POLITECNICO DI TORINO

Department of Management and Production Engineering
Master's degree in Engineering and Management

Master's degree Thesis

IMPLEMENTATION OF A MANUFACTURING DATA VISUALIZATION SYSTEM THROUGH AN OPEN-SOURCE BUSINESS INTELLIGENCE TOOL

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Academic Year 2020 - 2021

ACKNOWLEDGMENTS

Vorrei innanzitutto ringraziare la Professoressa Bruno per avermi guidato in questo progetto, rendendosi sempre disponibile a supportarmi elargendo consigli preziosi durante tutta la stesura dell'elaborato. Un sentito grazie va anche al Professor Lombardi per avermi dato la possibilità di conoscere la realtà di Eurodies ed avermi permesso di analizzarne i processi produttivi in prima persona.

Ringrazio Eurodies per l'ospitalità mostrata durante i miei giorni di permanenza in azienda e per avermi fornito i dati necessari per poter sviluppare il progetto.

Un ringraziamento speciale va alla mia fidanzata Elena, con la quale ho condiviso interamente questo percorso e che lo ha reso unico. Ti ringrazio per essermi stata vicina anche nei momenti più difficili e per avermi dato la spinta a dare sempre il massimo.

Ringrazio i miei coinquilini di via Colombo Andrea, Lorenzo e Michele con i quali mi sono sentito sempre a casa. Così come ringrazio Fra, Ale, Luca, Max, Edo, Lollo, Tognaz e Gigi perchè senza di loro questo percorso non sarebbe stato lo stesso.

Last but not least, ringrazio i miei genitori, per aver sempre assecondato ogni mia necessità esaudendo ogni mio desiderio, le mie nonne Teresa e Paola, e mio fratello Umbi, con il quale, nonostante la distanza, ho condiviso momenti indimenticabili.

Dedico questo traguardo a mio nonno Virgilio, che mi ha insegnato come impegno e dedizione siano la chiave per raggiungere qualsiasi risultato.

ABSTRACT

IMPLEMENTATION OF A MANUFACTURING DATA VISUALIZATION SYSTEM THROUGH AN OPEN-SOURCE BUSINESS INTELLIGENCE TOOL

Data represents a very valuable source for companies, since it allows supporting decision-making and managerial control. This is even more relevant for those companies operating in a mass customization environment, where products specifications and features are constantly changing.

In order to manage the data continuously generated, companies are more and more relying on different information systems, such as Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) and Product Lifecycle Management (PLM). However, such systems are scarcely integrated, and it is difficult to have a clear picture of the status of the company.

The objective of this work is, therefore, to provide companies with a simple and intuitive data visualization system, which gives access in a clear and structured way to the information collected by the different information systems, in order to exploit the intrinsic added value of data. The data visualization system has been developed by using Grafana, an open source business intelligence tool. A case study has been developed for an Italian car prototyping company to illustrate the potentiality of the proposed system.

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INTRODUCTION

One of the most recurring themes in today's discussions is data and the value it has for running any type of business. From an industrial point of view, this concept is part of the Industry 4.0 universe and it represents one of the most significant challenges that companies are facing. The goal is to be able to extract targeted information in order to improve company's performance and optimize its' decision-making process. This is made possible by a tool known as Business Intelligence (BI).

Becoming data driven, however, is by no means trivial. There is a number of steps that needs to be undertaken in order to obtain an effective and sustainable result in the long term.

This paper aims at analyzing the necessary procedures for the effective implementation of a Business Intelligence system within a manufacturing company, focusing specifically on the creation of a manufacturing data visualization system. The project is realized with Grafana, an open-source Business Intelligence software. In order to show its potentialities, the proposed system is applied to a case study for an Italian car prototyping company.

The first chapter focuses on the definition of the BI concept and the interpretation given to it in this paper. The maturity model of this technology and its architecture are also presented.

The second chapter discusses what are the requirements to successfully integrate BI in a company, with a digression both on industrial information systems and on performance management techniques and best practices. Finally, the state of art and the related research opportunities are presented.

The purpose of the third chapter is to show in detail what are the steps that companies must follow to pursue a digitization process to be able to fully exploit BI benefits. The focus here is narrowed to the so-called One-of-a-Kind Production companies and the importance of creating value by reusing and exploiting their knowledge. Furthermore, Knowledge-Based System (KBS) and its data model it is also described.

The fourth chapter focuses exclusively on dashboards as a data visualization tool. A brief definition and classification at a generic level is followed by a study on the characteristics of dashboards used for manufacturing companies. A generic example of a dashboard is also shown with a detailed description of the monitored indicators and their link to the data model. Finally, Grafana is presented, explaining the reasons why it was chosen, and which are its main features.

The last two chapters are about the description of the case study and the implementation of the project respectively. Chapter five contains a detailed description of the company with a specific digression on its production process and an analysis on its digitization status, where it is underlined the importance of this project to complete the digitization process. Chapter six presents the results of the project by explaining the characteristics of the implemented data visualization system, with a detailed description of the selected indicators alongside with a panoramic of the different dashboards.

1 CHAPTER

BUSINESS INTELLIGENCE

1.1 Definition

The term *Business Intelligence* (BI) was originally coined in 1865 by R. M. Devens in the "Cyclopaedia of Commercial and Business Anecdotes" and it was used to describe how the banker Sir Henry Furnese gained profit by receiving and acting upon information about his environment (Anon., 2014).
The first official definition appeared in 1958 when H.P. Luhn, an IBM researcher, defined it is as the ability to apprehend the interrelationships of presented facts in such a way as to guide action towards a desired goal (Luhn, 1958).

Nowadays, finding a standard definition of Business Intelligence can be challenging. Depending on the background of the viewer, BI can be defined as a principle, as an information system tool or as a collection of different technologies. BI is also seen either as a process or a product.
The process view comprises all those definitions that address BI as a set of methods that gather information from multiple sources and analyze it to support organizational decision making. Product view instead refers to BI as an information tool able to predict the action of organization's business environment, ranging from competitors, customers, suppliers, markets, products and services (Vedder, et al., 1999).

A definition summarizing both views is *"Business intelligence (BI) is an umbrella term that includes the applications, infrastructure and tools, and best practices that enable access to the analysis of information to improve and optimize decisions and performance"* (Gartner, 2013).

By digging deeper in the literature, many different interpretations can be found. Some researchers address more the technical aspect such as Data Warehouse Systems (DWHs) or Online Analytical Processing (OLAP) as key actors in the support of data structuring and analysis, while others are more focused on data reporting and data visualization, showing a more managerial shade.

The reality is that the concept of Business Intelligence is extremely varied and takes on different nuances depending on the context in which it is inserted and the sector in which it is applied.

For this thesis project, the interpretation that is given is as follows:

A Business Intelligence system can be defined as an information system capable of analyzing a vast amount of data to support the decision processes of an organization. By relying on tools such as data warehouse, online analytical processing (OLAP) and dashboards, data is collected, aggregated and displayed to enable end-users to create ad hoc reports and drive the decision-making process (Ul-Ain, et al., 2019).

The definition of BI shows that its central objective is to extract the most relevant business information in order to support and improve decisions throughout the organization.
Business Intelligence systems represent the evolved and modernized version of the standard managerial support systems present in the history, such as Decision Support Systems (DSS), Management Information Systems (MIS) and Executive Information Systems (EIS). Contrarily to these previous tools, BI technology is equipped with a more centralized data structure, allowing better data processing, and with analytical functions, capable of extracting just relevant information (Marjamäki, 2017).

As shown by its history, the rise of this technology is due more to a market-pull rather than a technology push approach. Around the late 1980s, after the introduction of bar codes and retail scanners, organizations started collecting significant amount of valuable data about their customers, products and revenues and started realizing that this information could have been used for strategic purposes (Nylund, 1999). Yet, the current technology was not capable of satisfying such needs. Therefore, DWHs and OLAP were developed, introducing new ways and methods to model and analyze data. A few years later, the world was witnessing the birth of spreadsheet programs that allowed users to discover the potential of gathering and manipulating data (Rasmussen & Goldy, 2002).
All these events played a key role in Business Intelligence growth and development, that started at the beginning of the new millennium and keeps growing today, fostered by the successful implementation and evolution of all its underlying technologies.

1.2 Evolution and Typologies

The degree of integration of Business Intelligence systems within organizations is not always of the same type. Depending on the size of the company and its needs, the capital invested in this technology and its degree of acceptance by employees, it is possible to distinguish between three different levels of integration (Razzicchia, 2012).

The first corresponds to a minimum, almost non-existent, level of integration. These are cases in which the BI is used for the production of ex-post on demand reports. Very often the true value of the information collected is not even recognized and exploited adequately because the interest of those responsible is more focused on solving the individual problem than on optimizing the processes as a whole.

The second involves a higher but still very low level of integration, where reporting is linked to the indicators defined in the strategy and is used to keep all business processes under control. This is a systematic use of BI but still unidirectional (from strategy to control), which then receives input from the strategic plan. The potential of the method, however, has not yet been understood or applied to such an extent that it can change the strategic plan, from which the reporting and various controls are originated.

The third corresponds to a complete or almost complete level of integration, where the information gathered in previous cycles of monitoring and performance management is used as a key element for strategic choices and where each defined process is monitored with the further objective of providing feedback to be used for the review of decisions taken.

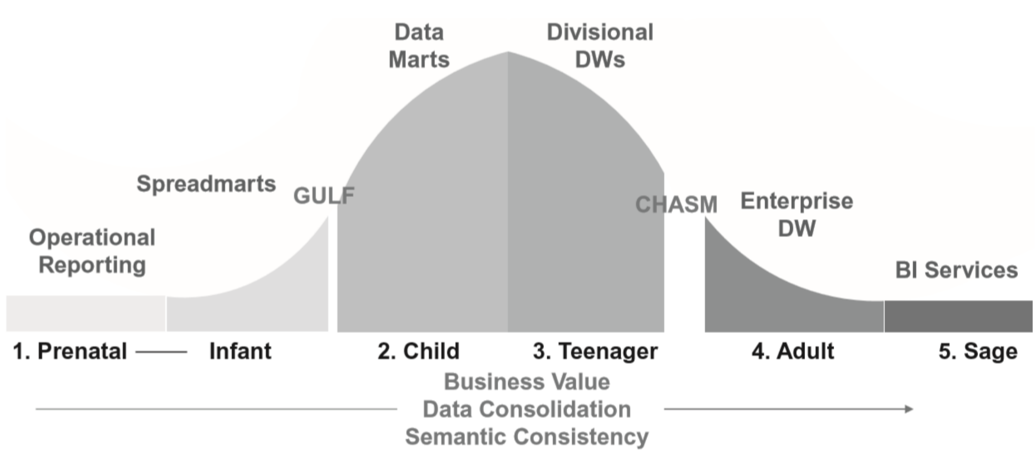

Figure 1: BI maturity model (Source: Wayne W. Eckerson, Performance Dashboards: Measuring, Monitoring and Managing Your Business, John Wiley and Sons, 2nd edition 2010, p.58)

The way organizations move from one level to another is described by Wayne W. Eckerson in his maturity model for Business Intelligence (Eckerson, 2010).
In Eckerson view, the model is organized in six stages, as shown in Figure 1:

1. Prenatal: reports are produced by conventional data-centric systems such as ERP or CRM and are distributed across the organization by email. For any kind of customization, IT specialists must work manually on it, increasing latency in decision-making.

2. Infant: in order to save time, expert users such as business analysts try to bypass IT specialists by extracting directly the needed data from the system and loading it into so-called spreadmarts (spreadsheets and desktop databases).
   The problem here is that each spreadmart contains a unique set of data that is not aligned with the others, thus making impossible for managers to identify which information is right.

3. Child: the data volume increases and spreadmarts become inefficient. The information here is shared not only with executives, but also with knowledge workers. This stage is characterized by the introduction of data marts, a shared database for each department of the organization, each one with its own definitions and rules that do not facilitate the cross-departmental analysis.

4. Teenager: in this stage, to overcome the problems of decentralized information contained in different data marts, data is conveyed into a single divisional data warehouse where it is collected and standardized providing a deeper level of analysis.

5. Adult: divisional data warehouses are merged into a single enterprise data warehouse, providing all users with the same set of tools and spreading BI powerfulness across the whole organization. The distinction between operational, tactical and strategic dashboard is made. Data can be provided to the end users in near-real-time.

6. Sage: BI turns from a reporting tool to an analytical tool capable of driving company decisions. It becomes a service, because BI team can help customers and suppliers managing their operations, thus increasing their efficiency. It can be either a free of

charge service with the purpose of locking in customers and suppliers, or a paid one that finally turns data warehouse from a cost center into a revenue center.

As explained in the literature, the switch from one stage to another is not straightforward. Two main barriers are highlighted, namely the Gulf and the Chasm.

- Gulf: to switch from spreadmarts to data marts, organizations need to overcome two main challenges in order to successfully start implementing BI solutions.
  The first one is called sponsorship and consists in finding consensus from executives, that can be of two types: enlightened or traditional. The former are excellent sponsors, they view BI as a tool capable of decreasing the mental effort needed to run the business and will implement it easily. On the contrary, traditional are more reluctant in the project endorsement without seeing tangible benefits upfront.
  The second one is related with data quality and reliability. Data is coming from different sources and in different formats, organizations can face difficulties in identifying which sources are reliable and merging the relevant data.

- Chasm: it represents the biggest challenge for organizations, it consists in the migration from a divisional view to a single enterprise one. Analytical tools and definitions are standardized across the organization, creating difficulties for users to adapt to new practices.
  The whole infrastructure of the information system is changed to align data with the new requirements. The role of BI managers is crucial, on the one hand the must carry out the technical switch in the simplest way and on the other hand they must educate users and push them to exploit all the benefits of the new architecture.

Eckerson's model is based on the concept of latency which is the temporal delay between the initiation of an event and the moment the event effectively shows up. In a decision-making process, latency is of three types:

- Data latency: time span between data collection and data storage
- Analytical latency: time span between data analysis and data transformation into useful information
- Decisional latency: time span between information processing and action

When moving from one stage the another the decision latency decreases because the evolution of the technology and its architecture provide the organization with increasing data freshness, passing from a state of awareness to a decision automation state.

By relying on BI maturity model, it is possible to identify four different types of Business Intelligence: Strategic BI, Tactical BI, Operational BI, Real-time BI (Sandu, 2008).

Strategic BI is mainly used by top management and financial analysts, interested in analyzing the performance of the company from a strategic point of view. Objectives such as profit increasing, cutting costs, gaining market share and improving customer relationships are the main focus of strategic BI, with a temporal window of months and years.

Tactical BI helps the organization to reach tactical objectives, defined by the strategic organizational goals. The main users of the technology are business managers, which are responsible for managing and monitoring business operations on a weekly and monthly basis.

Strategical and Tactical BI are forming the traditional BI. Traditional BI is characterized by the fact that, on average, valuable information is available only to the 15% of the employees of the organization, excluding all the workers on the front lines of business.

Operational BI try to overcome the obstacles faced by traditional BI, by providing visibility of the status of business operations to the users across the organization. The idea is that workers can monitor actively the performance metrics of the company and take corrective actions when problems arise.

Real-time BI is the evolution of Operational BI, the concept is the same but, in this case, data is analyzed as soon as it enters the organization. The objective is to reduce the latency to zero and it can be achieved with the implementation of powerful data warehouses with increased refresh cycles.

Nowadays, the competitiveness and dynamicity of business environment has increased significantly. In order to survive in such conditions, organizations need to provide the right information, at the right time, to the right people, in the right format (4R law) and BI is the technology capable of doing so.

1.3 Architecture

To better understand how Business Intelligence systems work, it is necessary to understand its components and its architecture, shown in Figure 2 and Figure 3 respectively. According to (Vercellis, 2009) a BI system is composed by six levels:

Data sources: it consists of gathering and integrating data coming from different sources, which are heterogeneous in origin and type. Information is coming mostly from operational systems, but it can be contained also in unstructured documents or emails.

Data warehouses and data marts: data coming from different sources is conveyed in databases by utilizing the so-called extract, transform, load (ETL) tools.

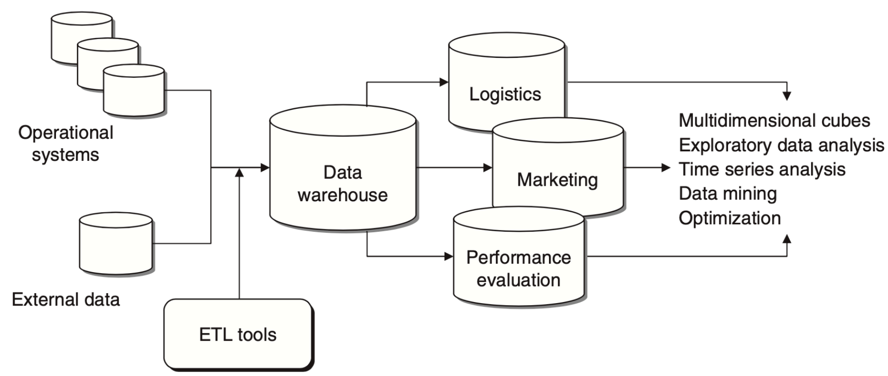

Figure 2: BI architecture (Source: Vercellis C., Business Intelligence: Data Mining and Optimization for Decision Making, Wiley, 2009, p.9)

Data exploration: the analysis made at this level is referred to as passive. In fact, decision makers firstly define data extraction criteria and generate hypothesis, then they use query, statistical analysis and reporting systems to find answers to their original insights.

