/mai	04/mai	05/mai	06/mai	07/mai	08/mai	09/mai	24/mai	25/mai	26/mai	27/mai	28/mai	29/mai	30/mai									
Critical Part R	Consumption		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		39799																						
	Coverage		38791	37639	36390	35742	35742	35742	35097	45003	44787	44787	44139	44139	44139	44139	42627	42011	41055	40203	35485	29565	19453	...	-32839
Critical Part S	Consumption		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Planned Receipts		0	0	0	0	32	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	...	0
	Stock on Hand		13																						
	Coverage		13	13	13	13	45	45	45	226	226	226	226	226	226	226	269	269	269	269	269	269	269	...	269
Critical Part T	Consumption		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		18718																						
	Coverage		17710	16558	15309	14661	14661	14661	14016	12181	11965	11965	11317	11317	11317	11317	9805	9189	8233	7381	2663	-3257	-13369	...	-65661
Critical Part U	Consumption		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
	Planned Receipts		554	0	831	693	388	0	0	2808	0	0	0	0	0	0	1349	0	0	0	0	0	0	...	0
	Stock on Hand		2793																						
	Coverage		2340	1188	770	814	1202	1202	557	-4138	-4354	-4354	-5002	-5002	-5002	-5002	-5165	-5781	-6737	-7589	-12307	-18227	-28339	...	-80631
Critical Part V	Consumption		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		42383																						
	Coverage		41375	40223	38974	38326	38326	38326	37681	36051	35835	35835	35187	35187	35187	35187	33675	33059	32103	31251	26533	20613	10501	...	-41791
Critical Part W	Consumption		1008	1152	1249	648	0	0	645	432	216	0	648	0	0	0	1512	616	956	852	4718	5920	10112	...	5603
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	16736	4082	0	0	0	0	0	...	0
	Stock on Hand		39581																						
	Coverage		38573	37421	36172	35524	35524	35524	34879	25172	24956	24956	24308	24308	24308	24308	39532	42998	42042	41190	36472	30552	20440	...	-31852
Critical Part X	Consumption		0	0	486	432	0	0	439	0	0	0	432	0	0	0	216	0	648	432	432	216	3240	...	216
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		0																						
	Coverage		0	0	-486	-918	-918	-918	-1357	-3489	-3489	-3489	-3921	-3921	-3921	-3921	-4137	-4137	-4785	-5217	-5649	-5865	-9105	...	-17513
Critical Part Y	Consumption		432	432	432	216	0	0	0	432	216	0	216	0	0	0	648	616	216	102	4286	4286	4502	...	2771
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		7248																						
	Coverage		6816	6384	5952	5736	5736	5736	5736	22029	21813	21813	21597	21597	21597	21597	20949	20333	20117	20015	15729	11443	6941	...	-21001
Critical Part Z	Consumption		576	720	331	0	0	0	206	0	0	0	0	0	0	0	648	0	2	318	0	1418	2370	...	2616
	Planned Receipts		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Stock on Hand		8883																						
	Coverage		8307	7587	7256	7256	7256	7256	7050	4782	4782	4782	4782	4782	4782	4782	4134	4134	4132	3814	3814	2396	26	...	-15916

Figure 28 – Proposed Standard Allocation Files by Project – Sheet Macro analysis example (1).

The quantities of stock and planned receipts of each Critical Part represented in the Figure 28 do not represent the full availability of raw material, but the quantities allocated to PJ4 according to the percentage of FS of each critical part destined for the project (Figure 29). For Critical Part X, as the FS is very low, the quantities of planned receipts and stock to be allocated for PJ4 are also very low.

Critical Part	Project	18.2021		21.2021	22.2021	23.2021	24.2021	25.2021	26.2021	27.2021	28.2021		34.2021
Critical Part R	PJ4	91,33%	...	90,80%	88,79%	95,35%	50,81%	83,57%	83,57%	83,57%	83,57%	...	83,57%
Critical Part S	PJ4	3,62%	...	1,83%	1,22%	1,07%	0,00%	0,00%	0,00%	0,00%	0,00%	...	0,00%
Critical Part T	PJ4	37,17%	...	36,44%	25,30%	83,41%	26,56%	24,64%	24,64%	24,64%	24,64%	...	24,64%
Critical Part U	PJ4	0,00%	...	5,38%	5,62%	5,40%	0,00%	0,00%	0,00%	0,00%	0,00%	...	0,00%
Critical Part V	PJ4	41,24%	...	37,39%	39,14%	61,30%	26,17%	39,23%	39,23%	39,23%	39,23%	...	39,23%
Critical Part W	PJ4	40,68%	...	24,38%	34,06%	60,86%	37,11%	31,25%	31,25%	31,25%	31,25%	...	31,25%
Critical Part X	PJ4	0,78%	...	0,16%	0,38%	0,16%	0,40%	0,15%	0,15%	0,15%	0,15%	...	0,15%
Critical Part Y	PJ4	100,00%	...	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	...	100,00%
Critical Part Z	PJ4	93,48%	...	87,55%	87,42%	77,83%	81,44%	83,71%	83,71%	83,71%	83,71%	...	83,71%

Figure 29 – Fair Share Allocation – Analysis example.

Figure 30 contains information on orders and quantities to be produced for each final product of PJ4, where it is also possible to simulate adjustments to production plans. Note that most of the backlog is focused on Final Product 06, with 54 815 PC to re-plan.

