Universidade de Aveiro Departamento de Economia, Gestão, Engenharia Industrial e Turismo
2020

ANA RITA DA SILVA MENDES

***QUALITY DATA MART*: DESENVOLVIMENTO DE *DASHBOARDS* RELATIVOS À QUALIDADE DE PRODUTOS E PROCESSOS**

QUALITY DATA MART: DEVELOPMENT OF DASHBOARDS WITH MEANINGFUL DATA ABOUT THE QUALITY OF PRODUCTS AND PROCESSES

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Relatório de projeto apresentado à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Gestão Industrial, realizado sob a orientação científica da Doutora Helena Maria Pereira Pinto Dourado e Alvelos, Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro.

“I’m inviting you to step forward, to be seen, and to ask yourself:
If not me, who?
If not now, when?”

- Emma Watson’s speech at the United Nations

Dedico este trabalho a todos que, no seu dia a dia, têm a coragem de enfrentar os seus desafios e que acreditam que podem fazer do mundo um lugar melhor.

o júri

Presidente

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Professora auxiliar da Universidade de Aveiro

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Agradecimentos

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A vocês, obrigada pelo voto de confiança, por acreditarem no meu potencial e por estarem lá para mim.

palavras-chave

quality data mart, dashboard, visualização de dados, controlo de processo, DMAIC, CRISP-DM

Resumo

Com o desenvolvimento de novas tecnologias, surge uma maior capacidade de armazenar e analisar dados. As empresas podem obter vantagem competitiva ao utilizar os dados disponíveis para obter informação sobre sua produção.

O projeto decorreu no departamento de qualidade de uma fábrica de produtos de eletrónicos e combina as áreas de controlo de características do produto, controlo de processo e análise e exploração de dados.

O desafio abordado prendeu-se com o facto de a informação relativa à qualidade da produção não se encontrar disponível de modo fácil e rápido, dificultando a sua utilização pelas diferentes partes interessadas.

O objetivo do projeto foi o de desenvolver dois *quality data marts* e propor um procedimento padrão para a criação deste tipo de instrumento. Para desenvolver o *quality data mart* foi utilizada uma metodologia baseada no CRISP-DM. Simultaneamente, para estudar o desafio apresentado foram aplicadas as fases do ciclo DMAIC. O estudo começou por definir o âmbito do projeto, seguido de uma caracterização da situação inicial. Em seguida, foram analisadas as áreas de qualidade, dados e execução de *dashboard*s. Para cada dimensão, foram desenhadas e implementadas soluções. Por fim, foi feita uma revisão do projeto.

Como resultado, foram estabelecidas as bases para o desenvolvimento de *quality data marts*, com o processo definido e materiais de apoio criados, tendo sido também implementado um projeto piloto. A criação de *dashboards* com informação disponibilizada quase em tempo real, permite aos seus utilizadores beneficiarem dessa informação no seu processo de tomada de decisão, contribuindo para melhores e mais rápidas decisões.

Para além do contributo referido, verifica-se que o presente projeto contribuiu para o desenvolvimento, na empresa, de uma mentalidade mais orientada para a tomada de decisão baseada em factos.

keywords

quality data mart, dashboard, data visualization, process control, DMAIC, CRISP-DM

abstract

With the emerge of powerful technologies, it is easier nowadays to store and analyse data. Companies can gain a competitive advantage by using the data available to gain valuable information about their production.

The project took place in the quality department of an electronic manufacturing plant. It brings together the areas of monitoring products' characteristics, process control and data analysis and mining.

The challenge encountered was that the needed data is not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production.

The goal of the project was to develop two quality data marts and to propose a standard procedure for their creation. Therefore, to develop the quality data mart a methodology based on CRISP-DM was used. Simultaneously, to study the challenge presented, the DMAIC phases were applied. The study started by defining the project scope, followed by a characterization of the initial situation. Then the areas of quality, data and dashboard execution were analysed. For each dimension, solutions were designed and implemented. Lastly, a review of the project was done.

As a result, the foundations for the development of quality data marts are set, with a defined process, support materials and a pilot project. The creation of dashboards with near-real-time data enables the stakeholders to use it in their decision-making process. Therefore, the results of this project allow stakeholders to make better and quicker decisions and contribute to the development of a data-driven mindset in the company.