Data mining: It is the level of active analysis. By utilizing mathematical models, machine learning, and data mining techniques data is converted into knowledge without any criteria nor hypothesis formulated upfront by the decision makers.

Optimization: among a set of different alternatives, at this level the system identifies which one is the best.

Decisions: By considering also informal and unstructured information not elaborated by the BI system, the decision maker take the final decision by eventually adapting or modifying the output of the Optimization level.

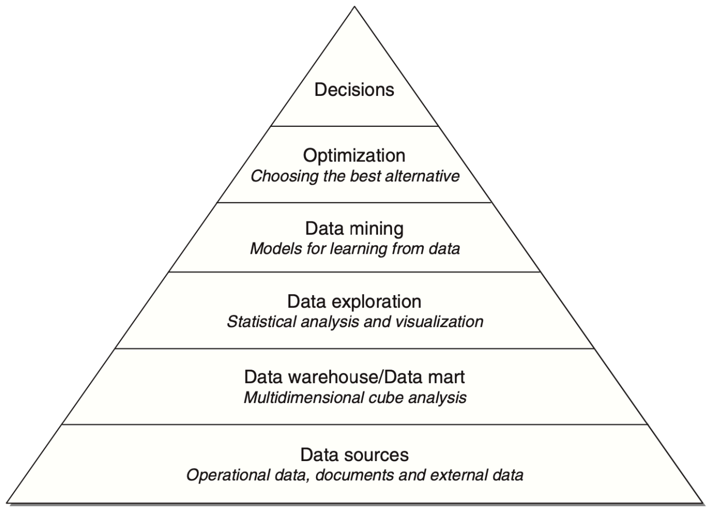

Figure 3: BI layers (Source: Vercellis C., Business Intelligence: Data Mining and Optimization for Decision Making, Wiley, 2009, p.10)

2 CHAPTER

BUSINESS INTELLIGENCE IN INDUSTRY 4.0

2.1 Industry 4.0

The term Industry 4.0 refers to the fourth industrial revolution and consists in the utilization of digital technologies such as advanced software, cloud, robotics and technological tools that promote the creation of an interconnected and automated industrial production.

The aim of Industry 4.0 is to improve the performance and maintenance of the machines by converting them into self-aware and self-learning machines, creating a smart manufacturing platform. The objective is to track products' position and status, to provide real time data monitoring and to hold the instructions to control the production process (Lee, et al., 2014), (Almada-Lobo, 2015).

Industry 4.0 is characterized by nine pillars that support the transformation of the manufacturing process into a fully digitized and intelligent one (Vaidya, et al., 2018).

1. Big Data & Analytics: represents the capability of collecting, standardizing and elaborating data coming from different sources to support real time decision making

2. Autonomous Robots: automate and facilitate production tasks difficult to be carried out by human workers, by interacting with one another

3. Simulation: using real-time data, it is possible to simulate the physical world in a virtual model. It is particularly used in production processes to optimize down times, energy consumption and production failures

4. Horizontal & Vertical System Integration: allows the flow of data across different business functions (horizontal) and with different partners across the value chain (vertical)

5. The Industrial Internet of Things: is the network of interconnected objects that communicate via standard protocols

6. Cyber security: technology that protects all information exchanged by the machines and stored in the network

7. The Cloud: facilitates data sharing of different devices and systems across the same organization

8. Additive Manufacturing: decreases time to market and product customization

9. Augmented Reality: AR based systems support different services such as selecting spare parts and sending repair instructions over mobile devices.

2.2 Manufacturing Information Systems

The advent of industry 4.0 has had a significant impact especially on manufacturing companies, that need to implement solutions to digitize their production processes in order to remain competitive in the market.

The first step consists in the implementation and maintenance of the information systems, from which they depend closely. These systems in fact allow companies to manage all activities related to products, production and management of relations with other companies or external organizations.
The information systems in which manufacturing companies invest are Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) and Product Lifecycle Management (PLM) system.

PLM
Product Lifecycle Management (PLM) is defined as "the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of." (Stark, 2015).
PLM systems allow a continuous monitoring of the product throughout its lifecycle, from product design to production and commercialization with the objective of creating a communication among all these phases to constantly generate results to be used in later stages and future projects.

The goal of a PLM system is to centralize products data and integrate design with production and commercialization processes, to manage product development projects in a formal manner. The continuous flow of information proper of a PLM system is made possible by a database, where useful information is stored in order to be reused and exploited.
In summary, PLM systems have a double function, on the one hand they provide for all the information related to the products and on the other hand they serve as a communication channel between the different parties involved in product lifecycle.

MES

Manufacturing Execution Systems (MESs) are computerized systems developed to monitor and manage the production processes in a plant.
MES are responsible for collecting real-time data about production system faults and machine status, they track products and components, control the status of the production and manage the resources. Their main task is to make sure that production execution remains stick to production planning.

By using a MES, organizations can experience several advantages such as increase in the efficiency and productivity, reduction of manufacturing time and costs, process and consumptions optimization and greater agility of the supply chain.

ERP

Enterprise Resource Planning (ERP) systems are complex information systems used to control all the operations of the organization and to collect and organize data coming from different levels of the company.
ERP systems collect information from sales, purchasing, manufacturing and distribution as well as from human resources, finance and accounting, allowing the company to have a better understanding of its operations.

They facilitate the information flow among all business functions within the organization and manage communications with external parties, guaranteeing the integration of information exchanged. By relying on an ERP system, organization can manage their business in a more effective way, eliminating wastes and inefficiencies.

2.3 Business Intelligence Integration

The Industry 4.0 concept has broadened the horizons of Business Intelligence. New sources of data, never taken into consideration until now, allow companies to gain new competitive advantage by giving meaning to the collected information.

An important element behind the Industry 4.0 boom is the ability to immediately analyze the information collected, making it possible to make decisions in real time (edge data integration). The ability to distinguish between normal and abnormal behavior implies a saving of time and money, which has actually changed the way of working at the operational level.

This represents an evolution also for the analysts themselves: from working on a database to working with a data stream, from using information derived from business activities to information collected from environments strongly influenced by hardware.

Another factor that comes into play in Industry 4.0 projects is data processing. The main challenges in this area are to distinguish between relevant or redundant data, to understand if it is necessary to keep the information or if all possible meanings have already been extracted, and to define the level of aggregation.

Once data have been received and stored, the information obtained must be used. There are several options and the capacity for analytical representation of the information is virtually unlimited: from dashboards for real-time monitoring and alerting management through decision-making tools, to the presentation of historical information and the evolution of a sensor or alarm indicators (Techedge Group, 2018).

Several research papers present in the literature discuss the integration of Business Intelligence systems in the organization to overcome Industry 4.0 main challenges. The focus is mainly oriented on operational value creation, demonstrated by measuring the effective variation of the most relevant performance indicators before and after BI utilization.

However, the literature shows no evidence that this value creation was reflected on companies' strategic objectives, and this is the reason why, in top management view, more than 70% of BI projects have failed to give the expected results (Ul-Ain, et al., 2019), (Boyton, et al., 2015), (Puklavec, et al., 2014). Therefore, it is of particular interest to evaluate how this misalignment can be mitigated.

In (Cortes, et al., 2016), the authors propose a framework that allows companies to evaluate whether future lean implementation are in line with strategic objectives of the company. Their idea is to combine the lean manufacturing approach with the Six Sigma methodology, creating a Lean-Six-Sigma Framework (LSSF). Lean manufacturing identifies wastes and problems to be solved, while Six Sigma analyzes the data supported by statistical methods and technology.

To gather the data needed to implement such a solution, the authors propose an integration between ERP and MES. Although there is no mention of the technology used for data analysis, the study is of particular interest because a BI solution can be used.

The LSSF is based on different steps, ranging from KPI definition to system control and improvement. The core part of the discussion is related with the operational and strategic objectives alignment, which consists in the following:

Firstly, it is necessary to identify the strategic manufacturing goals, long term objectives defined by the management which are based on the mission and vision of the company. Managers then translate these goals into strategic functional requirements, associating them with measurable performance indicators. A selection of the most relevant KPI is performed according to management decisions and priorities, and to each KPI is assigned a target value.

This study has two important takeaways. It shows the importance of starting from the strategic requirements of the company to effectively track tactical and operational performance by defining the most relevant key performance indicators and it demonstrates that industrial information systems integration is necessary to pursue strategic and operational alignment.

To better understand what these concepts mean in the following sub sections a digression on KPIs and on industrial information systems integration is respectively presented.

2.4 Performance Management

Modern manufacturing industry is becoming increasingly competitive and to fulfill demand changes companies must ensure that production systems are characterized by high productivity and quality, performing well in terms of reliability, productivity, flexibility and sustainability.

To do so, companies rely on performance measurement systems (PMS), a set of metrics that are able to quantify the efficiency and effectiveness of manufacturing operations (Neely, 1995). Companies firstly determine their strategic goals that then are supported by a set of detailed indicators to be measured and monitored, referred to as key performance indicators (KPI). KPIs are defined as a set of quantifiable and strategic measurements that reflect the critical success factors of an enterprise (Kang, et al., 2016).

The identification, maintenance and continuous review of the correct set of KPIs is crucial for the success of an organization. However, this is not a simple task, managers should follow specific steps and guidelines in order not to identify the wrong set of indicators. Research in the literature have developed and presented different frameworks to support organizations in such a critical activity. Below, two examples are presented.

According to (Kang, et al., 2016), KPIs can be assigned to three different levels: supporting elements, basic KPIs and comprehensive KPIs (Figure 4). Parameters at each level are then grouped based on their functions or attributes.
Supporting elements represent data directly collected and monitored during production, divided into time and quantity groups, they are used to derive the basic KPIs. Basic KPIs purpose is to reveal an aspect of performance of a specific work unit or system and can be categorized according to three aspects: quality, productivity and maintenance. Comprehensive KPIs are then identified by combining different basic KPIs.

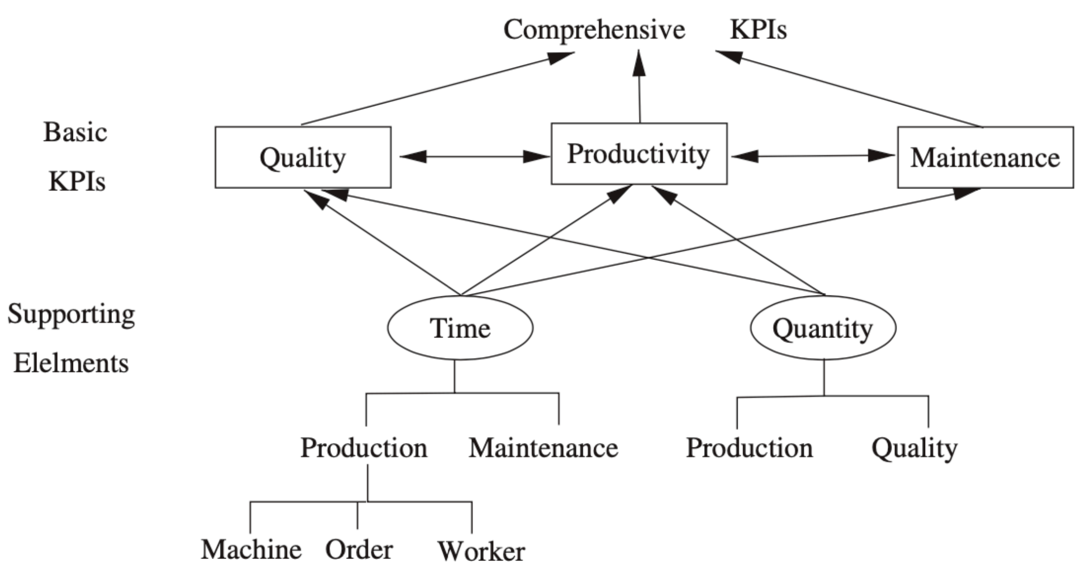

Figure 4: KPI layers (Source: Kang N. et al. (2016). A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. International Journal of Production Research, 54(21), 6333–6350, p.3)

In (Marek, et al., 2020) a framework called *performance dimension square* is proposed, with the objective of determining a general set of KPIs to be used by manufacturing companies to measure operational performance.
The authors divide performance management into four dimensions namely time, cost & efficiency, quality and flexibility and allocate 11 different KPIs obtained through a systematic literature review to each dimension.

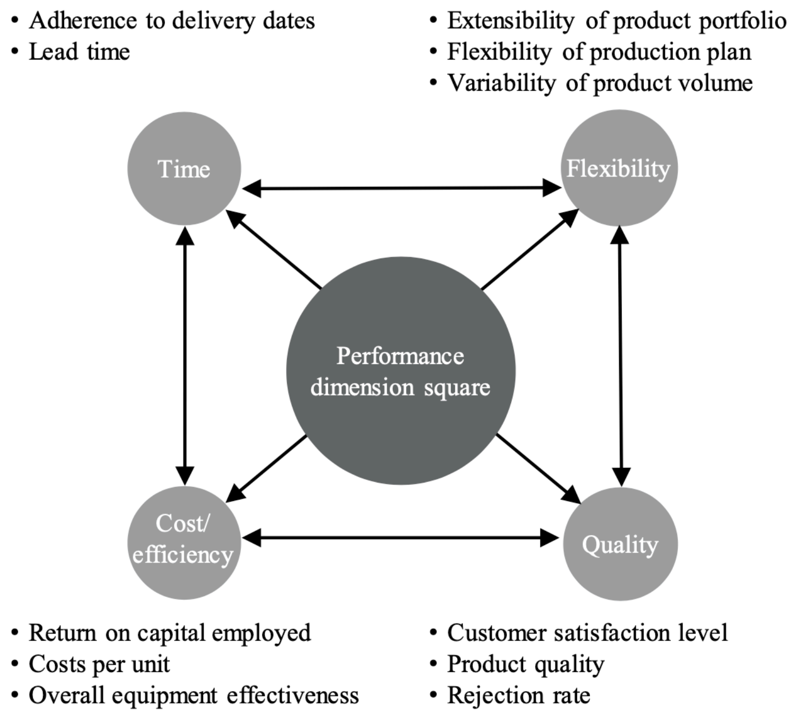

Figure 5: Performance dimension square (Source: Ing. Marek, et al. (2020). Identification of multidimensional key performance indicators for manufacturing companies, p.2)

In the literature is frequently mentioned that not every measure is a KPI and it is very important to distinguish and identify the correct KPIs to track effectively company performance. In (Roubtsova & Vaughan, 2013), the authors identify six properties that a measure must fulfill in order to be addressed as a KPI.

1) Quantifiability: it should be possible to express it in form of numbers
2) Sensitivity to change: the variation should be associated to a change in an input process or of the states of selected concepts in the models
3) Linearity: it should be able to be shown by a mathematical relationship in its simplest form

4) Reliability: the algorithm determining the calculation must be free of errors and robust both in routine and unexpected circumstances
5) Efficiency: it should be intuitive, unambiguous and easy to use
6) Oriented to improvement: it must address whether a business is actually improving to keep business performance competitive

As previously discussed, KPI definition and measurement should be aligned with organization's strategic objectives. A supporting tool widely used to guarantee such an alignment is the so called KPI Tree, a tree diagram on which KPI are positioned to have a clear structure amongst them.

KPI Trees help organization in KPI structure visualization to understand their hierarchy, guarantee more clarity and avoid redundancy. At the top there is usually the main comprehensive KPI to be defined, that is further divided into its basic KPIs and measurements, thus passing from a strategic view, to a tactical and then to an operational one.

To better understand how KPI Trees work and are developed, an example taken from the literature is reported below.

In (Ante, et al., 2018) authors propose a KPI Tree to describe the Performance Measurement System (PMS) of a lean production system of Bosch. The vision of Bosch Production System (BPS) is to focus on customer satisfaction and continuous improvement of value contribution through the elimination of waste and defects.
The tree is divided in a five-level hierarchical structure (Figure 6). Value Contribution is at the top, descending the Key Performance Results (KPR) are identified as Quality, Total Cost and Delivery Service describing the aggregated performance. At the monitoring level are calculated specific KPI for a given area of the shop floor system while elementary performance is measured at the improvement level, where the losses in performance are identified and measured, thus allowing the design of specific actions for performance raising.

To further understand how this practically works, a calculation example is reported. Starting from the Cost domain, Direct Productivity is defined as the ratio between produced good quantity (GQ) and the multiplication of the direct number of workers (DWN) and the planned working time per person (PPWT).

At this step is important to highlight how to calculate a specific index, it is necessary to move down in the KPI Tree to identify those measures necessary to define the desired index, passing from KPR to Monitoring KPI.
Moving forward, each monitoring KPI mentioned above is in turn determined by other basic KPI and their relative elements at the improvement level.
A simplified version of the KPI tree showing the above calculation is reported in the figure below.