Final Product	Week		CW18							CW21							CW22	CW23	CW24	CW25	CW26	CW27	CW28	CW_	CW34
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}									
Final Product 00	Customer Orders	2727	0	0	432	0	0	0	0	0	432	0	0	0	0	0	216	0	0	216	216	432	216	...	216
	Production Plan		0	0	0	432	0	0	0	0	0	0	432	0	0	0	216	0	0	432	432	216	0	...	216
	Inventory		0																						
	Coverage w/ Orders		-2727	-2727	-3159	-2727	-2727	-2727	-2727	-2727	-3159	-3159	-2727	-2727	-2727	-2727	-2727	-2727	-2727	-2511	-2295	-2511	-2727	...	-1174
Final Product 01	Customer Orders	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-54	-54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Final Product 02	Customer Orders	62	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	30	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	30	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-62	-62	-62	-62	-62	-62	0	5	5	5	5	0	0	0	0	0	0	0	0	0	0	...	0
Final Product 03	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
Final Product 04	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	72	0	72	72	144	0	...	144
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	288	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		0	0	0	0	0	0	0	0	0	0	0	0	0	0	144	72	72	288	216	72	72	...	0
Final Product 05	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		0	0	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	...	39
Final Product 06	Customer Orders	54815	1512	5184	0	0	0	0	0	1080	0	0	0	0	0	0	17280	0	432	1296	432	7992	3240	...	9504
	Production Plan		432	432	432	216	0	0	0	432	216	0	216	0	0	0	648	616	0	102	4286	4286	4286	...	2771
	Inventory		1080																						
	Coverage w/ Orders		-54815	-59567	-59135	-58919	-58919	-58919	-58919	-57284	-57068	-57068	-56852	-56852	-56852	-56852	-73484	-72868	-73300	-74494	-70640	-74346	-73300	...	-83950
Final Product 07	Customer Orders	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	-72	...	-72
Final Product 08	Customer Orders	432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	0	216	...	0
	Inventory		410																						
	Coverage w/ Orders		-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	-22	194	194	194	194	410	...	4010
Final Product 09	Customer Orders	4688	0	0	648	0	0	0	0	0	648	0	0	0	0	0	216	0	0	432	432	864	216	...	432
	Production Plan		0	0	432	0	0	0	439	0	0	0	0	0	0	0	0	0	648	0	0	0	3240	...	0
	Inventory		21																						
	Coverage w/ Orders		-4667	-4667	-4883	-4883	-4883	-4883	-4444	-5336	-5984	-5984	-5984	-5984	-5984	-5984	-6200	-6200	-5552	-5984	-6416	-7280	-4256	...	-1073
Final Product 10	Customer Orders	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	-18	...	-18
Final Product 11	Customer Orders	1584	0	0	0	252	0	0	0	270	0	0	0	0	0	0	0	0	288	270	288	270	288	...	252
	Production Plan		0	0	288	0	0	0	0	0	0	0	0	0	0	0	432	0	0	0	0	0	936	...	510
	Inventory		0																						
	Coverage w/ Orders		-1584	-1584	-1296	-1548	-1548	-1548	-1548	-1908	-1908	-1908	-1908	-1908	-1908	-1908	-1476	-1476	-1764	-2034	-2322	-2592	-1944	...	-1134
Final Product 12	Customer Orders	1114	864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	...	-1978
Final Product 12	Customer Orders	1114	864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	-1978	...	-1978
Final Product 13	Customer Orders	108	144	0	144	0	0	0	0	342	252	378	684	216	0	0	684	0	684	1494	1494	2502	324	...	2020
	Production Plan		576	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1418	1434	...	2106
	Inventory		123																						
	Coverage w/ Orders		447	1167	1023	1023	1023	1023	1023	152	-100	-478	-1162	-1378	-1378	-1378	-2062	-2062	-2746	-4240	-5734	-6818	-5708	...	-5404
Final Product 14	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
	Production Plan		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
	Inventory		0																						
	Coverage w/ Orders		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0

Figure 30 – Proposed Standard Allocation Files by Project – Sheet Macro analysis example (2).

Figure 31 demonstrates the RM-FG relationship and usage quantities, where it is possible to see the direct relationship between ordered quantities and the final product to be produced and the raw material used. From Figure 31, it is identified that Final Product 06 only uses Critical Parts R and Y, and the availability of these parts will enable the increase in the quantity of final product to be produced.

PJ4	Description of PJ4 for Customer C		Week		CW_{18}							CW_{21}							CW_{22}	CW_{23}	CW_{24}	CW_{25}	CW_{26}	CW_{27}	CW_{28}	CW...	CW_{36}
			Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Usage	Raw Material	Final Product	Date	02/mai	03/mai	04/mai	05/mai	06/mai	07/mai	08/mai	09/mai	24/mai	25/mai	26/mai	27/mai	28/mai	29/mai	30/mai									
1	Critical Part R	Final Product 00	Customer Orders	2727	0	0	432	0	0	0	0	0	432	0	0	0	0	0	216	0	0	216	216	432	216	...	216
			Production Plan	0	0	0	0	432	0	0	0	0	0	0	432	0	0	0	216	0	0	432	432	216	0	...	216
1	Critical Part R	Final Product 01	Customer Orders	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part R	Final Product 02	Customer Orders	62	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	30	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	30	0	0	0	...	0
1	Critical Part R	Final Product 03	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part R	Final Product 04	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	72	0	72	72	144	0	...	144
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	288	0	0	0	...	0
1	Critical Part R	Final Product 05	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part R	Final Product 06	Customer Orders	54815	1512	5184	0	0	0	0	0	1080	0	0	0	0	0	0	17280	0	432	1296	432	7992	3240	...	9504
			Production Plan	0	432	432	432	216	0	0	0	432	216	0	216	0	0	0	648	616	0	102	4286	4286	4286	...	2771
1	Critical Part R	Final Product 07	Customer Orders	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part R	Final Product 08	Customer Orders	432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	0	216	...	0
1	Critical Part R	Final Product 09	Customer Orders	4688	0	0	648	0	0	0	0	0	648	0	0	0	0	0	216	0	0	432	432	864	216	...	432
			Production Plan	0	0	0	432	0	0	0	439	0	0	0	0	0	0	0	0	0	648	0	0	0	3240	...	0
1	Critical Part R	Final Product 10	Customer Orders	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part R	Final Product 11	Customer Orders	1584	0	0	0	252	0	0	0	270	0	0	0	0	0	0	0	0	288	270	288	270	288	...	252
			Production Plan	0	0	0	288	0	0	0	0	0	0	0	0	0	0	0	432	0	0	0	0	0	936	...	510
1	Critical Part R	Final Product 12	Customer Orders	1114	864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
1	Critical Part R	Final Product 13	Customer Orders	108	144	0	144	0	0	0	0	342	252	378	684	216	0	0	684	0	684	1494	1494	2502	324	...	2020
			Production Plan	0	576	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1418	1434	...	2106
1	Critical Part R	Final Product 14	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
1	Critical Part T	Final Product 02	Customer Orders	62	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	30	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	30	0	0	0	...	0
												IMAGE BREAK															
1	Critical Part W	Final Product 14	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
1	Critical Part W	Final Product 12	Customer Orders	1114	864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
1	Critical Part W	Final Product 13	Customer Orders	108	144	0	144	0	0	0	0	342	252	378	684	216	0	0	684	0	684	1494	1494	2502	324	...	2020
			Production Plan	0	576	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1418	1434	...	2106
1	Critical Part X	Final Product 00	Customer Orders	2727	0	0	432	0	0	0	0	0	432	0	0	0	0	0	216	0	0	216	216	432	216	...	216
			Production Plan	0	0	0	0	432	0	0	0	0	0	0	432	0	0	0	216	0	0	432	432	216	0	...	216
1	Critical Part X	Final Product 01	Customer Orders	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part X	Final Product 09	Customer Orders	4688	0	0	648	0	0	0	0	0	648	0	0	0	0	0	216	0	0	432	432	864	216	...	432
			Production Plan	0	0	0	432	0	0	0	439	0	0	0	0	0	0	0	0	0	648	0	0	0	3240	...	0
1	Critical Part Y	Final Product 06	Customer Orders	54815	1512	5184	0	0	0	0	0	1080	0	0	0	0	0	0	17280	0	432	1296	432	7992	3240	...	9504
			Production Plan	0	432	432	432	216	0	0	0	432	216	0	216	0	0	0	648	616	0	102	4286	4286	4286	...	2771
1	Critical Part Y	Final Product 07	Customer Orders	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part Y	Final Product 08	Customer Orders	432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	0	216	...	0
1	Critical Part Z	Final Product 02	Customer Orders	62	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	30	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	30	0	0	0	...	0
1	Critical Part Z	Final Product 03	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part Z	Final Product 04	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	72	0	72	72	144	0	...	144
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216	0	0	288	0	0	0	...	0
1	Critical Part Z	Final Product 05	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part Z	Final Product 10	Customer Orders	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
1	Critical Part Z	Final Product 11	Customer Orders	1584	0	0	0	252	0	0	0	270	0	0	0	0	0	0	0	0	288	270	288	270	288	...	252
			Production Plan	0	0	0	288	0	0	0	0	0	0	0	0	0	0	0	432	0	0	0	0	0	936	...	510
1	Critical Part Z	Final Product 12	Customer Orders	1114	864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
			Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	...	0
1	Critical Part Z	Final Product 13	Customer Orders	108	144	0	144	0	0	0	0	342	252	378	684	216	0	0	684	0	684	1494	1494	2502	324	...	2020
			Production Plan	0	576	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1418	1434	...	2106