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GLOSSARY AND ABBREVIATIONS

1. INTRODUCTION

Quality does not happen by accident.

This is one of the main messages from the quality guru Joseph Juran. In his work, he presented a quality trilogy: quality planning, quality improvement and quality control (Marchewka, 2016, p. 239). With the development of new technologies at the production site, a new improved portfolio of tools can be developed to ensure manufacturing quality.

This report presents the project developed at Bosch Ovar plant. The work mainly focuses on the quality control aspect, but it is influenced by the other two quality pillars. The scope of the study is the management of products' and process' characteristics to ensure the products' quality. By leveraging the development at the information technology (IT) field, the focus is on the creation and implementation of quality data marts, an information system that collects, analyses and displays information about the quality of the production in near-real-time.

In this chapter, the motivation for the project is presented and the research challenge is described, followed by the presentation of the internship goals and methodology. The last section contains the outline of the document.

1.1. MOTIVATION AND BACKGROUND

With the developments in the field of IT, detailed data regarding products, processes, collaborators, clients, suppliers, and other company's assets are easy to get and to store. With the massive amount of data available today and the simplicity to access the data, such important projects of knowledge discovery and data mining can easily be supported (Maimon & Rokach, 2010). More and more, companies look for ways to take advantage of this reality and to have data-driven decisions and actions.

Data mining frequently appears described as "the process of discovering correlations, patterns, trends or relationships by searching through a large amount of data stored in repositories, corporate databases, and data warehouses" (Soroush Rohanizadeh & Moghadam, 2009). This can and should be applied in diverse industrial fields, like quality control, process optimization, human factors, job shop scheduling, material handling, maintenance and reliability of production systems (Soroush Rohanizadeh & Moghadam, 2009).

The application of data mining techniques in quality control activities brings benefits to the industry by providing the stakeholders with meaningful data about the characteristics of products and processes. "To achieve product quality improvement, we need to predict product quality from operating conditions, to derive better operating conditions that can improve the product quality, and to detect faults or malfunctions for preventing undesirable operation" (Kano & Nakagawa, 2008, p. 13).

The raw data available at the servers is not sufficient for the stakeholders to have an overview of the quality of the products and processes. In order to support them, business analytics play an important role to extract the information from the available data. Moreover, data needs to be cleaned, analysed and distributed in such a way that it provides useful information.

With near real-time data, stakeholders can monitor closely the product and process, which allows them to identify the deviations and problems faster. Consequently, it may lead to actions to be taken early, to the detection of some trends in the data and to anticipate behaviours.

This study is interesting by combining the areas of managing the product's quality as well as data and IT developments. The project contributes to the improvement of the work of the quality professionals by applying new technologies supporting the Quality 4.0 vision, of applying Industry 4.0 concepts into the quality field.

1.2. PROJECT CHALLENGE

This project is about bringing together the areas of product characteristics monitorization and data analysis and mining. Its scope involves the creation and implementation of quality data marts for various products and processes.

The study focusses on the following questions:

- What is meaningful data regarding the products' and processes' quality for the different stakeholders?
- How can the information to monitor each product and process be analysed and represented?
- How can the data from the production be accessed and how can information be distributed to the relevant stakeholders?

At the moment, at Bosch Ovar, the needed data for quality control is handled mainly by test engineers, responsible for the test equipment and the test's data, and IT engineers, responsible for the data storage and the data warehouses. When a stakeholder such as a customer, quality engineer, production engineer or the management, wants to have more information and wants to see the data, a report is asked to the IT department. This leads to several pain points as data reports are only performed by request and as a reaction to a need or situation, instead of being used in a proactive and preventive way. Also, the IT engineers' insights about the product and respectively process context may not be enough to deliver relevant data reports with meaning to the user.

This leads to the problem that the needed data is not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production.

1.3. OBJECTIVES AND METHODOLOGY

The project aims to study the problem described above and to study the implementation of dashboards that display the data regarding the quality characteristics of the products and its processes.

Therefore, the main goals of the study are:

- To analyse and define the requirements and information needed by the different stakeholders of the company to make better decisions in a smaller timespan.
- To study two different cases where the adequate methodology to extract information from the analysed data will be applied and displayed to the different stakeholders by the creation of dashboards.
- To propose a standard procedure for the creation of a quality dashboard, when industrializing a new product.