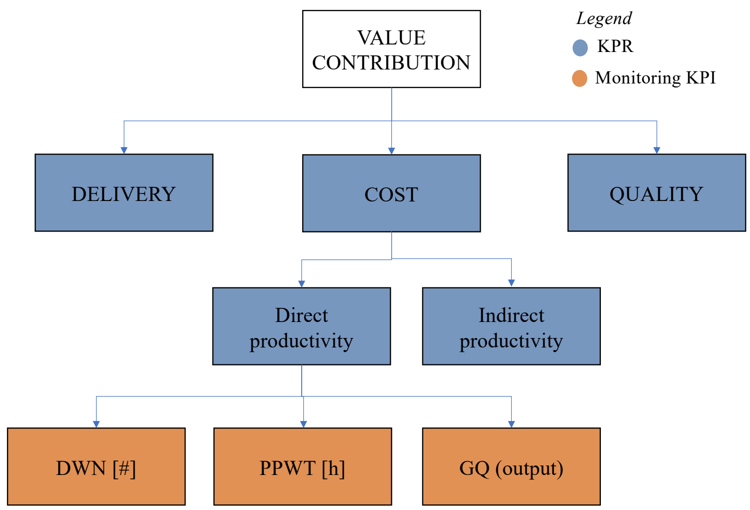

Figure 6: KPI tree example (Source: Adapted from Ante, G. et al. (2018). Developing a key performance indicators tree for lean and smart production systems. IFAC-PapersOnLine, 51(11), 13–18, p.15)

At this stage, readers have gained knowledge regarding what is a key performance indicator, how to distinguish between a KPI and a simple measure, and how to build a KPI tree. In the next section the focus of discussion is pointed towards data gathering, to make the calculation of the identified indicators possible.

2.5 Manufacturing Information Systems Integration

One of the core characteristics of Industry 4.0 revolution is given by the concept of connectivity, that represents the idea of implementing a factory where all physical and human assets interact to each other's in real time. To make this occur, it is necessary to have communication channels among all these entities.

As presented earlier in the chapter, the role of manufacturing information systems is to collect data related to different business processes and functions in order to improve operations management.
Analyzing these data using BI technology and techniques with ad-hoc Key Performance Indicators can strongly help organizations in gaining competitive advantage and create value from their activities.
However, this is effective only if data collected from ERP, PLM and MES can be exchanged, meaning that these three entities are properly integrated. By doing so, it is possible to fully exploit the benefits given by the combination of BI and Industry 4.0 technologies.

By integrating different ERP, MES, PLM systems it is possible to analyze and monitor, in real time, the production phases. It is possible to control inventory, orders and resources; monitor the activities carried out, the operators involved, the machines used and any downtime; identify the cause of errors and intervene on defective products.
The improvement in efficiency also leads to a reduction in costs, driven by a reduction in wastes and overhauls. In this way, operators are able to carry out activities more efficiently and quickly.

Companies relying on BI systems for data analysis and reporting are frequently facing problems related with latency and accuracy, because the information received and stored is manually reported and suffer delays. For example, the detailed information of the work schedule is transmitted from the ERP system to the workers in the form of paper timesheets, while operators report the progress of an order once per shit or once per day. These exchanges of information create the mentioned delays and inaccuracies that can impact on time delivery and subsequent customer satisfaction.
The integration of ERP, MES and PLM systems, permits to overcome such problems, guaranteeing a real time and automated information exchange, allowing BI systems to perform better analysis and improve data reporting quality (Kucharska, et al., 2015).

The degree of integration of these three systems depends on product typology and on the type of manufacturing, which can be continuous or discrete.
Continuous production characterizes those manufacturing systems where a single system is capable of producing several products by changing the recipe, while discrete production is proper of those systems that produce separate units that have to be assembled to get a new product.

Continuous production is generally characterized by a high level of automation that simplifies data acquisition but requires close monitoring in terms of production changes. Companies characterized by continuous or batch manufacturing usually opt for the integration of MES and ERP system.

ERP - MES integration helps to increase operational efficiency, reduce production time, increase flexibility and speed of decision making. With ERP - MES integration, manufacturers can place new orders before a product runs out. In fact, the integration of real-time material availability data helps manufacturers reduce unnecessary interruptions and delays.
MES systems simplify factory operations by managing and monitoring all stages of production in real time and allowing traceability of materials and products throughout their life cycle. If defective material is detected, it can be removed from inventory and returned to the supplier. The manufacturer can save money by eliminating waste due to defective raw material and reducing exposure to recalls and possible liability issues.

In discrete production data acquisition is more complex, because the level of automation varies for each company due to the difficulty in monitoring each single piece. The solution that is generally adopted is the integration between PLM and ERP systems.

PLM – ERP integration allows to synchronize product information between the two systems and solve problems. These integrations allow paperless management avoiding the risk of human error due to the manual input of BOMs into the ERP system.
The problem, however, is represented by a lack of proper control of the manufacturing operations.

It is therefore necessary to integrate PLM and MES. This model focuses on product design and production control concurrently, increasing quality of produced products and their design by identifying and tracing causes of errors and the related defects. It becomes even more important as product complexity and variations, production work and quality validation increase.

In Figure 7 is shown the integration among ERP, MES and PLM with the relative information flow.

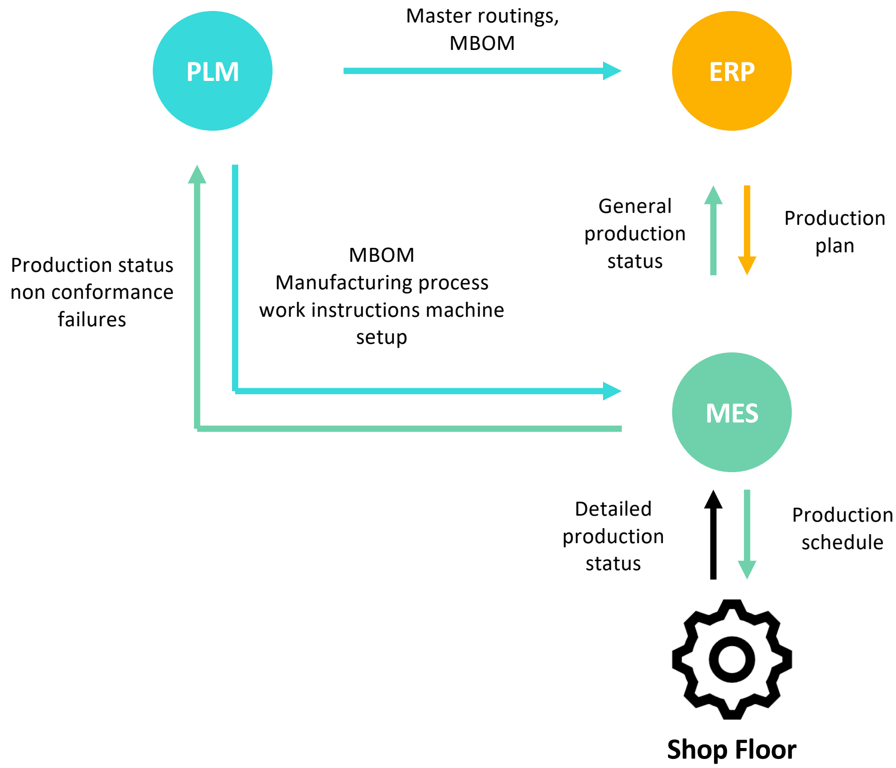

Figure 7: PLM – ERP – MES architecture (Source: Adapted from Khedher, A. B. et al. (2011, September). Integration between MES and product lifecycle management. In ETFA2011 (pp. 1-8). IEEE. P.6)

2.6 State of Art and Research Opportunities

The application of Business Intelligence in companies operating in an Industry 4.0 context is a relative widely discussed topic in the literature. The first publications started appearing around 2012 showing consistency with the date of emergence of Industry 4.0 and the interest in the subject has grown exponentially from that year onward.

Publications can be divided into two macro categories, on the one hand there are those focused on purely technical aspects while on the other those that analyze the topic from a more managerial point of view. Some authors' approach is just theoretical, while others opt for a more practical application.
Topics of discussion vary from data analysis, system architecture, data presentation and data extraction.

Regarding system architecture, several papers are focused on cyber-physical systems while others on the smart factory and data analysis.
Regarding the former topic, in (Lee, et al., 2015) is proposed a general architecture composed of five layers, while (Fleischmann, et al., 2016) and (Fleischmann, et al., 2016) focus is on a specific architecture to monitor machines conditions and in (Bagheri, et al., 2015) an adaptive clustering for self-adjusting machines is presented.
For the latter, in (Hänel & Felden, 2016) is proposed an architecture to apply operational BI to analyze data in real time while in (Eiskop, et al., 2014) the focus is on SME, with the proposal of ad hoc production monitoring system.

With respect to data analysis and data visualization, publications tackle specific industrial processes, a few of them are focused on improving quality monitoring, such as (Brandenburger, et al., 2016) and (Chen, et al., 2016) while others are more oriented on the assembly phase (Xu, et al., 2017) or the shipping phase (Wang, et al., 2016).

Focusing on research that prove BI value creation by validating a specific model on real case studies, it is worth to mention (Babatunde, et al., 2019) that applies BI techniques to predict customer orders in an MTO market. While papers such as (Felden, et al., 2013) and (Ahmad, et al., 2020) show the benefits obtained by the integration of a BI system in different industrial contexts, ranging from the textile industry, to IT and tool manufacturing.

Several publications mention using Manufacturing Execution Systems (MES) to integrate real time data coming from machines, products and devices to feed dashboards (Eiskop, et al., 2014) while others analyze BI integration with ERP systems (Hänel & Felden, 2016), (Gröger, et al., 2016).
In general, companies prefer to rely on commercial BI platforms such as Tableau, Power BI or Qlik but there are evidences of projects using free and open-source solutions as well, such in (Costa, et al., 2020) where it is used Grafana.

Despite the many publications on this topic, the research spectrum is so wide that it is easy to identify different gaps depending on the declination taken.
In this specific case the literature shows that there is no mention of studies focused on the use of BI in industrial environments where there is integration between MES and PLM systems.

The objective of this study is therefore to overcome the identified gap, implementing a performance analysis system using an open-source BI software in a SME operating in a PLM – MES integrated environment.

The idea is to propose a hybrid study discussing both technical and managerial aspects, developing the theory and showing practical results.

On the one hand the PLM – MES integration is presented, as well as the database structure and relations. On the other hand, company performance is monitored and analyzed by using specific identified KPIs ensuring consistency between project results and company strategic mission and vision.

3 CHAPTER

DIGITIZATION OF ONE-OF-A-KIND PRODUCTION COMPANIES

Up to now the focus of discussion has been oriented towards the understanding of what is Business Intelligence and how it can be used as a supportive tool for the decision management of an organization.
It is clear that companies, in order to effectively use such a technology, must broaden their horizons by introducing Industry 4.0 technologies in the organization, hence pursuing a digitization process.

The purpose of the following chapter is to dig deeper in such an aspect, by narrowing the focus on companies acting in a production environment characterized by mass customization, the so-called One-of-a-Kind production (OKP) companies.

3.1 One-of-a-Kind Production

Customers behaviour changes along time and manufacturers must adapt to new trends in order to survive in the market.
Latest trends have shown an increase in the demand for customized products, but with shorter time deliveries and at a similar price of mass-produced items, keeping quality intact. This phenomenon is called mass customization, and it has become a common goal to be achieved by several manufacturing companies in the market.

Mass customization concept joins the advantages of single piece production, characterized by individuality and precision, with mass production, characterized by rapidness and inexpensiveness.
Its' attractiveness from customers viewpoint it is represented by its capability of fulfilling different clients' expectations, adjusting products to specific needs. However, this represents a threat for companies, leveraging design and manufacturing costs, and the related risks of failure.
An extreme and special case of mass customization is called One-of-a-Kind Production (OKP) (Wortmann, 1992), new manufacturing paradigm with the objective of producing customized products according to individual customers requirements, maintaining mass production quality and efficiency (Pine, 1993), (Tseng & Piller, 2003).

OKP systems are characterized by a high degree of customization, an increase in product variety, a decrease in product life cycle and are generally proper systems of Small or Medium size Enterprises (SMEs).

High degree of customization implies frequent changes of customer requirements that can lead to reworks and longer lead times. To avoid these problems, products are successfully developed first time right with a constant customers involvement throughout the design and production processes.

The decrease in product life cycle and increase in product variety generate different problems. The available time for product development decreases, while small order sizes imply concurrent development and concurrent manufacturing, causing complex process planning and manufacturing scheduling problems (Li, et al., 2011). Companies, therefore, must re-think internal processes and rely on historical knowledge to speed up product development.

SMEs are usually characterized by limited number of resources and working with an OKP system can be challenging, especially when experienced workforce leave the company and knowledge might get lost. It is therefore necessary to record, track and recall historical product knowledge to make sure it remains in the company.

OKP system characteristics can be summarized as following (Tu, et al., 2006):

1. 'Once' successful development: no prototype is made throughout the development lifecycle
2. Product design consists in the combination and modification of existing products
3. Continuous customer involvement throughout product design and production
4. Mix-product production
5. Optimal utilization of technologies and resources

3.2 Digitization Process

To overcome the above identified problems, companies must rely on Industry 4.0 technologies to operate in a smart factory environment. Beyond new technical solutions in manufacturing area, companies have to innovate product design and production preparation and control, generating a revolution at the macro level.

The final goal is to develop a system capable to store, integrate and use data coming from different sources to analyze past and current trends and to perform rapid testing of different alternatives. This system consists of a digital representation of products and production processes (Figure 8) and it is made possible by three different typologies of integration: horizontal, vertical and end-to-end integration (Vaidya, et al., 2018).
Horizontal integration is referred to data along different business functions internal to the company, such as design, R&D, production, purchasing and human resources. On the contrary, vertical integration refers to data exchange with players and partners external to the organization, such as suppliers and customers. Finally, end-to-end integration enables the creation of customized products and services across the value chain (Stock & Seliger, 2016) by operating throughout product lifecycle.

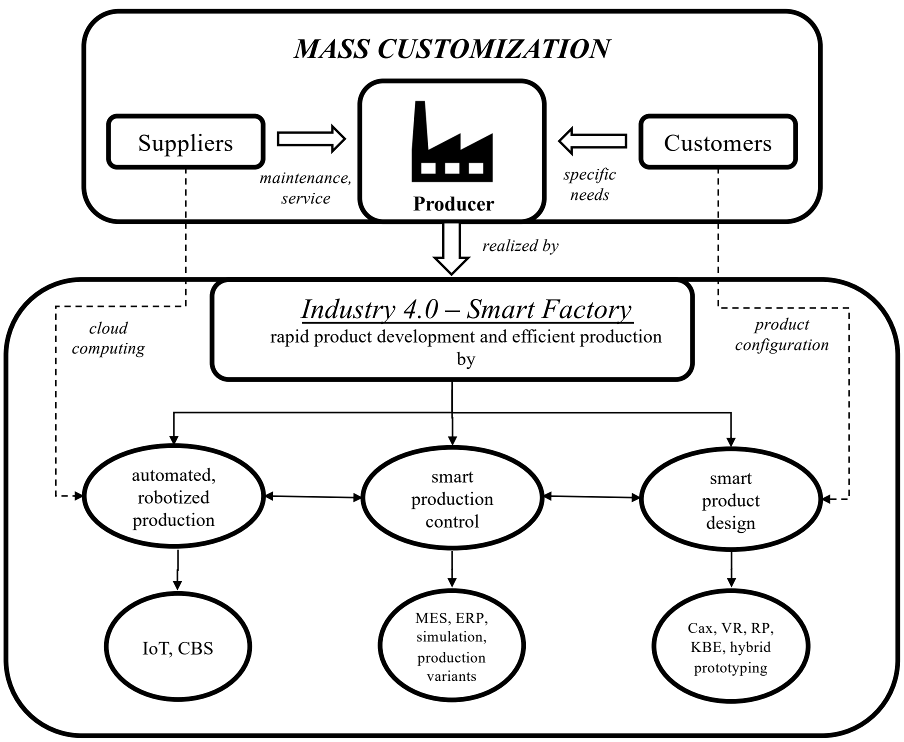

Figure 8: Mass customization in an intelligent factory (Source: Zawadzki, P., & Żywicki, K. (2016). Smart Product Design and Production Control for Effective Mass Customization in the Industry 4.0 Concept. Management and Production Engineering Review, 7(3), 105–112. P.106)

The elements present in a smart factory are many and each of them can be analyzed with different levels of detail, depending on the context. In this case, the two concepts playing a key role in the efficient realization of a mass customization strategy for a smart factory are product design and production control.

Product design

In an OKP system the design must be correct in the first iteration, to reach such a goal companies need past and current knowledge to take relevant information from and it represents one of the most critical processes in product design.

The information is stored in knowledge databases and different technologies are responsible for processing it, from sources identification and knowledge acquisition the information is then represented and analyzed. The system creates repositories that can be accessed and shared.

It is estimated that the effective implementation of such a system causes 80% of solutions to be prepared in an immediate manner (Verhagen, et al., 2012), accelerating the whole process.

Production control

Mass customization has an impact on production in terms of costs, efficiency and resource availability. To guarantee an efficient production system in such an environment it is necessary to implement control methods to react dynamically to internal and external factors that can have an impact on the functioning of it.

The most important aspects are the synchronization of material flow and the integration between scheduling and production planning to guarantee quick reaction to frequent changes (figure 9).

To successfully implement a production control system in this environment it is necessary to rely on IoT technologies that allow data about material flow, machine operations and manufacturing devices to be exchanged through a computer network. By doing so it is possible to monitor the system in real time and to analyze historical data to take corrective actions for the future. It facilitates maintenance planning and spare parts ordering, conferring flexibility and dynamicity to the system (Zawadzki, et al., 2016).