Figure 31 – Proposed Standard Allocation Files by Project – Sheet Micro analysis example (3).

With the information made available in the allocation file, the planner can then change the values of the production plans (Figure 32) and instantly see the impact of the adjustments on the coverage of the affected raw materials. It is possible to carry out these adjustments for each final product presented in the file.

	Week		CW_{18}						
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Final Product 00	Customer Orders	2727	0	0	432	0	0	0	0
	Production Plan		0	0	0	432	0	0	0
	Inventory		0						
	Coverage w/ Orders		-2727	-2727	-3159	-2727	-2727	-2727	-2727
Final Product 01	Customer Orders	54	0	0	0	0	0	0	0
	Production Plan		0	0	54	0	0	0	0
	Inventory		0						
	Coverage w/ Orders		-54	-54	0	0	0	0	0
Final Product 13	Customer Orders	108	144	0	144	0	0	0	0
	Production Plan		576	720	0	0	0	0	0
	Inventory		123						
	Coverage w/ Orders		447	1167	1023	1023	1023	1023	1023
Final Product 14	Customer Orders	0	0	0	0	0	0	0	0
	Production Plan		0	0	0	0	0	0	0
	Inventory		0						
	Coverage w/ Orders		0	0	0	0	0	0	0

	Week	CW_{21}							CW_{22}	CW_{23}	CW_{24}	CW_{25}	CW_{26}	CW_{27}	CW_{28}	$CW_{...}$	CW_{34}
	Week Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday									
Final Product	Date	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}									
Final Product 00	Customer Orders	0	432	0	0	0	0	0	216	0	0	216	216	432	216	...	216
	Production Plan	0	0	0	432	0	0	0	216	0	0	432	432	216	0	...	216
	Inventory																
	Coverage w/ Orders	-2727	-3159	-3159	-2727	-2727	-2727	-2727	-2727	-2727	-2727	-2511	-2295	-2511	-2727	...	-1174
Final Product 01	Customer Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	Inventory																
	Coverage w/ Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0
	IMAGE BREAK																
Final Product 13	Customer Orders	342	252	378	684	216	0	0	684	0	684	1494	1494	2502	324	...	2020
	Production Plan	0	0	0	0	0	0	0	0	0	0	0	0	1418	1434	...	2106
	Inventory																
	Coverage w/ Orders	152	-100	-478	-1162	-1378	-1378	-1378	-2062	-2062	-2746	-4240	-5734	-6818	-5708	...	-5404
Final Product 14	Customer Orders	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
	Production Plan	0	0	0	0	0	0	0	0	0	90	0	0	0	0	...	0
	Inventory																
	Coverage w/ Orders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	0

Figure 32 – Proposed Standard Allocation Files by Project – Simulation fields.

The developed allocation files provide planners with a tool capable of not only reporting on raw material availability but also planning and adjusting production accordingly. It will make possible to obtain an aggregated and detailed view of the status of orders, allowing for transparency and agility in the sharing of information and communication with customers.

5.3 Main Results & Discussion

By this time, both projects developed are available and tested by the planners, whose response on its accuracy and suitability provides further improvements for customer order management and production planning.

The customer order variation dashboard covers 72% of customers and 74% of projects within the plant, with over 18 000 customer orders being automatically evaluated per week. To cover the entire range of projects and customers, guidelines for projects with the *specific rules* standard or *must comply* standard could be aligned with one of the two standards covered by the dashboard. Automating this task allows for potential savings up to 1 337 hours per year in the department, reducing the time spent on the analysis of customer orders variation and comparison with flexibility rules to 1h per week per planner (Table 17).

Table 17 – Order Variation Dashboard implementation results.

	Initial Process		**After Implementation**		**Variation**
	weekly	daily	weekly	daily	weekly
Data Collection Variation Calculations Select & Adjust Limits	2,5 h	0,5 h	0,07 h	0,01 h	- 1,5 h **- 97,2 %**
Report variation to customer	1 h	0,2 h	0,93 h	0,19 h	- 0,07 h **- 7 %**
Total	**3,5 h**	**0,7 h**	**1 h**	**0,2 h**	- 2,5 h **- 71,43 %**

The allocation files allow the analysis of every raw material included in the list of critical parts. At the time of writing this dissertation, for the 90 raw materials identified as critical parts, it is possible to generate allocation files for 66 projects and automatically analyse more than 890 final products affected by the identified critical parts. The time spent updating the data and generating an allocation file for a critical part depends on the number of projects that are affected by that critical part. Each raw material identified as critical parts at the time of writing, on average, affects 5 projects. Update the data and generate a file for a critical part affecting 5 projects takes approximately 1 minute per file. If, every week, one planner generates an allocation file for every critical part identified, this would translate in a total of 1,5 hours spent every week, considering 90 critical parts. Manually, it would take around 2 hours per file for the collection of all the data, filtering and filling the template, with the same critical part affecting the same 5 projects (Table 18).

Table 18 – Standard Allocation Files by raw material implementation results.

	Initial Process		**After Implementation**		**Variation**
	weekly	daily	weekly	daily	weekly
Data Collection	135 h	27 h	1,37 h	0,28 h	- 133,6 h **- 98,99 %**
Generate and populate allocation file	45 h	9 h	0,08 h	0,02 h	- 44,92 h **- 99,82 %**
Total	**180 h**	**36 h**	**1,5 h**	**0,30 h**	- 178,5 h **- 99,17 %**

For the allocation files by project, the time to update and generate the file depends on the number of RM-FP combinations in the project to be analysed. The projects affected by the 90 critical parts identified contain, on average, 91 RM-FP combinations, which translates into approximately 2 minutes expended updating and generating each file, and over 2 hours every week to generate a file for all 66 projects affected by the 90 critical parts identified (Table 19).