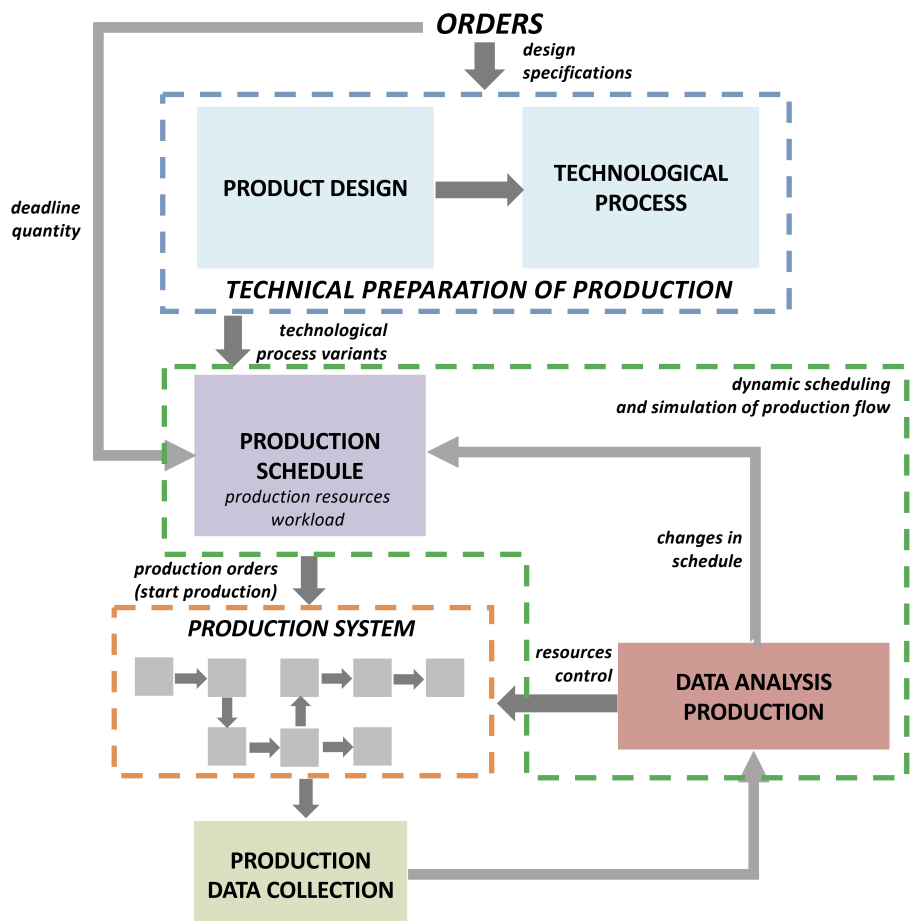

Figure 9: Process of control of production flow (Source: Zawadzki, P., & Żywicki, K. (2016). Smart Product Design and Production Control for Effective Mass Customization in the Industry 4.0 Concept. Management and Production Engineering Review, 7(3), 105–112. P.110)

To successfully achieve system integration, product design and production control must be interconnected to constantly exchange information. This can be achieved by the integration of their IT management platforms, respectively PLM and MES.

PLM and MES integration help the designers observing the production flow, receiving feedback and checking for anomalies to be corrected on the go and to improve the process for future production. This knowledge is of great importance when a new product is designed, especially for OKP companies that usually need several trial-and-errors cycles before finding the correct process steps.
The problem these companies are constantly facing is that such knowledge is kept in people's mind or transferred verbally and overtime it gets inevitably lost (Bruno, et al., 2014), (Bruno, et al., 2018). The same happens for operators on the production line when find difficult to report occurrences of problems and anomalies in a structured way.

The point is that companies relying on oral communication and knowledge based on the experience of their employees cannot compete on global markets, hence they need to implement a knowledge-based information system (KBS) to store and consult knowledge anytime its needed (Bruno, et al., 2021).

3.3 Knowledge-Based Systems

The secret of value creation in OKP companies relies in their capability of gathering and reusing product knowledge. By processing information about drawings, assembly instructions, manufacturing processes and decisions taken in the past from historical successful products, companies can foster future products design and manufacturing.
To remain competitive in the market, companies must rely on Knowledge-Based Systems (KBSs), central databases where relevant data from PLM and MES is conveyed and stored, acting as a bridge from process design and process execution.

A Knowledge-Based System is a computer system capable of gathering information and data from different sources and to create a knowledge base. It is mainly used for problem solving and decision making, and it relies on Artificial Intelligence (AI) techniques.

A KBS is composed by three layers (Figure 10): the knowledge base layer, the inference engine tool layer, and the user interface layer (Li, et al., 2011).
Knowledge bases layers contain reusable knowledge collected from previous processes, while inference engine tools enable the extraction of knowledge from current processes and customers opinions. Finally, interfaces facilitate the efficient communication, interaction and coordination between companies and customers.

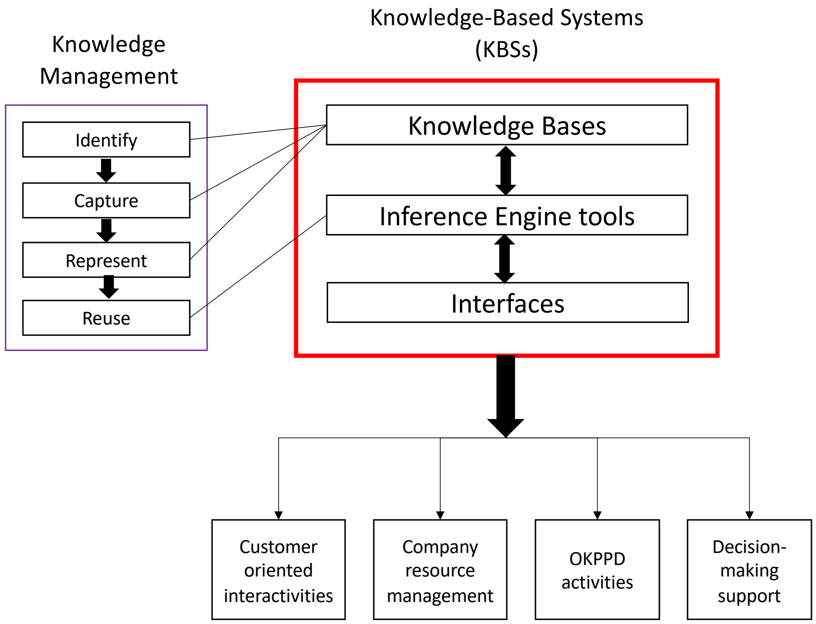

Figure 10: KBS layers composition (Source: Li et al. (2011). Recent development of knowledge-based systems, methods and tools for One-of-a-Kind Production. Knowledge-Based Systems, 24(7), 1108–1119. P.1110)

Compared to a traditional computer system, a KBS can handle larger amounts of data intelligently, developing a more detailed and efficient documentation in order to help decision-making experts.

The real powerfulness of such a system relies in its ability of creating new knowledge from stored content, allowing for a greater level of detail and experience, resulting in better productivity.

To successfully implement a Knowledge-Based System, organizations must follow a set of preliminary steps.

Firstly, it is necessary to analyze the business environment in which the company operates, taking into account all internal and external factors that may influence business processes and their performance. An example presents in the literature of a tool to be used to perform such an analysis is the PESTEL analysis (Political, Economic, Social, Technological, Environmental and Legal factors).

Through this, the company can define its objectives and the related risks, to be grouped into three categories: strategical, tactical and operational objectives.

Once company goals are clear, three further phases must be carried out: Functional phase, Technical phase, Technological phase.

- Functional phase: defines which functions the system should perform, which KPIs should be monitored and to whom they are addressed to identify possible improvements
- Technical phase: defines how the identified functions will be performed, the database structure and the frequency of database tables interrogation
- Technological phase: defines the magnitude and the investment typology, based on the goals to be achieved. It consists of selecting the proper hardware and software to physically build the database

To guarantee that the implemented information system is in line with company's objectives, a map of metrics to verify its efficiency and effectiveness should be defined. This verification system has the purpose to generate continuous improvement of the database (Bruno, et al., 2021).

3.4 KBS data model

Data in a KBS for a generic manufacturing company can be divided in five macro-categories:

1. Product data: contains information regarding products and customer orders;
2. Production data: comprises all the resources of the company and the operations that can be executed;
3. Process design data: contains information of the design of the production cycles for each product;
4. Production planning data: assign the operations of production cycles to the resources;
5. Production monitoring data: real time monitoring of operations, with starting and finishing times and quality assessment of the produced parts;

Each category is composed by different entities, containing different pieces of information. In Figure 11 is represented an entity relationship diagram (ERD) of the KBS, where only foreign key relationships are highlighted. Data coming from the PLM is highlighted in blue, while in green is highlighted data coming from the MES.

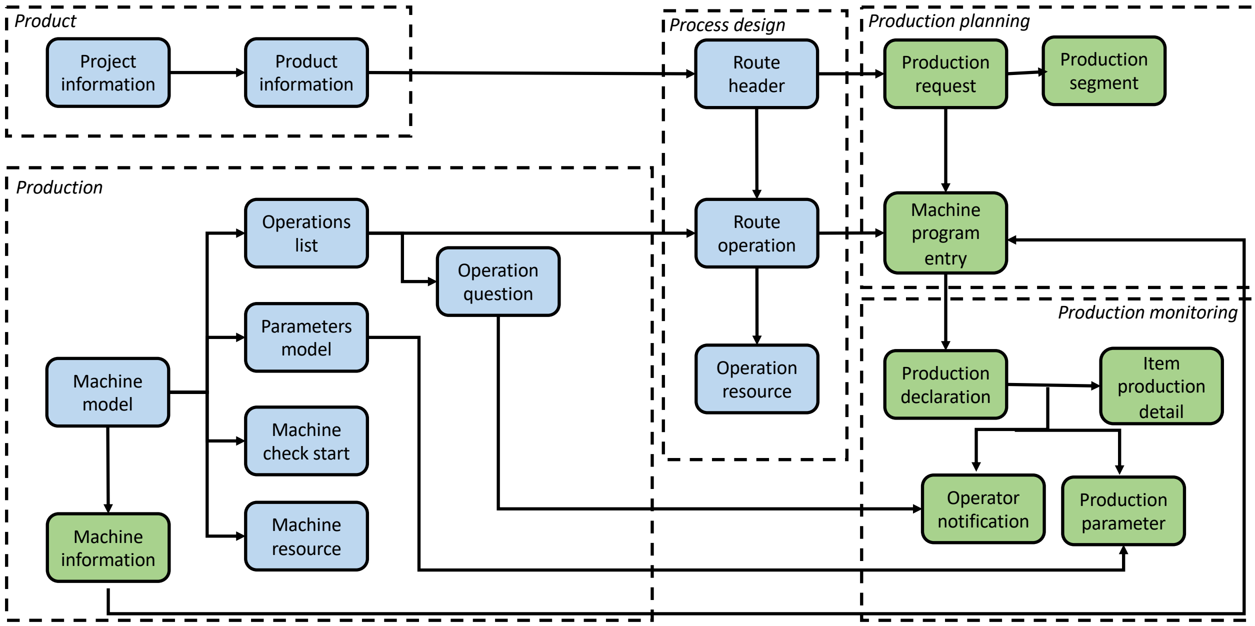

Figure 11: ERD of a generic KBS for a manufacturing company

Product data

- **Project information**: contains the data coming from the ERP of customers' orders.

Table 1: Project Information

Column Name	*Description*
ID	Order number
Customer	Customer name
Description	Project description
CustomerRequestDate	Date of order
CustomerRequestID	Customer order ID
Quantity	Quantity requested
Duration	Expected duration
ExternalDocumentID	External reference
EarliestStartTime	Requested starting time
ReasonType	Project typology

- **Product information:** contains the data of products, raw materials and tools.

Table 2: Material Information

Column Name	*Description*
ID	Item code
Description	Item description
UnitOfMeasure	Standard unit of measure
PublishedDate	Creation date
MaterialClass	Item typology (FP, RM, SF, TOOL)
MaterialDefinitionIDType	External item typology
BaseMaterial	Base material code
Family	Family ID
Subfamily	Subfamily ID
RouteCode	Production cycle code
UpdateTime	Time of record update
PalletQuantity	Standard pallet quantity
CycleQuantity	Product quantity per cycle
Complexity	Product complexity
CADFile	CAD link
Dimensions	Dimension of the material
Type	Typology of material
SideorSymmetry	Side of piece
Progressive	
DesignNumber	Design code
Index	
Weight	Weight of the object
Zone	Stored zone
Project	Project code
FirstDeliveryDate	First date of delivery
FirstDeliveryQuantity	Quantity of the first delivery
TotalNumberofDeliveries	Total amount of deliveries
DeliveryFrequency	Frequency of each delivery
QuantityperDelivery	Quantity of each delivery
DeliverydateperDelivery	
TotalQuantityofOrder	Total order quantity
Note	Notes

Production data

- **Machine model:** represents the types of machines available in the plant

Table 3: Machine Model

Column Name	*Description*
ID	Model code
Description	Function description
Family	Machine type
Subfamily	Machine subtype
OtherParameter	Family parameter
OtherParameterName	Family parameter name
Note	Additional notes

- **Machine check start**: collects the list of checks to be done before executing the operations on a machine

Table 4: Machine Check Start

Column Name	*Description*
ID	Unique code
MachineModel	Machine model ID
Resource	Resource code
CheckStart	Check description

- **Parameters model**: represents the parameters to be set on a machine before executing an operation and their related maximum and minimum values

Table 5: Parameters Model

Column Name	*Description*
ID	Parameter code
Description	Parameter description
MachineModel	Machine model ID
ValueType	Parameter type
MinValue	Minimu value

MaxValue	Maximum value

- **Machine information:** lists all the machines physically available in the plant, each one associated to a machine model and to a description.

Table 6: Machine Information

Column Name	*Description*
ID	Machine code
WorkCenter	Work center name
MachineModel	Machine model ID
Description	Machine description
TechnologicalLevel	Machine technological level
MachineSize1	Machine first dimension (width)
MachineSize2	Machine second dimension (length)
Note	Additional notes

- **Operations list:** contains a list of all the operations that can be executed on the different machines in the plant.

Table 7: Operations List

Column Name	*Description*
ID	Operation code
Description	Activity description
TypeCode	Operation type code
TypeDescription	Operation type description
ProcessCode	ID related parameter

- **Operation questions:** lists all the questions operators reply once an operation is executed to check if the result is fine.

Table 8: Operation Question

Column Name	*Description*
ID	Unique code
OperationID	Operations list ID
Question	Question text

- **Resource information:** contains data related to the other secondary resources needed by the machines to work correctly, (e.g., oil, rasp, nylon).

Table 9: Resource Information

Column Name	*Description*
ID	Unique code
Description	Resource description
Resource	Resource name

Process design

- **Route header:** contains information about the production cycles, to each product can be associated more than one production cycle due to the revisions. The production cycle consists of an ordered list of operations to be executed to obtain a product.

Table 10: Route Header

Column Name	*Description*
ID	Unique code
Description	Description
Product	Product code
Revision	Revision code
Duration	Duration

- **Route operation:** contains information about all the operations done in each cycle.

Table 11: Route Operation

Column Name	*Description*
ID	Operation ID
RouteCode	Route ID
Sequence	Operation sequence
Operation	Operation code
MachineModel	Machine model ID
ToolingTime	Tooling time (expected)
WorkingTime	Working time (expected)

- **Operation resource:** represent the resources used in each operation.

Table 12: Operation Resource

Column Name	*Description*
ID	Unique code
Sequence	Check before the operation
Description	Resource description
Product	Product information ID
OperationCode	Cycle operation code
Resource	Resource code

Production planning

- **Production request:** associate different production cycles to customers' orders specifying for each cycle the quantity to be produced and the estimated duration of the operations, as well as other parameters.

Table 13: Production Request

Column Name	*Description*
ID	Manufacturing order number
Description	Order description
Product	Product code
Project	Project reference
Priority	Sequence priority
Quantity	Requested quantity
EarliestStartTime	Requested start time
LatestStartTime	Requested end time
Duration	Request duration
RouteCode	Production cycle code
BillOfMaterial	Materials detail

- **Production segment:** reports for each operation of the production cycle the assigned machine, the estimated duration, the earliest start time and the latest end time.

Table 14: Production Segment

Column Name	*Description*
ID	Operation ID
ProductionRequestID	Manufacturing order number
ProductionSegmentSequence	Production sequence code
ProductionSegmentID	Operation code
Quantity	Requested quantity
EarliestStartTime	Requested start time
LatestStartTime	Requested end time
Machine	Machine code
Priority	Sequence priority
ToolingTime	Tooling time (actual)
WorkingTime	Working time (actual)
CycleQuantity	Quantity per cycle

- **Machine program entry:** associates the schedule of operations to each machine, with the planned start and end time.

Table 15: Machine Program Entry

Column Name	*Description*
ID	Program code
Machine	Machine information ID
Product	Material information ID
ProductionRequestID	Project information ID
Operation	Route operation ID
Description	Operation description
Priority	Sequence priority
SchedStart	Scheduled starting date
SchedEnd	Scheduled end date

Production monitoring

- **Production declarations:** represents the actual duration of the operations on the machines, categorizing setup and eventual downtimes and the corresponding reasons; here, also the quantity of good and discarded parts is reported.

Table 16: Production Declarations

Column Name	*Description*
ID	Operation ID
ProductionRequestID	Production request ID
ProductionSegmentSequence	Cycle sequence
PersonnelID	Operator code
Machine	Machine code
GoodsQuantity	Quantity of good products
ScrapQuanity	Quantity of scrap products
DateFrom	Starting time
DateTo	Finish time
Time	Total time
RecordType	Type of record (working, setup, block)
ReasonCode	Reason for the record type
Annotation	Notes
SegmentCompleted	Order status (closed, opened, aborted)
Attachment	External file ID

- **Production parameters:** reports the values of the parameters set in each machine for each executed operation.