Table 19 – Standard Allocation Files by project implementation results.

	Initial Process		**After Implementation**		**Variation**
	weekly	daily	weekly	daily	weekly
Data Collection	132 h	26,4 h	1,28 h	0,26 h	- 130,72 h **- 99,03 %**
Generate and populate allocation file	66 h	13,2 h	1 h	0,2 h	- 65 h **- 98,48 %**
Total	**198 h**	**39,6 h**	**2,28 h**	**0,46 h**	- 195,8 h **- 98,89 %**

The 18 planners of the Planning and Fulfilment department of Bosch retain 2960 hours per month for planning and executing their tasks, which corresponds approximately 7,83 hours of work per day, 21 days per month. As the responsibilities are divided among the various planners, both in terms of analysing variations in customer orders and planning and controlling production, the total weekly availability of the 18 planners was considered. From the total of 705 hours per week, 377 hours would be saved with the proposed implementations. (Table 20).

Table 20 – Total savings after implementations.

	Availability	**Savings**
Total weekly	**704,8 h** **18 x**	**2,5 + 178,5 + 195,8 = 376,8 h** **- 9,6 x**

In terms of quantification of waste in information logistics KPIs, both DA and DU values reach 100%, as all the information desired for the analysis of order variation and examining the coverage of critical parts was captured and used as intended. DR reached only 77% since, currently, the Flexibility Rules Report must be updated manually every time a new customer needs to be added or existing limits re-defined, the critical parts and planned receipts in the Critical Raw Material & Planned Receipts Report are manually identified and added by LOS planners and the system does not allow for the automatic retrieve of BOMs for the BOM Report, which are manually downloaded for the raw materials in the critical parts list (Table 21).

Table 21 – Quantification of waste after implementation.

	After Implementation	
DR	10/13	**76,9%**
DA	13/13	**100%**
DU	13/13	**100%**

Overall, it is possible to observe great improvements both in expended time as well as necessary manual effort in the collection, cleaning and use of information, allowing not only to streamline the decision-making process of the planning team but also provide essential tools for the execution of their daily tasks.

6. Conclusions & Future Work

The development of the projects described in this dissertation allowed accomplishing the proposed objectives, saving time and streamlining the tasks of the planning and fulfilment department planners. Simultaneously, these projects permitted additional contributions directly and indirectly associated to the responsibilities of the planners. This chapter concludes this dissertation project with the presentation of the main contributions of the work developed and future work prospects for its continuous improvement.

Despite being successful, the development of these projects presented its challenges. With the Covid-19 pandemic, homeworking became a widespread practice which brought challenges to communication and cooperation with the planning team. In spite of the difficulties, it was possible to maintain regular meetings between all the team involved in the development of the projects and together work on its progression.

6.1 Main Contributions

Despite being available, the current circumstances of the crisis of electrical components make it impossible to use the order variation dashboard as intended. As there are shortages of various materials and there are not enough quantities to satisfy customer requests, any changes to the ordered quantities are not accepted by the planners. At the moment, planning is made according to the availability of raw material and not according to customer requests, making it essential to use the developed allocation files. However, it is expected that active work will continue to be made to improve these tools and allow greater agility and flexibility in the tasks performed by planners.

In addition to saving 2,5 hours per week in the assessment of variations in customer orders, the developed dashboard could be beneficial not only to LOP planners but also other departments within LOG. Each customer group has stipulated flexibility rules applied to all projects associated with that customer, although there are projects associated with multiple customers with different rule sets. Selecting the flexibility rule and the project as two independent parameters presents the planner the ability to evaluate one project by different rules and allows for greater flexibility in the analysis and support in the periodic review of flexibility rules with the customer. Another contribution made possible by the order variation dashboard concerns the response to demand fluctuations. Having an automated record of variation in customer orders allows the planning department to better forecast and predict production plans, and also the purchasing department to align this variation in orders with the variation in raw material purchases. In the future, based on the data provided by the dashboard, flexibility rules adapted to the needs of the plant can be agreed with suppliers and a new dashboard to inspect these variations can be created, since the standard is already developed.

Through the allocation files, it is now possible to have a detailed view of the coverage of each critical part and each project, allowing the planner to identify when the production lines will run out of material to operate and readjust the planning accordingly. The allocation files provide the planning team with a tool to respond more rapidly to deviations, unforeseen events such as raw material shortages, and to obtain more flexible analysis on demand. The development of these files allows for savings of over 370 hours per week in the collection and preparation of information. The ability to simulate production plans and review the coverage also allows to mitigate the effects of the crisis of electronic components, making it possible to level production and avoid line stoppages, thus not having to keep workers in layoff for long periods of time. It is important to note that one of the greatest contributions of the automation of allocation files is the availability of information "on-demand". Although the information was always available, its aggregation was a very time-consuming process, which often limited planners in the amount of information and analysis that were performed. Another contribution of these files regards the creation of a standard. Although the data integration was developed specifically for these tables, its application it is not limited to the allocation files. New templates with new focuses can be easily created and data effortlessly adapted, allowing for custom analysis on demand.

The development of these projects allowed not only to save almost 400 hours per week within the LOP department, but also to contribute positively to the digital transformation promoted by BPS, contributing to the increase in quality and efficiency of the planners' tasks through automation and data-driven intelligence. The integration of Lean information management concepts allowed not only to take full advantage of the information that is continuously generated by Bosch, but also to transform and integrate it in order to satisfy the information needs of planners, providing them with the necessary information when required and guaranteeing its quality. In addition, the introduction of KPIs related to information management allows for a standardized review of processes that can be improved through digitalization, through the assessment of the availability and use of the captured information, and digital resources available for the various processes maintained at Bosch.

6.2 Future Work

Enhancements can be developed in future work, both in the order variation dashboard and standard allocation files.

Regarding the order variation dashboard, improvements such as the flexibility of reports and dashboard, as with a more detailed and real-time analysis of customer order launches. It was stated that the variation in releases would be calculated on a weekly basis as there were no significant daily variations. However, a variation to an already planned quantity would be registered once a week. Orders received the next days would only be considered the following week, substantial or not. A potential solution would be reducing the time between updates and to replace weekly snapshots with daily snapshots. Furthermore, the calculation of variations always considers the current week of the analysis. In order to increase the flexibility of the analysis, another proposal for improvement would be to allow the choice of weeks to be compared, regardless of the current week.

In the allocation files, the main improvement proposal would be the time expended on refreshing the reports and updating the final files, namely the allocation files per project. As mentioned in the previous chapter, the time consumed depends on the number of unique RM-FP combinations in each project. Currently, there are projects with only one combination, whose refresh and update takes no more than half a minute, as well as projects with more than three hundred unique combinations, which can take well over twenty minutes to update each file. During the update, the files are running a set of macros that make it impossible for the planner to use excel, blocking it. Other improvements can also include the adaptation of the data, either by deleting or adding information to meet the needs of planners. For example, in the allocation files by project, if the information in the sheet Micro proves to be unnecessary, it can be removed, making the update of the files faster. On the other hand, when planning production, it is also necessary to identify the capacity of the production lines affected. Such information is not considered in the developed files but is possible to adapt the existing tables for its integration.