Table 17: Production Parameters

Column Name	*Description*
ID	Unique code
DeclarationID	Item production details ID
ParameterID	Parameters model ID
Value	Preset value

- **Item production details:** reports all the discharged parts of an operation, specifying quantity discarded, the machine and the reason of the discard.

Table 18: Item Production Details

Column Name	*Description*
ID	Unique code

SessionID	Production declarations ID
Quantity	Declared quantity
Result	Item status
SerialNumber	Item code
PersonnelID	Personnel information ID
Machine	Machine information ID
Annotation	Operator notes
Parameters	Machine parameters ID
Attachment	External file ID
NotificationDate	Date

- **Operator notifications:** reports the answers for the operations executed on each machine, at the questions defined in the Operation questions.

Table 19: Operators Notification

Column Name	*Description*
ID	Unique code
DeclarationID	Item production details ID
QuestionID	Operation question ID
Answer	Binary input

The diagram shows that production planning entities and production monitoring entities contain data coming from the MES, while product, production and process design entities contain data coming from the PLM. Exception is made only for *Machine Information* which is stored in the MES, but it is grouped with PLM entities.

PLM and MES entities exchange information with the KBS, generating a data flow. Regarding PLM and KBS data flow, it can be an occasional one or a continuous one. The former refers to the information contained in the PLM that is entered or updated irregularly, such as information regarding a new machine installed in the plant or the steps of a new manufacturing operation. The latter instead refers to data entered daily, such as new customer orders and new production cycles.

PLM data communicated to the KBS is then transferred from the KBS to the MES. In fact, once the KBS registers a new production cycle under PLM input, the MES gather this information to update the production planning accordingly.

In general, the information flow between MES and KBS comprises all the information deriving from real time production monitoring. These data are recorded by the operators, who store information about finished and discarded products, operations starting and finishing date and time and all the relevant parameters useful to be tracked.

A real time monitoring system is particularly useful for production managers who, in case of failure, can define alternative procedures to obtain a better product.

4 CHAPTER

DASHBOARD – A DATA VISUALIZATION TOOL

The digitization of an OKP company is a laborious and complex process, but it is necessary to meet the challenges of the future and to continue to compete in the marketplace.
In the previous chapter has been discussed the importance of recording and analyzing information related to both design and production processes, as well as the need to automate the process of collecting data from machines and operators' knowledge.
Moreover, a solution to facilitate the communication between PLM and MES, known as KBS, was also presented.

What is missing is the ability to extract and interpret all the information collected, by creating a dynamic tool that makes the decision-making processes easier and more effective for those who manage the company, thus conferring the ability to fully exploit digitization benefits.

The purpose of this chapter is therefore to present the concept of dashboard, a tool used to visualize relevant information to drive company decision-making, and to show the characteristics and features of a generic dashboard for a manufacturing company.

4.1 Definition and Classification

A business dashboard is defined as an information management tool used to monitor the health of a business, by tracking, analyzing and displaying KPIs, metrics and specific data points. It is characterized by a high level of customization and it represents the most efficient way to track data coming from different sources, providing a central location where data is conveyed and displayed in an interactive, intuitive and visual way (Klipfolio, s.d.).

The purpose of a dashboard is to drive action. It is therefore mandatory for an organization to identify and associate the right dashboard to the right users. The first generic classification divides dashboards into operational and analytical.
An operational dashboard looks at the performance of the company in real-time, doing a constant comparison between the pre-defined KPIs and their related targets. This tool is used across various organizational levels and it serves to monitor company's operations.
Analytical dashboards, instead, are focused on company past performance, by analyzing historical data, organizations can set targets, get useful insights about where to improve and

can forecast future trends to anticipate possible problems. The ownership of such tools falls on business analysist and experts.

However, such a division is not sufficient to precisely identify dashboards' characteristics and its users. Therefore, a further classification is necessary. It is possible to distinguish between strategic, operational, analytical and tactical dashboards (Durcevic, 2020).

Strategic dashboard

Their purpose is to track performance metrics against company's strategic goals; therefore, performance is usually summarized over specific time frames (i.e., month, quarter, year). They are usually complex to be created, but when properly developed can significantly reduce operational costs, because they can provide senior managers with a clear view of strategic issues giving them the opportunity to define ad hoc actions.

Operational dashboard

Operational dashboards are used to monitor and manage operations with a shorter time horizon, and they are usually administrated by junior managers. Their purpose is to monitor and analyze company's activities in a given business area, by alerting users about business exceptions relying on real-time data. The level of detail is greater than strategic dashboards because administrators are generally taking direct actions, instead of further investigating as in the case of senior managers. They help departments to be proactive and to stay ahead of problems.

Analytical dashboard

Analytical dashboards are managed by analysts, that provide middle managers with a comprehensive overview of business data. Analysts' role is to deep dive in the historical data with the objective of identifying patterns and trends, do comparison and make predictions as well as setting targets.

These dashboards are mostly used when companies face complex and broad information that needs to be visualized in a clear and efficient way. Analytical dashboards represent a hybrid between strategical and operational ones.

Tactical dashboard

A tactical dashboard is used by middle managers to analyze and monitor companies' processes. They are categorized under the analytical dashboard group and are characterized

by their interactive nature, providing users the ability to explore data. The level of detail falls between the strategic and the operational dashboard.
Considering a sales dashboard, a tactical one would track sales targets considering actual revenues over forecasted revenues allowing users to filter data by region, sales manager and product while and operational dashboard would be rather focused on tracking sales of specific products against their competitors throughout the year.

To best show off their features, dashboards need the support of business intelligence software.
For this reason, nowadays, most BI platforms integrate a fully customizable data visualization interface. Among many features and functionalities, the most commons are the following:

- Direct connection to different data sources
- Different types of data visualizations such as tables, bar charts, line charts, bubble charts and tree maps
- Drill-down features, enabling users to get a deeper understanding about data by clicking on any visualization
- Data filters, enabling users to customize their view to center the focus on specific details
- Text boxes and tooltips, that provide explanation regarding the data being visualized

Dashboard typologies and their characteristics are summarized in Figure 12 below.

	STRATEGIC	TACTICAL & ANALYTICAL	OPERATIONAL
FOCUS	Execute strategy	Process optimization	Operations control
USERS	Executives	Managers	Staff
SCOPE	Enterprise	Departmental	Operational
TIME APPLICATION	Long-term	Medium-term	Routine
INFORMATION TYPE	Summary	Detailed/summary	Detailed

Figure 12: Typologies of dashboards

4.2 BI Dashboard in manufacturing

Once dashboards' have been classified, it is interesting to understand which typology are generally used in the manufacturing industry and what are their underlying characteristics.

In order to properly identify the above, a set of papers presenting different ad-hoc solutions have been analyzed and dashboards' main features have been extracted.

In general, manufacturing companies are facing problems related with the quality of the information gathered from the production floor, that can be unorganized (Higgins, et al., 2005), incomplete (Purdy, 2008), (Bai, et al., 2010) and delayed (McCaghren, 2005), (Hansoti, 2010), (Giriraj & Muthu, 2010). These create problems such as decrease in the production yield (Poobalan, 2009), (Purdy, 2008), (Charalambos, 2008), increase in the production cost (McCaghren, 2005), (Purdy, 2008), delay in the decision-making process (Hansoti, 2010), (Purdy, 2008), (Giriraj & Muthu, 2010), (Jambekar & Karol, 2006), (Higgins, et al., 2005) and poor customer service, (Jambekar & Karol, 2006), (Charalambos, 2008).

Organizations, therefore, prefer to track closely the shop floor, hence opting more for operational dashboards, with a few implementing tactical and analytical dashboards concurrently, leaving the strategic ones on the side. A must-have feature is the connection in real-time with the dataset, showing coherence with the characteristics of an organizational dashboard. Historical data storage and access is requested only by those companies that develop and maintain tactical and analytical dashboards as well. Graphical representations and a friendly user interface are others mandatory features, enriched by the possibility of including drill-down and tooltips in the visualizations.

Evidence shows that the benefits of using interactive dashboards include increased production efficiency (Poobalan, 2009), (McCaghren, 2005), (Giriraj & Muthu, 2010), improved decision making (Hansoti, 2010), (Charalambos, 2008), better customer service (Higgins, et al., 2005), reduced costs (Purdy, 2008), (McCaghren, 2005), (Charalambos, 2008), (Bai, et al., 2010), increased revenues (Purdy, 2008) and the possibility to create an access point to company information.

The information gathered from the literature suggests that manufacturing companies interested in improving the efficiency of their operations tend to focus on their shop floor performance as a starting point.
However, before implementing a data visualization system, organizations must identify which KPIs should be visualized following the procedures presented earlier in this work and generally speaking, their focus is on production efficiency, which is mainly affected by machines malfunctions, time wastes and excessive production wastes.

The indicators usually used to track such phenomena are the following:

- Machine setup time
- Machine blocks
- Number of scraps by machine
- Reason causes for scraps and for downtimes

Starting from these basic calculations, it is possible to widen the horizons of the analysis, shifting the focus from machines to products, thus identifying which products families create more problems or request longer working times, or by comparing their planned and actual production times to identify inconsistencies and possible forecasting mistakes.

Once all these indicators and their calculation methods are identified, it is necessary to understand which tables in the database contain the requested information and how it is extracted in order to be represented visually. These topics are ex

To provide readers with a better understanding on the above, the next two sections provide respectively information regarding the DB tables to be queried and an example of a generic manufacturing dashboard.

4.3 Database queries

To properly understand which tables must be accessed to obtain the needed information, it is necessary to further define KPIs formulas. Taking as a reference the indicators enumerated in the previous section, their calculation methods are presented below.

Machine setup time

$$\%\,Setup\ Time\ per\ Machine = \frac{\sum Setup\ time}{\sum Total\ time}$$

The tables involved are *Production Declarations* and *Machine Information*.

Inside *Production Declarations* table, the accessed columns are *Time* and *RecordType*. The former contains numeric information about the time of each record, while the latter associates to each time a specific typology helping to distinguish among working time, setup time, block time.

Machine Information table contains the column *MachineModel,* that lists all the machines physically available in the plant.

The two tables are joined together, and time data is grouped by machine, so to each machine are associated two-time values, one with the sum of the setup times and the other one with the total. By dividing these two values, the KPI is computer per each machine.

Machine blocks

$$Blocks\ per\ Machine = \sum blocks\ occurencies$$

The tables involved are *Production Declarations* and *Machine Information*, and the methodology is as above, with the only difference that the column *RecordType* is filtering just the records marked as “block”.

Scraps per machine

$$\%\ Scraps\ per\ Machine = \frac{\sum ScrapQuantity}{\sum(GoodsQuantity + ScrapQuantity)}$$

The tables involved are *Production Declarations* and *Machine Information***.**

Inside *Production Declarations* table, the accessed columns are *GoodsQuantity* and *ScrapQuantity*. The first one contains the number of good products while the second one contains the number of scraps products. By summing them together, it is possible to obtain the total number of products produced in each operation.

From *Machine Information* table it is taken the column *MachineModel*.

The two tables are joined together, and produced product quantities are grouped by machine, so to each machine are associated two values, one with the sum of the discarded goods and the other one with the total quantity of produced goods. By dividing these two values, the KPI is computed per each machine.

Scraps reason causes

$$Scrap\ reason\ frequency = \sum Quantity$$

The table involved is *Items Production Details***,** it reports details about the discarded items.

The accessed colums are *Quantity*, *Annotation* and *Result*. Result field associates to each record the status of the items, in this case just the results reporting scraps are considered. Quantity represents the amount of products associated to each record and annotation field associates to each record a comment with the problems occurred.
Per each annotation, quantities are summed up so it is possible to understand which problems have occurred more frequently.

Blocks reason causes

$$Block\ reason\ frequency = \sum count\ of\ ReasonCode$$

The table involved is *Production Declarations.*

The accessed columns are *ReasonCode* and *RecordType*. RecordType is filtered, to include just those records related to a block, to each block is associated a reason contained in the ReasonCode column.
The KPI consists in counting the number of times a reason reoccurs, to determine which problems occur more frequently.

By following the methodology exemplified in this section, it is possible to query and combine other tables of the database to show more results. For example, if a classification by product family instead of by machine is needed, the table join should be done on Production Declarations and Product Information tables.
To do so, it is necessary to deeply understand the relationship among primary key and foreign keys of the different tables populating the database. For this reason, is always a good practice

to go through the ERD several times and to have a good knowledge of all the fields populating the most important tables.

4.4 Example of a dashboard

The goal of this section is to show readers an example of a dashboard for a manufacturing company built with Grafana.

There are several BI tools and software available in the market that are used by companies to create dashboards. They can generally be distinguished among opensource software (OSS) or closed source software (CSS).

An opensource software is open to the public, its code is freely available on the Internet and it can be copied and edited by anyone. OSS is characterized by being generally free of charge, their programmers usually generate revenues by charging users for services and support.

Closed source software is the opposite, the code is proprietary, and it is not shared with end users. Any kind of modification fix and update must be authorized by its authors. They are characterized by a more user-friendly interface, but users must purchase a license to use the software.

Regardless of the type of software chosen, the example below remains unchanged.

Once the process of defining the indicators has been completed and after identifying how to extract the information from the database tables, it is finally possible to visualize the data graphically.

The dashboard represented in Figure 13 aims to support production managers in the decision-making process. The information shown is linked to a specific time range, which can be reduced or expanded at will, guaranteeing the possibility of extracting information at a weekly, monthly, quarterly or annual level.
Another advantage is being able to share dashboards with other members of the organization, even those generally less accustomed to read complex data sets.

The choice of charts represents a key element for the most accurate representation of different indicators. The charts in the example are of two types: bar charts and tree maps.

Bar charts are quantitative charts and in this specific case are used to represent KPIs related to machines: percentage of setup time, number of stops and percentage of rejected products. Tree maps, on the other hand, are qualitative. Their purpose is to highlight the most frequent causes for which waste or production stops are generated. Furthermore, each visualization can be enriched with tooltips features, to provide further specific information. As an example, by clicking on the squares of the tree maps it is possible to see the actual quantity of occurrences of a specific reason cause.

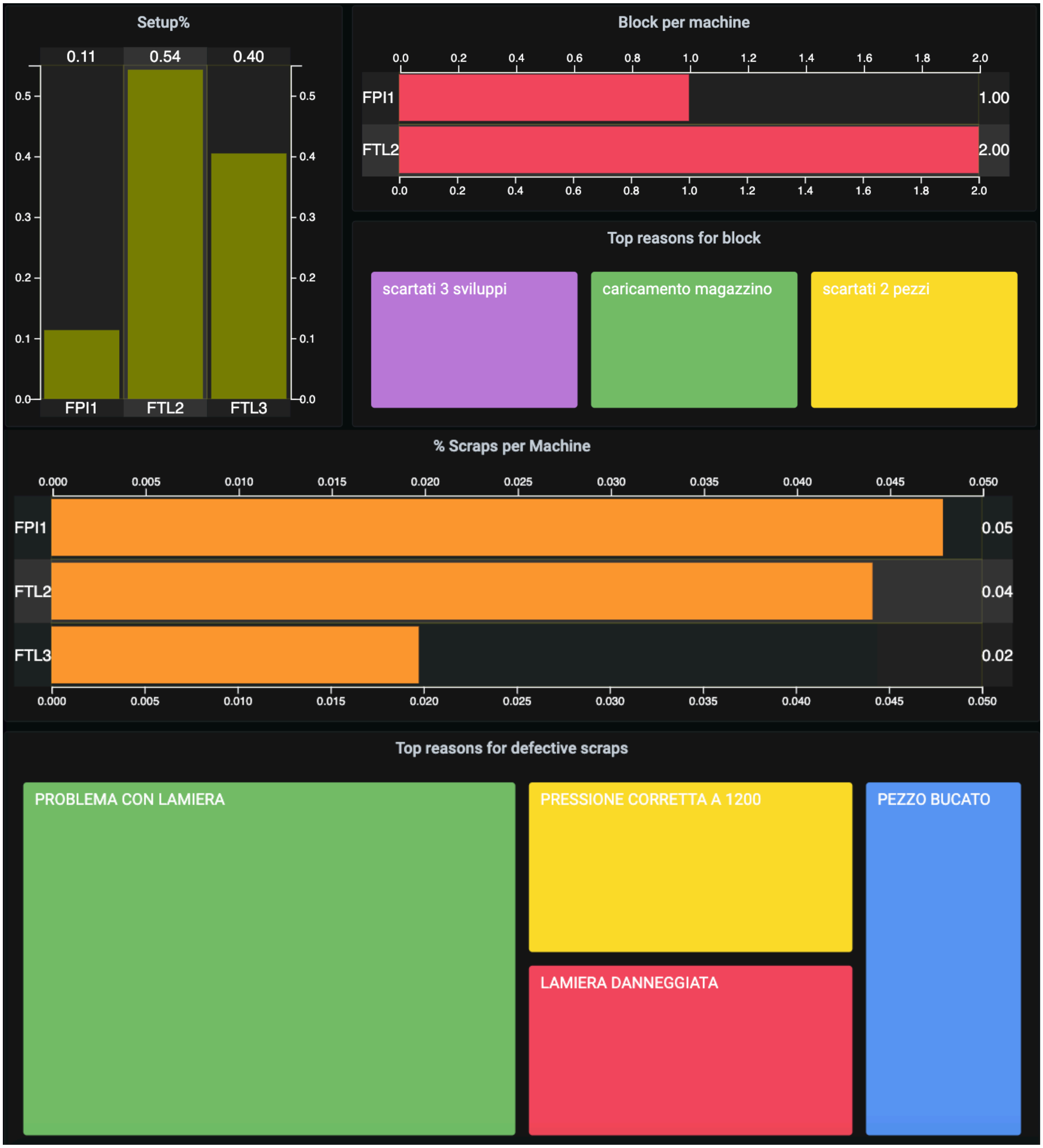

Figure 13: Example of a generic monitoring dashboard for a manufacturing company

4.5 Grafana

The goal of this section is to present Grafana and show the reasons why it has been selected as the tool to create the dashboards for this project.

Grafana is an online opensource tool that provides features of data visualization and analytics. Users can query, visualize and explore different business metrics by gathering data from multiple sources.

One of its main features is to allow direct connection to numerous databases, such as PostgreSQL, MySQL, Graphite, Influx DB, Prometheus and others. Furthermore, thanks to its opensource nature, it is possible to extend this list through the use of plugins, which can be downloaded for free or created from scratch according to the end user's different needs. This implies that a single dashboard can be composed of visualizations that refer to different data sources, thus providing the ability to unify these sources in a structured way.

Grafana offers a plethora of visualization options to build dashboards, such as graphs, tables, bar charts, gauges and tree maps. Like for data sources, also for visualizations there are several available online plugins that extend the offer.

Besides its core opensource solution, Grafana team offers two services for business: Grafana Cloud and Grafana Enterprise.

Grafana Cloud is a Software as a Service (SaaS) metrics platform, quite useful for users that do not want to take on the burden of hosting the solution on-site and want to remain free from the worry of managing the entire deployment infrastructure. The Enterprise service includes all Grafana Cloud features, adding premium plugins, data sources and premium support from the core organization.

The reasons why Grafana has been chosen as a tool for the realization of this project can be summarized as follows:

- it is an opensource, stable tool with comprehensive documentation
- it is configurable and expandable according to different needs
- it is actively developed and maintained, both by the core team and by users

- it is used by many companies in the IoT, FinTech or E-Commerce worlds
- it is relatively easy to use and visualizations are interactive and user friendly

4.6 Grafana user guide

Grafana is a relatively easy-to-use data visualization tool and it provides with an exhaustive documentation about its functioning and features, freely accessible on Grafana website.
The purpose of this section is to present and summarize those core steps needed to build the dashboard reported in Figure 13.

Installation & log-in
Grafana can be installed on different operating systems, as long as minimum hardware and software requirements are met. In particular, this tool runs directly on the browser, such as Chrome, Firefox or Safari and for a proper functioning they should be always up to date to the latest version.

Users can choose to download the enterprise or the opensource version. They are practically the same, but the enterprise one counts with additional features that can be unlocked with a purchased license.

The installation process on Windows is done via the installer, while on MacOS is done via the terminal with the support of Homebrew.

Once the installation is completed, Grafana interface is accessed via the browser on *localhost:3000* http address. Here, the user can set username and password for future accesses.

Data sources
Once the environment is set up, the first thing to do is to connect it to a data source. This is done by navigating to the configuration tab and selecting Data Sources. The options are several and are clustered according to their typology (i.e., time series databases).
In the settings is possible to specify the information needed to complete the connection, as well as setting some optional parameters.

Panels

The panel is the basic visualization in Grafana, it has a query editor associated to a specific data source and it belongs to a dashboard. They can be moved around the dashboard, renamed and formatted in several different ways.
Panels count with a query tab, where it is possible to query the associated data source, and with a transform tab that allow users to process the results of a query. Among the available options, it is possible to rename fields, add calculations and merge different queries.

Grafana offers a variety of visualizations, each one with its own customizable settings and options. More visualizations can be added with plugins.

Dashboards
A dashboard is a set of one or more panels. Dashboards can be renamed, shared and starred. It is possible to specify a time range to which the dashboard refers to, and to group panels into different rows.

Plugins
Plugins allow users to add extra options to their Grafana environment. Plugins can be installed directly from the Grafana website or users can build them on their own, thanks to the open-source nature of this tool.
Plugins can be divided in three types: panels, data sources and apps. Panels plugins are used when a visualization with specific features is needed to represent the queried data. Data sources plugins are useful to communicate with external sources of data not supported directly by Grafana.
Finally, apps plugins have the purpose of bundling data sources and panels to create a customized monitoring experience.

5 CHAPTER

CASE STUDY – EURODIES

5.1 Description of the company

Eurodies is an Italian company that operates in the automotive sector and is dedicated, through the design and modification of mathematical models, to the realization of samples and prototypes of car components. Its main activity consists in producing and assembling sheet metal and aluminium components for small series of cars, prototypes and other road vehicles.

Considering the life cycle of a car, the company's activity plays a fundamental role in the product design phase, in which there is a need to make prototypes in order to carry out tests and modifications to optimize the finished product. This process requires a great flexibility of production, being constrained by short deadlines and limited budget.
Once the characteristics of the finished product have been defined, Eurodies participates in the installation phase of mass production and has a contractual obligation to store the dies for a minimum period of ten years, thus following the entire production cycle of the product.

Eurodies has acquired, in a short time, an important position in the prototyping sector by combining the introduction of innovative processing systems with a continuous and targeted expansion of production capacity. The company is constantly working to improve its product offerings in order to increase the level of customer satisfaction. This has allowed Eurodies to compete with important realities both in Italy and abroad, especially in Germany. Among the different clients present in its portfolio, it is remarkable to name companies such as BMW, Porsche, Rolls-Royce and Volkswagen.

By dealing with the production of prototypes, Eurodies is categorized as an OKP company. As previously discussed in chapter three, OKP companies are characterized by a very high level of product customization. Therefore, in order to meet the daily challenges, it is necessary to combine workers experience with technological tools. By doing so it is possible to create high quality products at a low cost, making the production process as efficient as possible.

To better understand the information flow and functions assignment within Eurodies, Figure 14 shows the internal structure of the company, composed by nine offices and thirty-eight employees.

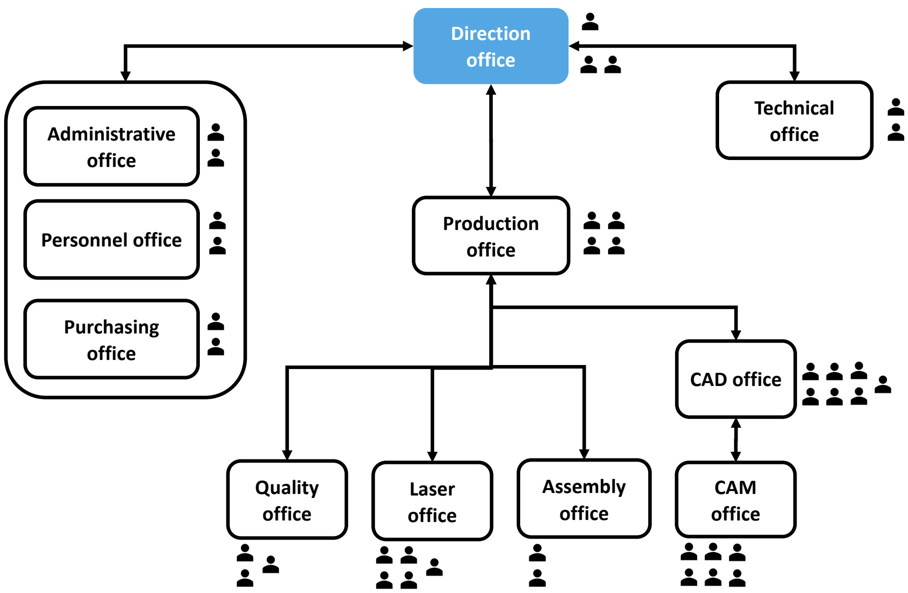

Figure 14: Departments of the company (Source: Eurodies 2019)

5.2 Eurodies production process

The company's production process consists of several stages (Figure 15). Once order specifications are received from the customer, they are translated into numerical values characterizing the geometry of the finished product. This is done using 3D CAD modelling software such as CATIA, whose final output represents the input of the production process.

Based on these parameters, molds are designed and produced. They are distinguished according to the construction type (left, right), the material (cast iron or resin) and the process in which they are used. In order to speed up the process and reduce the number of errors, the company creates molds with polystyrene to be used as a reference for the control of the subsequent production phases.

The actual molds are obtained through a milling process that consists of cutting the material with a rotating tool of several edges that performs movements on the three axes. The milling department of Eurodies has more than twenty CNC machines of very advanced technology, capable of producing extremely precise pieces.

Once the dies are realized, the metal sheets used to obtain the final product are sent to the laser office, here the raw material undergoes a two-dimensional cut and then it is transported to the presses area where it is performed the sheet metal forming operation.

The output of the first press operation is a semi-finished tri dimensional representation of the final product. Eurodies press department is composed by six presses with a capacity of 1600 tons and twelve presses with a capacity of 1000 tons.

Items are then returned to the laser office, where they undergo specific laser cutting according to customers specifications.

The production process ends with product testing and quality control, before reaching the assembly phase where prototypes and final products are obtained.

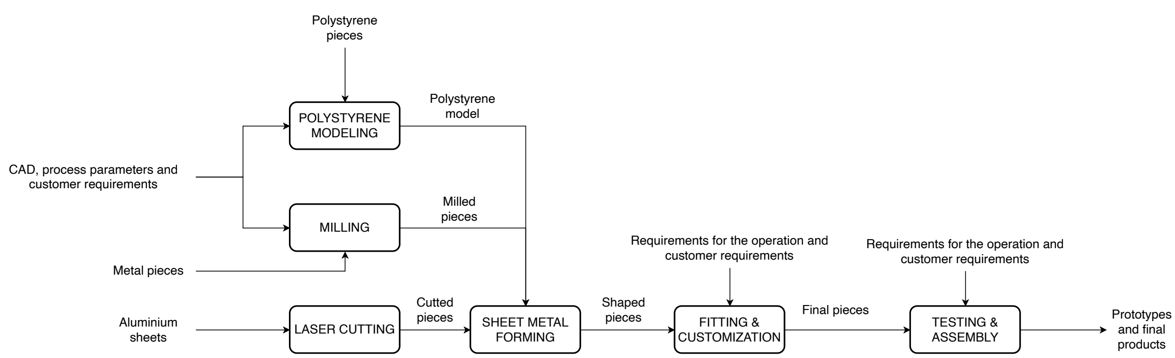

Figure 15: Generic production cycle

The process described changes according to products specifications, Eurodies produces different products with different characteristics. They are classified into four families: Panels, Structural Elements, Non-Structural Elements and Other Artifacts. Each family is composed by several subfamilies, to which is associated a level of complexity (0, A, B, C). A detailed classification of Eurodies products is represented in Figure 16.

Figure 17 represents all the production stages that a roof undergoes before being delivered to the client. This example is used here to explain the codification associated to each step of production.

The input is the raw material, a metal sheet to which is assigned a code composed by fourteen characters that specify its material type, thickness, and dimensions (i.e., z013414643073). The production cycle of a product consists of a succession of different operations, that are marked with a specific code indicating the stage (i.e., A0).
To each stage are associated two alphanumeric codes, the first indicates the type of operation carried out and the machine associated with that particular operation (i.e., A10L1), while the second one specifies the check the operator must perform before executing the task (i.e., CSA002).

A detailed explanation of these codifications is reported in Appendix A.

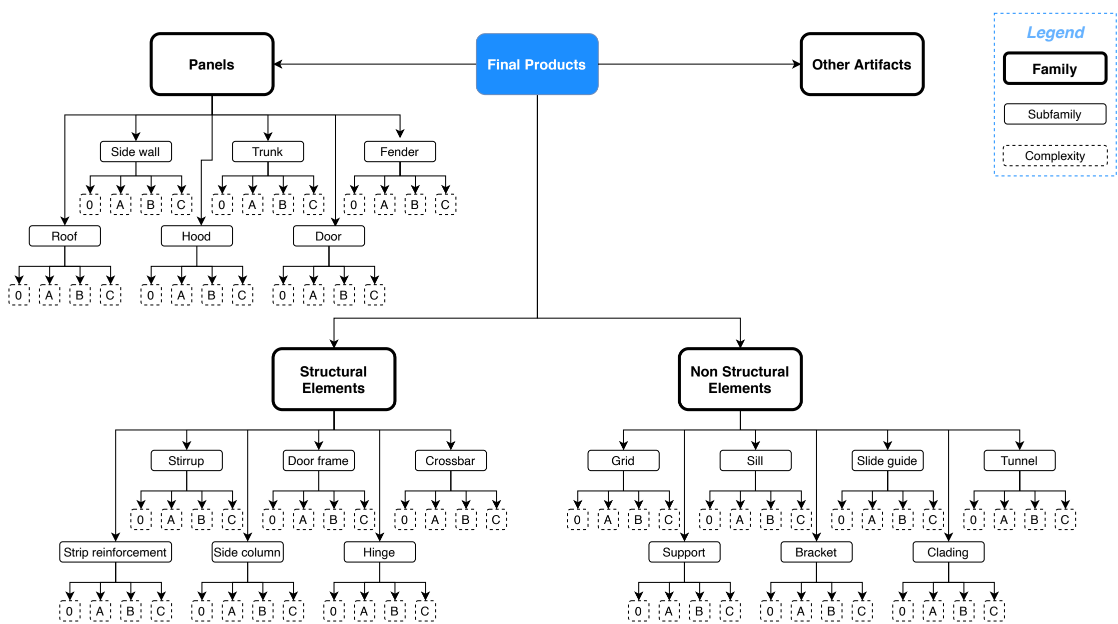

Figure 16: Final products classification (Source: Eurodies, 2019)

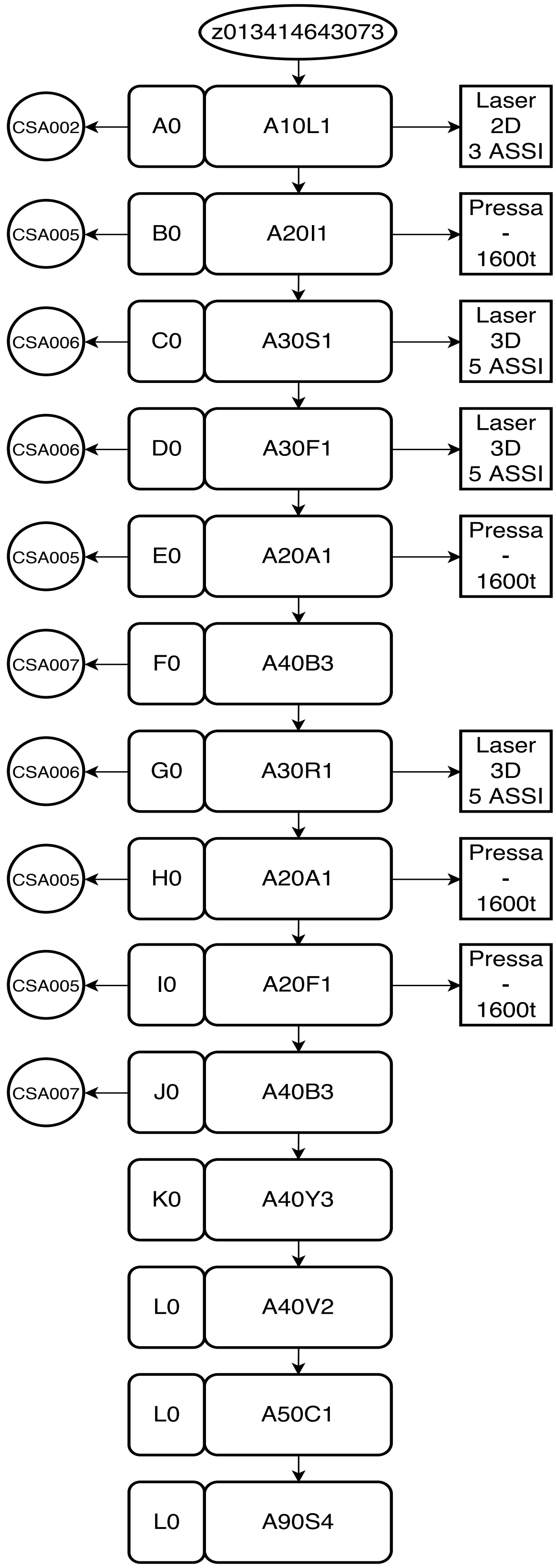

Figure 17: Production cycle of a roof (complexity C)
(Source: Eurodies 2019)

5.3 Digitization status

Eurodies is a small to medium-sized OKP company that, like many manufacturing companies of its caliber, has recently entered the world of digitalization. Until recently, all the activities that were managed thanks to PLM, MES, and ERP systems were done manually and the communication between the different stages of design and production or between different departments was only oral.

In 2019, the company embarked on its digitization journey to improve the quality of customer service, to optimize production processes, and to make internal communication and knowledge reuse more efficient.
The project consisted of introducing a PLM system and a MES system. The first one, implemented through the open-source software ARAS, aims to digitize and collect information about resources and production processes of the company's products. The second one, deals with collecting information about the activities related to the execution of production processes, and is provided by a commercial platform called JPiano.

These systems were later integrated thanks to a KBS, whose purpose is to interact with PLM and MES, collect information, and allowing a flow of communication between the two. The KBS also becomes the first point of access to the company's information, acting as a centralized database, created with PostgreSQL.