The implementation of these proposals will generate new opportunities for progress and will trigger other challenges following an endless cycle of continuous improvement.

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Appendix 1 – Order Variation Dashboard

Master Report ›

Calculator ›

Parameter 1: All

Parameter 2: All

Parameter 3: All

Calendar Week: All

Parameter 4: All

Project Description

Rule Set

1. Select a rule set | Rule set 2 | Rule set 1 | Rule set 3

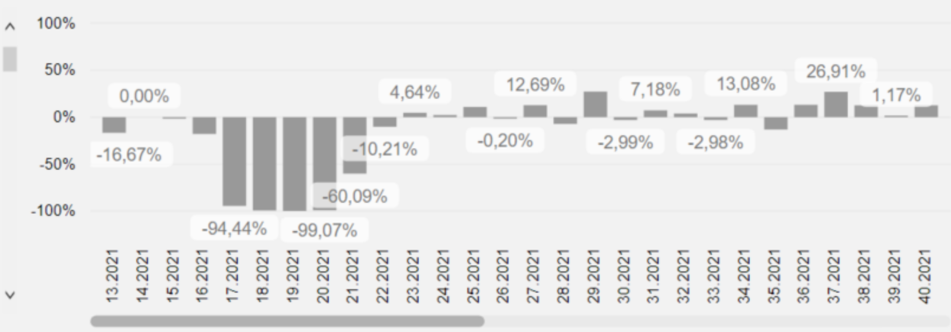
Flexibility Rule

No rule set selected

Releases

Calendar Week	SW15	SW16	SW17	SW18	SW19	SW20	SW21
⊞ 13.2021	38	13	12	12	12	12	10
⊞ 14.2021	898	159	51	51	51	51	51
⊞ 15.2021	278.101	4.133	589	302	152	151	151
⊞ 16.2021	335.456	199.198	4.336	137	134	134	110
⊞ 17.2021	384.797	352.737	230.485	21.889	108	10	6
⊞ 18.2021	377.911	347.987	334.107	221.711	4.918	36	34
⊞ 19.2021	334.469	344.116	345.032	313.014	204.155	6.353	293