At the end of this process, the company found itself with a system that functioned technically but was not usable in practice. The primary aim was to centralize information and facilitate internal communication to work more efficiently; however, although it is true that information is now contained in the KBS, it is equally true that it is not accessible quickly and intuitively.

To better understand this last concept, it is necessary to refer to the tables of the database reported in section 3.4 of this paper. The data collected by PLM and MES are conveyed into the KBS and populate these tables, but as can be easily understood, it is complicated to extract exhaustive and aggregate information from it.

Therefore, this project aims to provide the company with a simple and intuitive tool capable of extracting from the database information regarding the life cycles of products and their production processes according to different levels of detail, following what has been discussed so far.

The tool chosen is Grafana, since, besides offering the advantages previously listed, it is compatible with PostgreSQL database.

6 CHAPTER

PROJECT IMPLEMENTATION

6.1 Data visualization system

The realization of a data visualization system is not a trivial task, to obtain satisfactory results capable of effectively supporting the company it is necessary to fully understand what are the dynamics related to their production processes and what factors influence them.

These factors can be split into two categories: direct factors and indirect factors. Direct factors include machinery, processed products, and workforce, while indirect factors include suppliers and customers.
Monitoring each of these factors is important to identify any trends that highlight potential issues, which negatively affect the efficiency of the business.

Focusing on what has been said so far, and contextualizing it in the reality of Eurodies, it was decided to structure the data visualization system into three different dashboards, to cover, albeit partially, the internal and external factors that threaten the efficiency of production.
The factors excluded are personnel and suppliers, as the KBS is not yet integrated with the ERP system, resulting in the impossibility of obtaining this information in a structured manner.

The dashboards are therefore focused on Machines, Customers, and Products.

Once the categories to be analyzed have been defined, the focus shifts to figuring out which are the most meaningful indicators to represent. At this stage, a deep understanding of the production flow is essential. It is also very important to interview production managers to understand which are the most critical aspects to be investigated.

Following an exhaustive analysis, the chosen indicators belong to the following categories:

- Setup time
- Production scraps
- Production blocks
- Products quantities

- Products complexity
- Production time forecast accuracy

Each category mentioned above is associated with at least one KPI, each KPI in turn can be represented in a single dashboard or be common to multiple dashboards.
Section 6.2 describes what the KPIs are, to which categories they belong and in which dashboards they are represented, while section 6.3 details each panel composing each dashboard.

6.2 KPIs definition

Percentage of setup time

$$\%\ Setup\ Time = \frac{\sum Setup\ time}{\sum Total\ time}$$

This KPI belongs to the Setup Time category and it is represented both in Machines and Products dashboards. The goal of this indicator is to show which machines or products require long setup times, that in turn affect production efficiency.

Number of production blocks

$$Number\ of\ Blocks = \sum Blocks\ occurencies$$

This KPI belongs to the Production Blocks category and it is represented in Machines dashboard. Its purpose is to highlight which machines stops more frequently.

Reasons of production blocks

$$Blocks\ Reason\ Frequency = \sum Reasons\ occurencies$$

It is used to get a better understanding of machine blockages; it shows the main reasons why stops occur.

Percentage of production scraps

$$\% \, Production \, Scraps = \frac{\sum Quantity \, of \, scraps}{\sum Total \, produced \, goods}$$

This KPI belongs to the Production Scraps category and it is represented both in Machines and Products dashboards. The goal of this indicator is to show which machines generate the highest percentage of scraps or which product family is subjected to greatest scrap quantities.

Reasons of production scraps

$$Scraps \, Reason \, Frequency = \sum Reasons \, occurencies$$

It is used to get a better understanding of why scraps occur, listing the main reasons and their frequency of occurrence.

Total requested quantity

$$Total \, Requested \, Quantity = \sum Orders \, quantities$$

This KPI belongs to the Products Quantities category and it is represented both in Customers and Products dashboards. It shows the number of requested quantities per each customer and per each product family respectively.

Average quantity per order

$$Average \, Order \, Quanity = \frac{\sum Orders \, quantities}{\sum Number \, of \, orders}$$

Similarly to the previous indicator, the average quantity per order is represented in Customers dashboard as well. In this case, it evaluates what is the average requested quantity by each customer per order.

Average product complexity

$$Average\ Product\ Complexity = \frac{\sum Product\ complexity}{\sum Number\ of\ products}$$

It belongs to the Products Complexity category and it is represented in Customers dashboard. This indicator shows what is the average product complexity requested by each customer.

Average forecast bias

$$Average\ Forecast\ Bias = \frac{\sum(Actual\ duration - \ planned\ duration)}{Total\ number\ of\ projects(products)}$$

This KPI belongs to the Production Time Forecast Accuracy category and it is represented Customers, Machines and Products dashboards. It shows the average bias in production duration forecast, categorized by customer, machine or product family.

6.3 Dashboards

Customers Dashboard

The purpose of customers dashboard (Figure 18) is to categorize and highlight customers behavior according to four different indicators.

The first indicator is *Total Requested Quantity* and it is represented via two distinct tree map visualizations, which allows to identify in a qualitative way which customers requested greater amounts of products overtime and which typologies of products they request.
This information helps to understand which customers have the greatest impact on production volumes, making it possible to distinguish between those who order products for mass production and those who request them for prototypes. The precise number of requested products can be gathered by moving the cursor over the visualization to see data in the tooltip. These visualizations are obtained by querying the database as below.

```
SELECT projectinformation.customer,
SUM(projectinformation.quantity) AS “Quantity”
FROM projectinformation
GROUP BY projectinformation.customer;

SELECT materialinformation.family,
projectinformation.customer,
(SUM(productiondeclarations.goodsquantity) +
```

```
SUM(productiondeclarations.scrapquantity)) AS "Total
quantity"
FROM productionrequest
JOIN productiondeclarations ON
productiondeclarations.productionrequestid =
productionrequest.id
JOIN projectinformation ON projectinformation.id =
productionrequest.project
JOIN materialinformation ON materialinformation.id =
productionrequest.product
GROUP BY projectinformation.customer,
materialinformation.family;
```

The second indicator is *Average Order Quantity* and it highlights which is the average amount of pieces requested in a single order by each customer. Its goal is to give an idea of the size of each customer's future orders based on historical trends, allowing managers to plan production accordingly. Information is represented via a horizontal bar chart that shows data in a quantitative way.
This visualization is obtained by querying the database as below, and by using the Transform function of Grafana to divide Quantity and Number of orders.

```
SELECT projectinformation.customer,
SUM(projectinformation.quantity) AS "Quantity", COUNT
(projectinformation.id) AS "Number of orders"
FROM projectinformation
GROUP BY projectinformation.customer;
```

The third indicator is *Average Forecast Bias* and it shows the average bias in production duration forecast per each customer. The visualization chosen is a histogram, as it allows to visually distinguish between positive and negative values. Positive values indicate a delay on average, as the actual timing is greater than expected, and are highlighted in orange. Negative values instead highlight the opposite trend and are marked in yellow. The difference of colors has been chosen so as to distinguish the two cases.
Values that exceed the upper and lower limits are highlighted in red regardless of whether they are positive or negative. In this way it is possible to identify immediately those customers for which the forecast of the production times is more complicated.
This visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Merge of the three tables
- Calculation of the difference between actual time and planned time

- Calculation of the indicator by dividing the calculated difference with the number of projects

```
SELECT projectinformation.customer,
SUM(productiondeclarations.time) AS "Actual time"
FROM productionrequest
JOIN productiondeclarations ON
productiondeclarations.productionrequestid =
productionrequest.id
JOIN projectinformation ON projectinformation.id =
productionrequest.project
GROUP BY projectinformation.customer;

SELECT projectinformation.customer, COUNT
(productionrequest.project) AS "Number of projects"
FROM productionrequest
JOIN projectinformation ON projectinformation.id =
productionrequest.project
GROUP BY projectinformation.customer;

SELECT projectinformation.customer, SUM
(productionrequest.duration) AS "Planned time"
FROM productionrequest
JOIN projectinformation ON projectinformation.id =
productionrequest.project
GROUP BY projectinformation.customer;
```

The fourth indicator is *Average Product Complexity* and it shows the average level of complexity of the requested products by each customer. This information can come in handy during the production planning process. In fact, more complex products usually correspond to longer manufacturing lead times. Not taking this variable into account can adversely affect the accuracy of the duration forecast, resulting in delays. The visualization chosen is a horizontal bar chart.

This visualization is obtained by querying the database as below, and by using the Transform function of Grafana to divide Complexity and Number of orders, in order to obtain the desired indicator.

```
SELECT projectinformation.customer,
SUM(materialinformation.complexity) AS "Complexity", COUNT
(productionrequest.project) AS "Number of orders"
FROM projectinformation
JOIN productionrequest ON productionrequest.project =
projectinformation.id
```

```
JOIN materialinformation ON materialinformation.id =
productionrequest.product
GROUP BY projectinformation.customer;
```

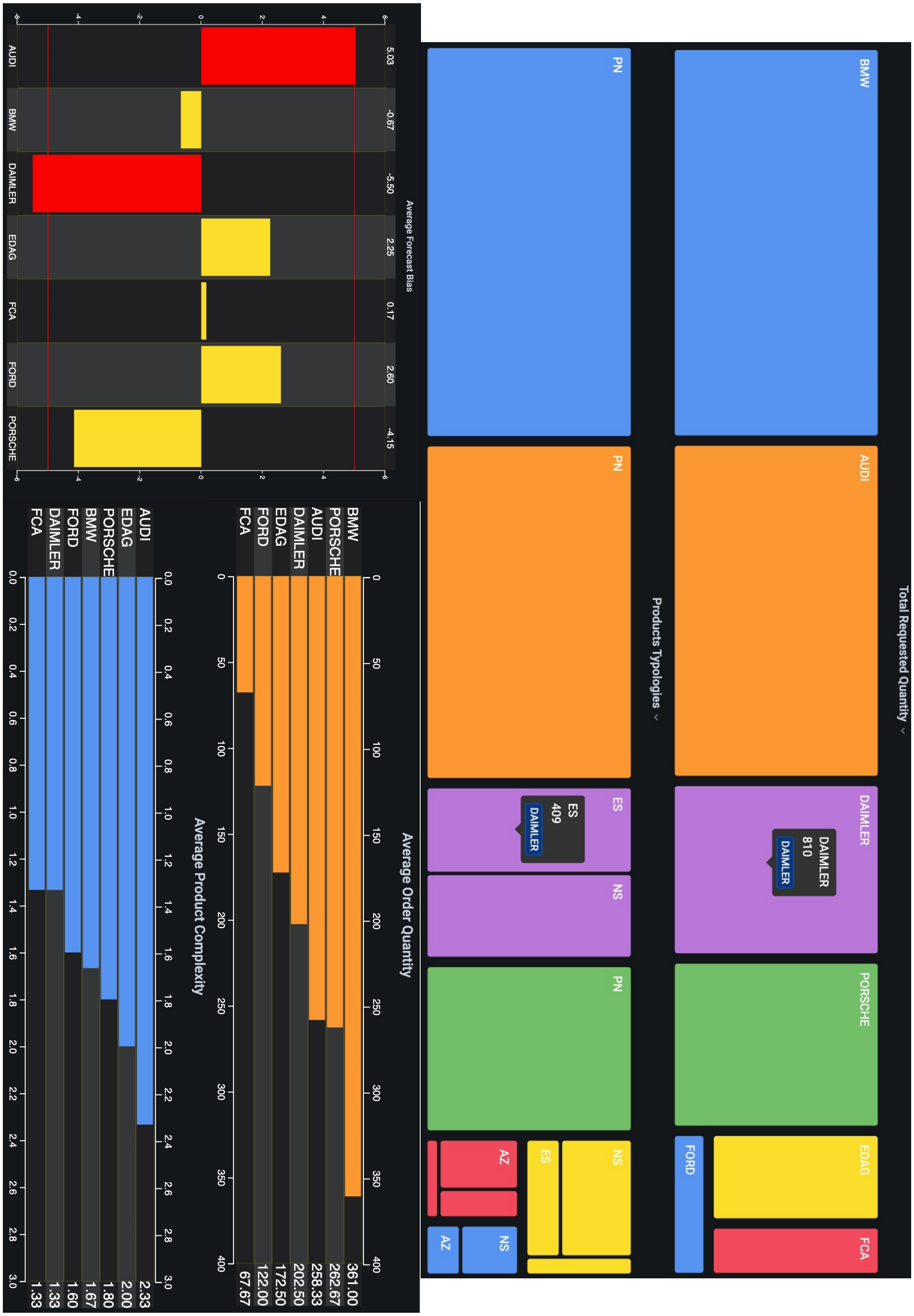

Figure 18: Customers dashboard

Machines dashboard

The objective of machines dashboard is to categorize and highlight, via six different indicators, those problems that directly affect production efficiency.

In this case, two separate dashboards have been implemented, representing two different types of machines: lasers (Figure) and presses (Figure).

For lasers, a distinction is made between 2D lasers (FTL2) and 3D lasers (FTL3) according to the geometry of the cut piece, while for presses a distinction is made on the basis of their capacity, which can be 1600 tons (FPI1), 600 tons (FPI2), 250 tons (FPI3) or 160 tons (FPI4).

The first indicator is *% Setup Time* and it highlights which machine families require longer setup times. The objective in this case is to identify, in a given time span, any anomalies to further investigate on the causes. It can be used to analyze historical data but also to monitor the trends on a daily basis and take corrective actions on the go.

The visualization chosen is a histogram. It is useful to immediately identify anomalies since it color codes those machine families exceeding the preset maximum limit.

This visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Merge of the two tables
- Calculation of the indicator by dividing Setup time and Total time

```
SELECT machineinformation.machinemodel,
SUM(productiondeclarations.time) AS "Setup time"
FROM productiondeclarations
JOIN machineinformation ON machineinformation.id =
productiondeclarations.machine
WHERE productiondeclarations.recordtype = 'setup' AND
machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;

SELECT machineinformation.machinemodel,
SUM(productiondeclarations.time) AS "Total time"
FROM productiondeclarations
JOIN machineinformation on machineinformation.id =
productiondeclarations.machine
WHERE machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;
```

The second indicator is *Average Forecast Bias* and it works in the same way as described for Customers dashboard, the only difference here is that the classification is made by machine.

This visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Merge of the three tables
- Calculation of the difference between actual time and planned time
- Calculation of the indicator by dividing the calculated difference with the number of projects

```
SELECT machineinformation.machinemodel, SUM
(productiondeclarations.time) AS "Actual time"
FROM productiondeclarations
JOIN machineinformation ON machineinformation.id =
productiondeclarations.machine
WHERE productiondeclarations.personnelid = 'LEO' AND
machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;

SELECT machineinformation.machinemodel, (SUM
(productionsegment.toolingtime) + SUM
(productionsegment.workingtime)) AS "Planned time"
FROM productionsegment
JOIN machineinformation ON machineinformation.id =
productionsegment.machine
WHERE productionsegment.productionsegmentid = 'LEO' AND
machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;

SELECT machineinformation.machinemodel, (SUM
(productiondeclarations.goodsquantity) + SUM
(productiondeclarations.scrapquantity)) AS "Total quantity"
FROM productiondeclarations
JOIN machineinformation ON machineinformation.id =
productiondeclarations.machine
WHERE productiondeclarations.personnelid = 'LEO' AND
machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;
```

The third indicator is *% Production Scraps*, it is represented via a histogram and it shows which are the machine families that produce higher scrap quantities. Excessive scrap production is a problem that must be investigated further, therefore this indicator is coupled with the fourth one, *Scraps Reason Frequency*, which shows the main reasons why scraps occurred, thus making it possible to identify and tackle directly the most frequent problems. Information is shown qualitatively via a tree map and in the tooltip is specified the exact number of occurrences.

The third visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Calculation of the sum between good products and scraps to obtain the total quantity of produced goods
- Calculation of the indicator by dividing the number of scraps over the total number of produced goods

```
SELECT machineinformation.machinemodel,
SUM(productiondeclarations.goodsquantity) AS "Good products”,
SUM(productiondeclarations.scrapquantity) "Scraps"
FROM machineinformation
JOIN productiondeclarations ON productiondeclarations.machine
= machineinformation.id
WHERE machineinformation.machinemodel LIKE 'FPI%'
GROUP BY machineinformation.machinemodel;
```

The fourth visualization is obtained by querying the database as below.

```
SELECT itemproductiondetails.annotation, SUM
(itemproductiondetails.quantity)
FROM itemproductiondetails
JOIN machineinformation ON machineinformation.id =
itemproductiondetails.machine
WHERE machineinformation.machinemodel LIKE 'FPI%' AND result
= 'scrap'
GROUP BY itemproductiondetails.annotation;
```

The fifth indicator is *Number of Blocks* and it highlights which machine families stops more frequently. Excessive blocks have a negative impact on production efficiency, and it is necessary to understand the reasons why they occur. Therefore, a sixth indicator, *Blocks Reason Frequency* is introduced to show the main reasons why blocks occur.

The select visualizations for these indicators are a horizontal bar chart and a tree map respectively.