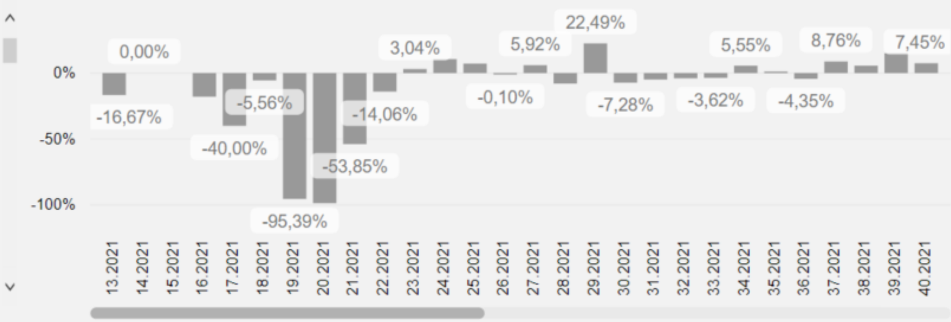
2 weeks to CW



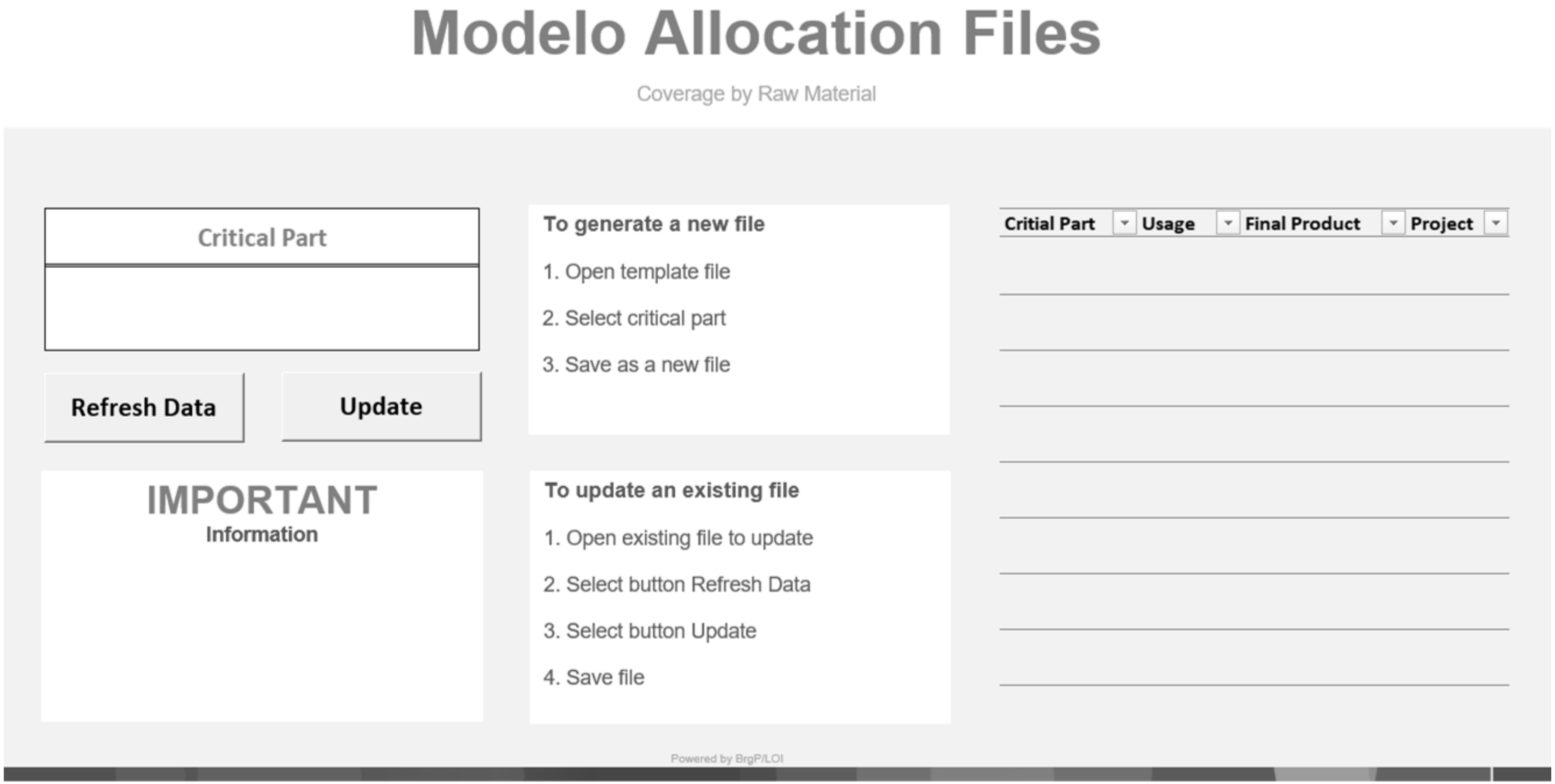
Differences

Calendar Week	SW15-21	SW16-21	SW17-21	SW18-21	SW19-21	SW20-21
⊞ 13.2021	-28	-3	-2	-2	-2	-2
⊞ 14.2021	-847	-108	0	0	0	0
⊞ 15.2021	-277.950	-3.982	-438	-151	-1	0
⊞ 16.2021	-335.346	-199.088	-4.226	-27	-24	-24
⊞ 17.2021	-384.791	-352.731	-230.479	-21.883	-102	-4
⊞ 18.2021	-377.877	-347.953	-334.073	-221.677	-4.884	-2
⊞ 19.2021	-334.176	-343.823	-344.739	-312.721	-203.862	-6.060

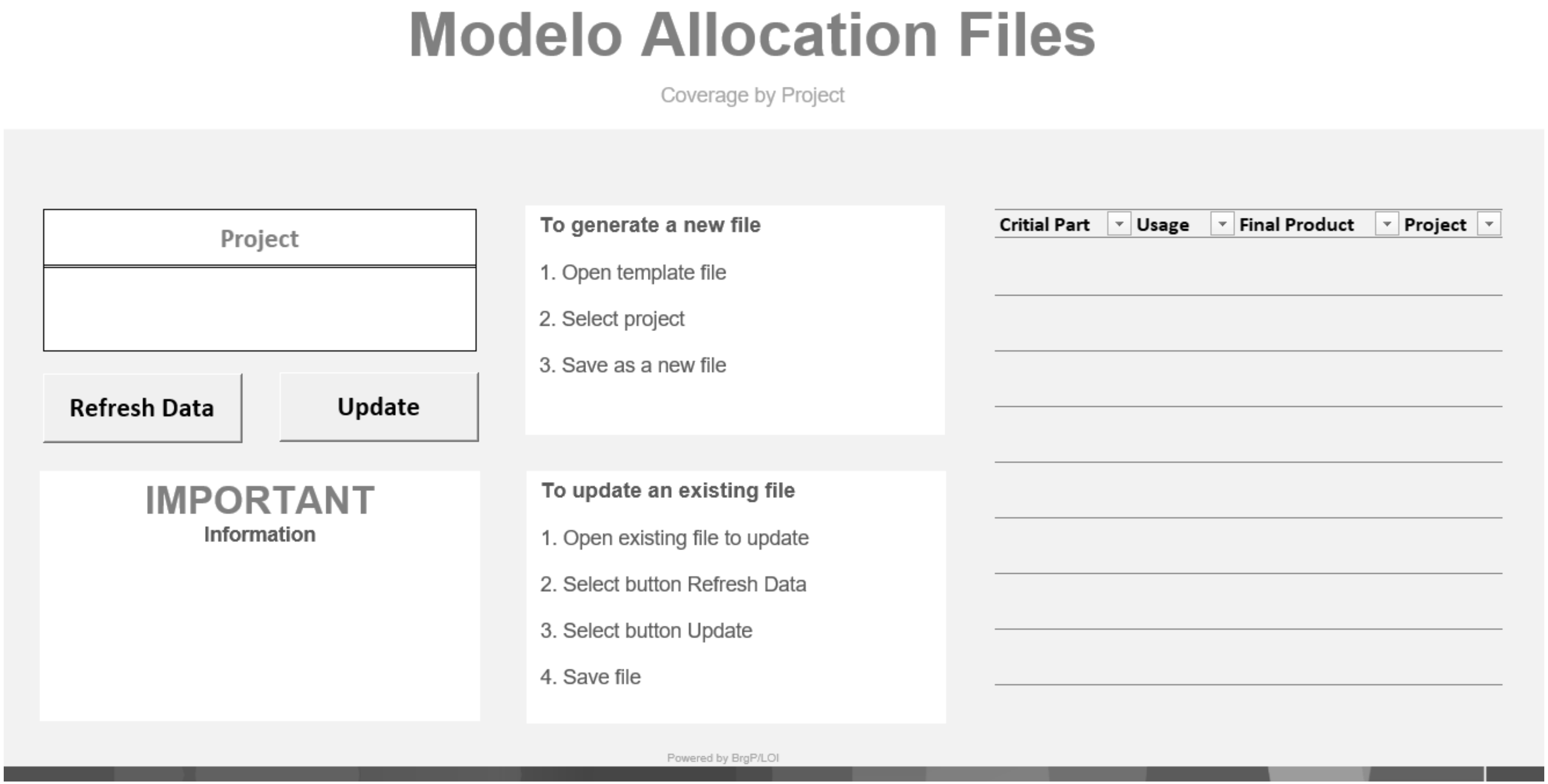
1 week to CW



Appendix 2 – Proposed Standard Allocation Files by Raw Material – Initial Page



Appendix 3 – Proposed Standard Allocation Files by Project – Initial Page



APPENDIX 4 – FORMULAS IN THE STANDARD ALLOCATION FILE BY RAW MATERIAL – BEFORE

		Week		CW						
Project	Customer	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Affected Project 1	Related Customer 1	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$						
		Production Plan		$Q_{Produced}$						
		Inventory		Q_{Stock}						
		Coverage w/ Orders		$C_{Final\ Product}$						
Affected Project 2	Related Customer 2	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$						
		Production Plan		$Q_{Produced}$						
		Inventory		Q_{Stock}						
		Coverage w/ Orders		$C_{Final\ Product}$						
Affected Project 3	Related Customer 3	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$						
		Production Plan		$Q_{Produced}$						
		Inventory		Q_{Stock}						
		Coverage w/ Orders		$C_{Final\ Product}$						
Critical Raw Material		Consumption	$Q_{Consumed}$							
		Planned Receipts		$Q_{Planned\ Receipts}$						
		Stock on Hand		Q_{Stock}						
		Coverage		$C_{Raw\ Material}$						

IMAGE BREAK

		Week	CW_{+3}							CW_{+4}	CW_{+5}	CW_{+6}	CW_{+7}
Project	Customer	Date	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Affected Project 1	Related Customer 1	Customer Orders	$Q_{Ordered}$										
		Production Plan	$Q_{Produced}$										
		Inventory											
		Coverage w/ Orders	$C_{Final\ Product}$										
Affected Project 2	Related Customer 2	Customer Orders	$Q_{Ordered}$										
		Production Plan	$Q_{Produced}$										
		Inventory											
		Coverage w/ Orders	$C_{Final\ Product}$										
Affected Project 3	Related Customer 3	Customer Orders	$Q_{Ordered}$										
		Production Plan	$Q_{Produced}$										
		Inventory											
		Coverage w/ Orders	$C_{Final\ Product}$										
Critical Raw Material		Consumption	$Q_{Consumed}$										
		Planned Receipts	$Q_{Planned\ Receipts}$										
		Stock on Hand											
		Coverage	$C_{Raw\ Material}$										

APPENDIX 5 – FORMULAS IN THE PROPOSED STANDARD ALLOCATION FILE BY RAW MATERIAL

	Week		CW							CW+3							CW+4	CW+5	CW+...	CW+15
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Critical Parts	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Critical & Consolidated Raw Materials	Consumption		$Q_{Consumed}$							$Q_{Consumed}$										
	Planned Receipts		$Q_{Planned\ Receipts}$							$Q_{Planned\ Receipts}$										
	Stock on Hand		Q_{Stock}																	
	Coverage		$C_{Raw\ Material}$ (considering $Q_{Received}$)							$C_{Raw\ Material}$ (considering $Q_{Received}$)										

IMAGE BREAK

		Week		CW							CW+3							CW+4	CW+5	CW+...	CW+15
		Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Project	Customer	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Affected Project 1	Related Customer 1	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$							$Q_{Ordered}$										
		Production Plan		$Q_{Produced}$							$Q_{Produced}$										
		Inventory		Q_{Stock}																	
		Coverage w/ Orders		$C_{Final\ Product}$							$C_{Final\ Product}$										
Affected Project 2	Related Customer 2	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$							$Q_{Ordered}$										
		Production Plan		$Q_{Produced}$							$Q_{Produced}$										
		Inventory		Q_{Stock}																	
		Coverage w/ Orders		$C_{Final\ Product}$							$C_{Final\ Product}$										
Affected Project 3	Related Customer 3	Customer Orders	$Q_{Backlog}$	$Q_{Ordered}$							$Q_{Ordered}$										
		Production Plan		$Q_{Produced}$							$Q_{Produced}$										
		Inventory		Q_{Stock}																	
		Coverage w/ Orders		$C_{Final\ Product}$							$C_{Final\ Product}$										

APPENDIX 6 – FORMULAS IN THE PROPOSED STANDARD ALLOCATION FILE BY PROJECT – SHEET MACRO

Project	Customer	Week		CW						
		Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Project	Customer	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Project	**Related Customer**	Customer Orders	$Q_{Backlog}$				$Q_{Ordered}$			
		Production Plan					$Q_{Produced}$			
		Inventory		Q_{Stock}						
		Coverage w/ Orders					$C_{Final\ Product}$			

Week		CW+3						CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
Week Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Date	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Customer Orders						$Q_{Ordered}$					
Production Plan						$Q_{Produced}$					
Inventory											
Coverage w/ Orders						$C_{Final\ Product}$					

Critical Parts	Week		CW						
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Critical Parts	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Affected Critical & Consolidated Raw Materials 1	Consumption				$Q_{Consumed}$				
	Planned Receipts					$Q_{Planned\ Receipts} * \%_{Fair\ Share}$			
	Stock on Hand		$Q_{stock} * \%_{FS}$						
	Coverage					$C_{Raw\ Material}$ (considering $Q_{Received}$)			
Affected Critical & Consolidated Raw Materials 2	Consumption				$Q_{Consumed}$				
	Planned Receipts					$Q_{Planned\ Receipts} * \%_{Fair\ Share}$			
	Stock on Hand		$Q_{stock} * \%_{FS}$						
	Coverage					$C_{Raw\ Material}$ (considering $Q_{Received}$)			

IMAGE BREAK

Week		CW_{+3}						CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
Week Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Date	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Consumption						$Q_{Consumed}$					
Planned Receipts						$Q_{Planned\ Receipts} * \%_{Fair\ Share}$					
Stock on Hand											
Coverage						$C_{Raw\ Material}$ (considering $Q_{Received}$)					
Consumption						$Q_{Consumed}$					
Planned Receipts						$Q_{Planned\ Receipts} * \%_{Fair\ Share}$					
Stock on Hand											
Coverage						$C_{Raw\ Material}$ (considering $Q_{Received}$)					

Final Product	Week		CW						
	Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Affected Final Product 1	Customer Orders	$Q_{Backlog}$				$Q_{Ordered}$			
	Production Plan					$Q_{Produced}$			
	Inventory		Q_{Stock}						
	Coverage w/ Orders					$C_{Final\ Product}$			
Affected Final Product 2	Customer Orders	$Q_{Backlog}$				$Q_{Ordered}$			
	Production Plan					$Q_{Produced}$			
	Inventory		Q_{Stock}						
	Coverage w/ Orders					$C_{Final\ Product}$			

Week		CW_{+3}						CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
Week Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
Date	CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
Customer Orders						$Q_{Ordered}$					
Production Plan						$Q_{Produced}$					
Inventory											
Coverage w/ Orders						$C_{Final\ Product}$					
Customer Orders						$Q_{Ordered}$					
Production Plan						$Q_{Produced}$					
Inventory											
Coverage w/ Orders						$C_{Final\ Product}$					

APPENDIX 7 – FORMULAS IN THE PROPOSED STANDARD ALLOCATION FILE BY PROJECT – SHEET MICRO

Project	Related Customer		Week		CW						
			Week Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Usage	Raw Material	Final Product	Date	CD_{-1}	CD	CD_{+1}	CD_{+2}	CD_{+3}	CD_{+4}	CD_{+5}	CD_{+6}
Usage 1	Affected Critical & Consolidated Raw Materials 1	Affected Final Product 1	Customer Orders		$Q_{Ordered}$ * Usage 1						
			Production Plan		$Q_{Produced}$ * Usage 1						
Usage 2	Affected Critical & Consolidated Raw Materials 1	Affected Final Product 2	Customer Orders		$Q_{Ordered}$ * Usage 2						
			Production Plan		$Q_{Produced}$ * Usage 2						
Usage 3	Affected Critical & Consolidated Raw Materials 2	Affected Final Product 1	Customer Orders		$Q_{Ordered}$ * Usage 3						
			Production Plan		$Q_{Produced}$ * Usage 3						
Usage 4	Affected Critical & Consolidated Raw Materials 2	Affected Final Product 2	Customer Orders		$Q_{Ordered}$ * Usage 4						
			Production Plan		$Q_{Produced}$ * Usage 4						

IMAGE BREAK

CW_{+3}							CW_{+4}	CW_{+5}	$CW_{+...}$	CW_{+15}
Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday				
CD_{+21}	CD_{+22}	CD_{+23}	CD_{+24}	CD_{+25}	CD_{+26}	CD_{+27}				
$Q_{Ordered}$ * Usage 1										
$QP_{roduced}$ * Usage 1										
$Q_{Ordered}$ * Usage 2										
$QP_{roduced}$ * Usage 2										
$Q_{Ordered}$ * Usage 3										
$QP_{roduced}$ * Usage 3										
$Q_{Ordered}$ * Usage 4										
$QP_{roduced}$ * Usage 4										