The fifth visualization is obtained by querying the database as below.

```
SELECT machineinformation.machinemodel,
COUNT(productiondeclarations.recordtype) AS "Number of
blocks"
FROM machineinformation
JOIN productiondeclarations ON productiondeclarations.machine
= machineinformation.id
```

```sql
WHERE machineinformation.machinemodel LIKE 'FPI%' AND
recordtype = 'block'
GROUP BY machineinformation.machinemodel;
```

The sixth visualization is obtained by querying the database as below.

```sql
SELECT productiondeclarations.reasoncode,
machineinformation.machinemodel, COUNT
(productiondeclarations.reasoncode) AS "Count of block
reasons"
FROM productiondeclarations
JOIN machineinformation ON machineinformation.id =
productiondeclarations.machine
WHERE machineinformation.machinemodel LIKE 'FPI%' AND
recordtype = 'block'
GROUP BY productiondeclarations.reasoncode,
machineinformation.machinemodel;
```

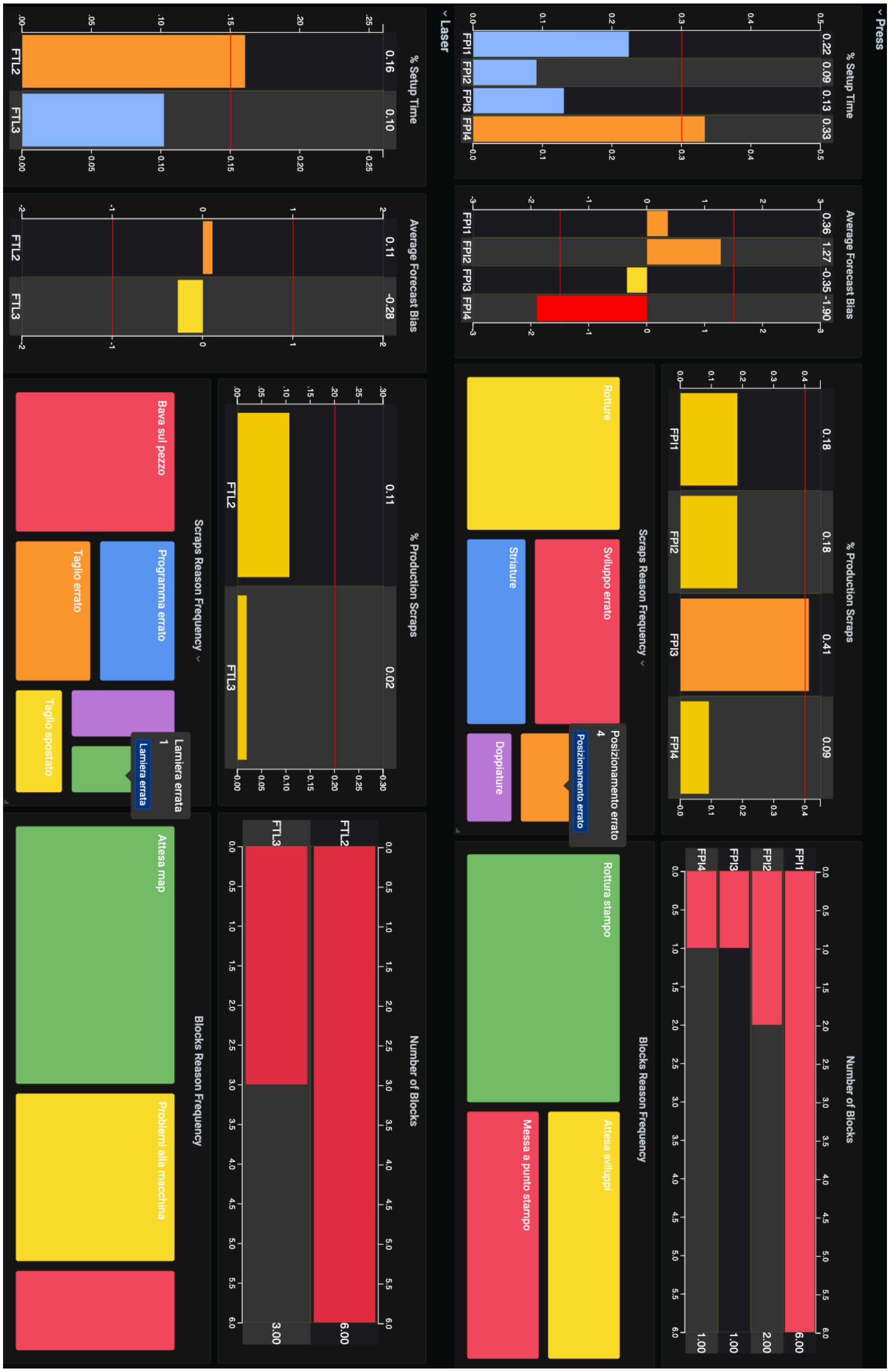

Figure 19: Machines dashboard

Products dashboard

The purpose of products dashboard is to combine indicators used in previous dashboards to show results from product families point of view, in order to identify problems related with products. The list of product families and subfamilies is contained in Appendix B.

Products in Eurodies are categorized as follow:

- PN – Panels
- ES – Structural elements
- NS – Nonstructural elements
- AZ – Other artifacts

The first indicator is *Total Requested Quantity*, represented via two distinct tree map visualizations. One showing the requested quantities per each product family, while the other one focusing on product subfamilies. Both visualizations have the tooltip feature to display the exact number of requested products. These visualizations are obtained by querying the database as below.

```
SELECT materialinformation.family,
(SUM(productiondeclarations.goodsquantity) +
SUM(productiondeclarations.scrapquantity)) AS "Total
quantity"
FROM productionrequest
JOIN productiondeclarations ON
productiondeclarations.productionrequestid =
productionrequest.id
JOIN materialinformation ON materialinformation.id =
productionrequest.product
GROUP BY materialinformation.family;

SELECT materialinformation.family,
materialinformation.subfamily,
(SUM(productiondeclarations.goodsquantity) +
SUM(productiondeclarations.scrapquantity)) AS "Total
quantity"
FROM productionrequest
JOIN productiondeclarations ON
productiondeclarations.productionrequestid =
productionrequest.id
JOIN materialinformation ON materialinformation.id =
productionrequest.product
GROUP BY materialinformation.family,
materialinformation.subfamily;
```

The second indicator is *% Production Scraps* and its purpose is to give an insight on which product families suffer more scraps production. The visualization chosen is a histogram that highlights which families overcome the upper limit.

This visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Calculation of the total produced goods by summing Good products and Scraps
- Calculation of the indicator by dividing Scraps over the total produced quantity

```
SELECT materialinformation.family,
SUM(productiondeclarations.goodsquantity) AS "Good products",
SUM (productiondeclarations.scrapquantity) AS "Scraps"
FROM materialinformation
JOIN productionrequest ON productionrequest.product =
materialinformation.id
JOIN productiondeclarations ON
productiondeclarations.productionrequestid =
productionrequest.id
GROUP BY materialinformation.family;
```

The third indicator is *% Setup Time* and it highlights which product families require longer setup times. The visualization used is a horizontal bar chart that includes a preset threshold in order to immediately highlight anomalies.

This visualization is obtained by querying the database as below, and by using the Transform function of Grafana. The transformations done are the following:

- Merge of the two tables
- Calculation of the indicator by dividing Setup time and Total time

```
SELECT materialinformation.family,
SUM(productiondeclarations.time) AS "Setup time"
FROM productiondeclarations
JOIN productionrequest ON productionrequest.id =
productiondeclarations.productionrequestid
JOIN materialinformation ON materialinformation.id =
productionrequest.product
WHERE productiondeclarations.recordtype = 'setup'
GROUP BY materialinformation.family;

SELECT materialinformation.family,
SUM(productiondeclarations.time) AS "Total time"
FROM productiondeclarations
JOIN productionrequest ON productionrequest.id =
productiondeclarations.productionrequestid
```

```sql
JOIN materialinformation ON materialinformation.id =
productionrequest.product
GROUP BY materialinformation.family;
```

The fourth indicator is *Average Forecast Bias* and it shows the average bias in production duration forecast per each product family. The visualization chosen is a histogram showing the same color coding and logic applied in the visualization in Customer dashboard.

```sql
SELECT materialinformation.family,
SUM(productiondeclarations.time) AS "Actual time",
SUM(productionrequest.duration) AS "Planned time", SUM
(productiondeclarations.goodsquantity) AS "Goods quantity"
FROM productiondeclarations
JOIN productionrequest on productionrequest.id =
productiondeclarations.productionrequestid
JOIN materialinformation on materialinformation.id =
productionrequest.product
GROUP BY materialinformation.family;
```

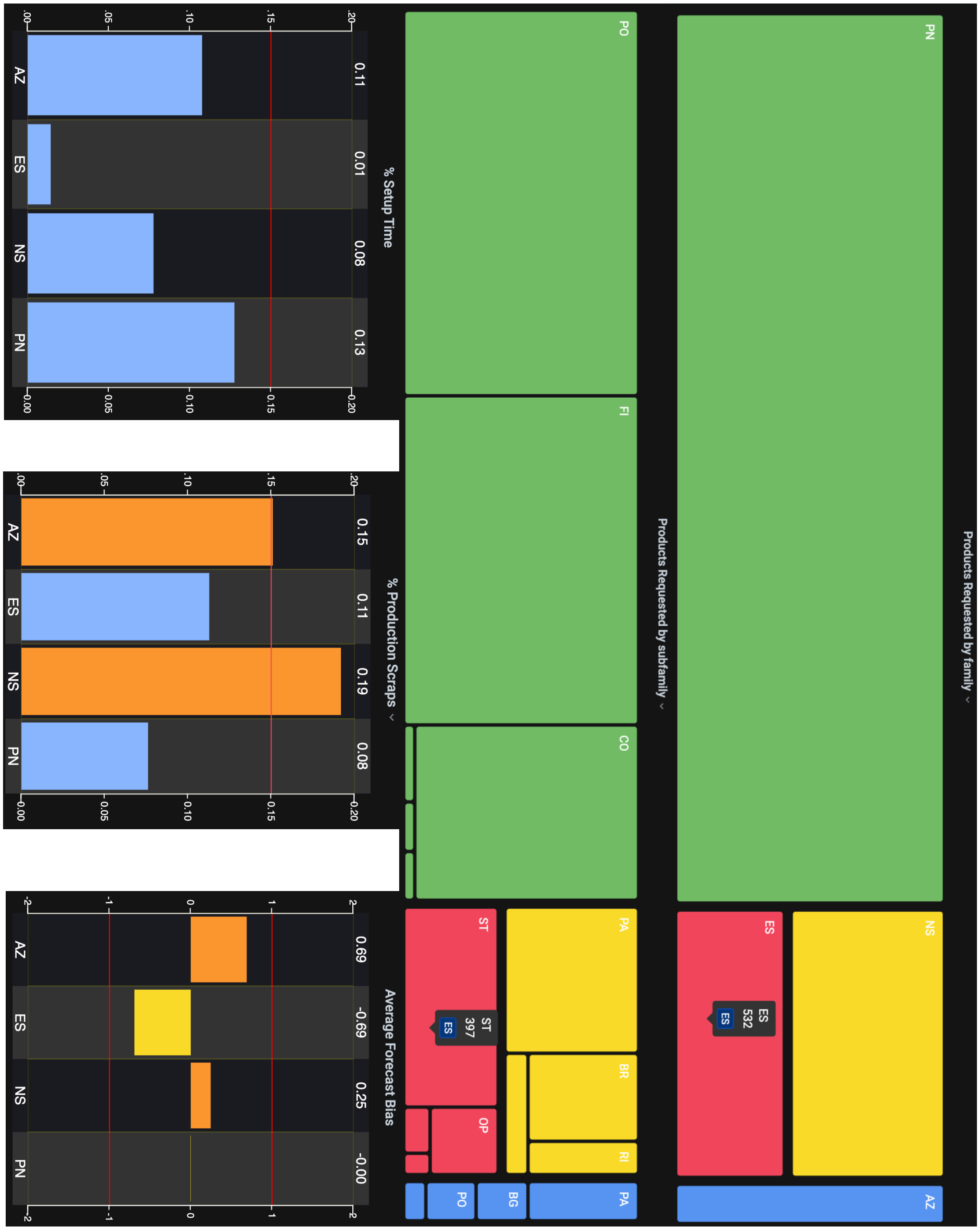

Figure 20: Products dashboard

CONCLUSION

Companies in today's landscape are confronted every day with the theme of digital transformation and the importance it has on the effective continuation of the business. Digital transformation does not simply mean investing in new technologies, but rather integrating them into the organization both physically and culturally and adapting the company's operating model to them.

One of the cornerstones of digital transformation is for companies to become data-driven, in order to leverage internal and external information to improve business management and remain competitive in the marketplace. The process itself is not trivial, firstly it is necessary to implement a set of information systems to collect different types of information in a structured way, secondly the information must be centralized and finally easily accessible.

This paper offers a detailed description of the typical digitization process of a company, focusing in particular on the accessibility and sharing of information. The results obtained show how, through the use of business intelligence, it is possible to extrapolate certain information, otherwise unreachable. The proposed solution is therefore effective, as well as easily adoptable and customizable.

The solution presented can also be developed further to create a tool that can access multiple sources of information. A future implementation, for example, may involve the integration of an ERP system, so that the information contained in it is conveyed to the KBS making it possible to create new indicators and new dashboards. By broadening the vision, this technology offers the possibility of integrating data sources external to the organization, theoretically allowing communication with clients and suppliers, making the exchange of information between parties faster and easier.

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APPENDIX A

Table 20: Eurodies Mechaning Processes

PROCESSING TYPE	PROCESS	DESCRIPTION	MACHINERY
10 SHEET PREPARATION	L1	Laser cutting	2D Laser
	C1	Shear cutting	Shear
	S1	Laser welding	3D Laser
	T1	Shearing	Mechanical Press
20 MOLDING	I1	Cupping	Press
	A1	Settling	Press
	T1	Shearing	Mechanical Pressing
	C1	Crimping	
	P1	Manual folding	
	F1	Flanging	Press
	R1	Turn-up	
30 LASER CUT	S1	Roughing	3D Laser
	F1	Finish	3D Laser
	R1	Recovery	3D Laser
40 MANUAL FINISHING	P1	Manual flattening	
	P2	Mallet flattening	
	B1	Undercut beating	
	B2	Flat beating	
	B3	Generic beating	
	V1	Item revision	
	V2	Calibration	
	V3	Preparation for flanging	
	V4	Turn-up	

PROCESSING TYPE	PROCESS	DESCRIPTION	MACHINERY
40 MANUAL FINISHING	V5	Folding fins for pliers	
	V6	Cold tip capping	
	V7	Hot tip capping	
	V8	Normal caulking	
	V9	Drop-shaped caulking	
	Y1	Break welding	
	Y2	Whole welding	
	Y3	Revision	
	Y4	Trimming of drains	
50 TEST METROLOGY	C1	Test approval	
	C2	First part correction	
	C3	Control via CMM	
	C4	Direct control on the mold	
	C5	Laser scanning	
60 ASSEMBLY	S1	Manual arc welding	
	S2	Manual spot welding	
	S3	Spot welding with robots	
	S9	Welding (masterpiece)	
	N1	Welding of standardized nuts	
	N2	Welding of standardized screws	
	N3	Press-in screw planting	
	C1	Press clinching	
	C2	Riveting	
99 SHIPMENT	S1	Shipment with customer container	
	S2	Shipment with third party container	
	S3	Shipment with Eurodies metal container (returnable)	
	S4	Shipment with Eurodies wooden container (returnable)	
	S5	Shipment with Eurodies carton container (returnable)	
	S6	Shipment with Eurodies metal container (disposable)	
	S7	Shipment with Eurodies wooden container (disposable)	
	S8	Shipment with Eurodies carton container (disposable)	

Table 21: Processes Check Start List

PROCESS	ID_A	DESCRIPTION	ID_CSA
Shear cutting	A10C1	Meter	CSA001
2D Laser cutting	A10L1	Trajectory design	CSA002
3D Laser welding	A10S1	Special head	CSA003
		Pliers for fixing the piece to the stand	
		Programming in self learning path of soldering	
Sheating	A10T1 A20S1	Mold	CSA004
		Mold mounting brackets	
		Supports for handling sheet metal	
Slimming and training	A20I1, A20A1, A20F1	Mold	CSA005
		Mold mounting brackets	
		Supports for handling sheet metal	
		Nylon sheets	
		Oil	
Roughing, finishing and 3D laser shooting	A30S1, A30F1, A30R1	Routes loaded with USB device	CSA006
		U-bolts for positioning the sheet	
		Pliers for fixing the piece to the U-bolt	
		Reference holes	
Manual molding	A40P1, A40P2, A40B1	Molds from the press department	CSA007
		Gauges	
		Various hammers	

APPENDIX B

Table 22: Product families

FAMILY	DESCRIPTION
PN	Panels
ES	Structural elements
NS	Non structural elements
AZ	Other artifacts

Table 23: Product subfamilies

SUBFAMILY	DESCRIPTION
PANELS	
TE	Tetto
FI	Fiancata
CO	Cofano anteriore
BA	Baule
PA	Parafango
PO	Porta
STRUCTURAL ELEMENTS	
OP	Ossatura porta
LO	Longherone
LR	Listello di rinforzo
ST	Staffa di rinforzo
MO	Rinforzo montante
PO	Piastra d'appoggio
CE	Cerniera
NON STRUCTURAL ELEMENTS	
MO	Modanatura
LE	Lesena
TP	Tunnel pavimento
RI	Rivestimento interno
GS	Guida scorrimento
SC	Staffa di collegamento
PA	Passaruota
BR	Brancardo
CO	Copertura
OTHER ARTIFACTS	
CM	Coprimotore
PG	Piegati
VA	Imbutiti vari
BA	Buale
PA	Parafanghi
PO	Porta