ANNEX 1 – WASTE IDENTIFICATION IN INFORMATION MANAGEMENT (HICKS, 2007)

A classification of information management issues with respect to waste

	Issue	Implications for waste	Waste category
1	Information exchange	Inability to automatically exchange information and enable value to flow results in additional processes necessary to overcome this lack of functionality/poorly functioning process	Flow demand
2	Manual systems and data entry	Processes and resources necessary to overcome (1) and also where processes are unavailable	Failure demand
3	Monitoring, control and costing	Information is required but has not been generated and cannot flow	Flow demand
4	Information flow from customers and/or sales	Information does not flow and processes are not well defined so additional effort is necessary to acquire information	Failure demand and flow demand
5	Functionality of information systems	Inability to perform certain functions to support the management and flow of information requires additional resources	Failure demand
6	Information storage	Excessive information is stored—partly because of a lack of understanding of potential value	Flow excess
9	Numbering and traceability of machines, assemblies and parts	Additional effort required to locate up-to-date/accurate build	Flow demand
10	Information availability and accessibility	Time and effort necessary to identify information to flow and unavailability of processes to support flow	Flow demand and failure demand
12	Information identification, location and organisation	Resources necessary to identify the information to flow. The level of resources increases as the amount of information increases	Flow demand and flow excess
13	Information completeness and accuracy	Effort necessary to verify and/or correct information and the effect of its use	Flawed flow
15	Information duplication	Effort necessary to arbitrate between multiple instances of information	Flow demand and flawed flow
16	Information currency	Out-of-date or inaccurate information requires additional effort to verify and/or update information	Flawed flow
7	End-user developed applications over COTS information systems	Acquisition of additional resources to overcome existing process limitations and also in an attempt to minimise cost (waste)	Failure demand and waste reduction
17	Paper systems over COTS information systems	Master records are maintained in an effort to reduce waste however they may arise due to failure of existing processes	Waste reduction and failure demand
8	Information systems use and maintenance	Activities are perceived as a waste by members of the organisation but arguably undertaking these activities might improve flow and eliminate waste	Value
11	Information systems implementation and customisation	Activities are perceived as a waste by members of the organisation but arguably undertaking these activities might improve flow and eliminate waste	Value
14	Implementation and operation of quality systems	Activities are perceived as a waste by members of the organisation because the value to the organisation is not understood or insufficient	Value
18	Information systems strategy and planning	A lack of understanding of the value of information and its flow across the organisation can result in a poorly performing system and arguably waste	Value and waste

Annex 2 – Supply chain paradigms performance measurement (Carvalho et al., 2011)

	Key indicators	Performance measures	Sources
Financial	Assets management	Inventory turn-over	Martin and Patterson (2009)
		Return on assets	Martin *et al.* (2009), Kainuma and Tawara (2006)
		Return on investment	Chia *et al.* (2009), Cai *et al.* (2009)
	Revenues	Number of customers retained	Chia *et al.* (2009), Sambasivan *et al.* (2009)
		Market share and earnings	Martin and Patterson (2009), Chia *et al.* (2009)
		Sales	Martin and Patterson (2009), Cai *et al.* (2009)
		Rate of losing sales	Cai *et al.* (2009)
		New customer orders	Sambasivan *et al.* (2009)
		Profitability, Payment terms	
		Gross revenue	Chia *et al.* (2009)
		Profit before tax	
	Cost	Design and engineering cost	Naylor *et al.* (1999)
		Conversion cost	
		Quality assurance cost	
		Administration cost	
		Materials cost	
		Inventory cost	Naylor *et al.* (1999), Cai *et al.* (2009), Sambasivan *et al.* (2009)
		Production and shipment cost	
		Supply chain management costs	Sambasivan *et al.* (2009)
		Turnover costs	Cai *et al.* (2009)
		Information management costs	
		Distribution costs	Naylor *et al.* (1999), Cai *et al.* (2009)
Environmental	Environmental wastage flexibility	Air emissions	
		Materials use and waste	EPA - United States Environmental Protection Agency (2007), Kainuma and Tawara (2006)
		Water use and waste and pollution	
		Energy use	
		Scrap/non-product output	EPA - United States Environmental Protection Agency (2007)
		Hazardous materials use and waste	
Flexibility	Operations flexibility	Delivery flexibility	Cai *et al.* (2009)
		Procurement flexibility	
		Information systems flexibility	

(*continued*)

	Key indicators	Performance measures	Sources
Financial	Assets management	Inventory turn-over	Martin and Patterson (2009)
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		New customer orders	Sambasivan *et al.* (2009)
		Profitability, Payment terms	
		Gross revenue	Chia *et al.* (2009)
		Profit before tax	
	Cost	Design and engineering cost	Naylor *et al.* (1999)
		Conversion cost	
		Quality assurance cost	
		Administration cost	
		Materials cost	
		Inventory cost	Naylor *et al.* (1999), Cai *et al.* (2009), Sambasivan *et al.* (2009)
		Production and shipment cost	
		Supply chain management costs	Sambasivan *et al.* (2009)
		Turnover costs	Cai *et al.* (2009)
		Information management costs	
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Environmental	Environmental wastage flexibility	Air emissions	
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		Energy use	
		Scrap/non-product output	EPA - United States Environmental Protection Agency (2007)
		Hazardous materials use and waste	
Flexibility	Operations flexibility	Delivery flexibility	Cai *et al.* (2009)
		Procurement flexibility	
		Information systems flexibility	

(*continued*)

Key indicators	Performance measures	Sources
	Quality (scrap and waste reduction)	Naylor *et al.* (1999), Chia *et al.* (2009), Sambasivan *et al.* (2009)
	Elimination of waste	
	Meeting customer requirements	Naylor *et al.* (1999)
	Fitness for use	
	Process integrity	
	Minimum variances	
	Continuous improvement	
	Customer support	
	Product services	
	Product support	
	Customer complaints	Cai *et al.* (2009)
Service level	On time delivery	Chia *et al.* (2009), Cai *et al.* (2009)
	Out-of-stock ratio	Kainuma and Tawara (2006)
	Customer satisfaction	Chia *et al.* (2009), Cai *et al.* (2009), Sambasivan *et al.* (2009)
	Order fulfillment rates	
	Delivery performance	Martin and Patterson (2009), Cai *et al.* (2009),
	Internal time performance	Sambasivan *et al.* (2009)
	Cycle times	Sambasivan *et al.* (2009)
Time	Time-to-market (concept to delivery, order entry	Sambasivan *et al.* (2009)
	to delivery)	Martin and Patterson (2009)
	Response to market forces	Naylor *et al.* (1999)
	Lead-time (design, conversion, eng., delivery)	
	Lead-time for materials and inventory	

ANNEX 3 – PERFORMANCE MEASURES AND SUPPLY CHAIN ATTRIBUTES CAUSE-EFFECT DIAGRAM (CARVALHO ET AL., 2011)