To tackle the problem and pursue the goals, the methodology can be separated into three parts. The first corresponds to the literature review, the training and the building of the report, which occurs throughout the full project. The practical project consists of the other two parts, which were developed during the internship. The focus of the second part is to study and improve the problem that the needed data is not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production. For that, a methodology based on the DMAIC phase was designed. The third and last part of the methodology focuses on the execution of two quality data marts, by applying the CRISP-DM method. In chapter 3, the designed methodologies are presented.

1.4. DOCUMENT OUTLINE

The project report is divided into the following seven main chapters:

Chapter 1: an introduction to the project is done, where the challenge to be solved is presented as well as the goals and the methodology.

Chapter 2: a theoretical background related to the main areas addressed is presented.

Chapter 3: a description of the two designed methodologies and their detailed activities are presented.

Chapter 4: the scope of the project is presented with information regarding the company and relevant procedures and concepts. The initial state of the project is explored during this chapter.

Chapter 5: several analyses done to different dimensions of the problem are presented as well as the outcomes of the work developed to solve the challenges are presented. The final state of the project is described at the end of this chapter.

Chapter 6: the two case studies are presented. It contains a detailed presentation of the products and their characteristics and the main outcome and results of the cases analysed.

Chapter 7: a summary of the project is presented with the main conclusions and reflection of the work developed. Proposals for future work activities are also referred.

2. THEORETICAL FRAMEWORK

This project focus on developing a quality data mart, that aims to distribute the information and data analyses about the quality of a product and its process. To develop it, the fields of information systems and quality and process control are applied.

The first two subchapters describe the frameworks and tools applied during the project. In the last subchapter, these two fields are analysed together, where the concept of Quality 4.0 is explored.

2.1. INFORMATION SYSTEMS

To make decisions, visualize complex data and analyse problems, companies use information systems to effectively execute these tasks. These systems are "a set of interrelated components that collect (or retrieve), process, store, and distribute information to support decision making and control in an organization" (Laudon & Laudon, 2012, p. 52).

In this subchapter frameworks related to the development of information systems are explored.

The first step to develop an information system is to identify the systems requirements (see subsection 2.1.2), then the data needed is identified and its quality evaluated (see subsection 2.1.3). To connect the different sources, data modelling techniques are used (presented in subsection 2.1.4). From the data, different analyses can be performed, in subsection 2.1.5 the topic of business analytics is explored. A key aspect of the data analysis is the visualization of data. In subsection 2.1.6, data visualization principles are presented. Lastly, a methodology to develop data mining projects is presented (see subsection 2.1.7).

But, before presenting the different frameworks the concept of a data mart is presented.

2.1.1. DATA MART

A data warehouse is described as "a subject-oriented, integrated, time-variant, non-volatile collection of data in support of management's decision-making process" (Inmon, 2002, p. 54). It contains data from a large number of diverse sources at the company or even external sources. With the purpose of supporting decision-making processes, the data warehouses differ from the organization operation systems that aim to support the daily business processes. This difference has a big impact on which data is stored and how it is stored. The concept of a data mart is generally described as a subset of a data warehouse. While the data warehouse stores data from diverse subjects of the entire organization the data mart keeps data about a single topic, for example, sales or quality (Jensen, Pedersen, & Thomsen, 2010, p. 32).

2.1.2. SYSTEM REQUIREMENTS

Use cases are the description of the actors' goals when using the system. Therefore, the use cases consist of the requirements that the system should fulfil in order to address all the users' goals (Cockburn, 1999; Larman, 1995).

Writing use cases is a compulsory technique when describing and understanding system requirements (Larman, 1995). Ivar Jacobson introduced, in 1986, the idea of describing functional requirements with use cases (Cockburn, 1999, p. 4). Alistair Cockburn presents in his work *Writing Effective Use Cases* (Cockburn, 1999) how to apply this technique.

When talking about use cases, the key actors and their goals have to be addressed. Frequently the system has several key actors, that have few high-level strategic goals, e.g. advertise, order, invoice (see Figure 1). For each strategic goal, a use case is made and a set of other goals of the user is described. The use cases of these goals are the ones that describe what an individual user wants to achieve from the system, e.g. monitor a promotion campaign or place an order. For each one of these goals, the use cases are divided into the subfunctions of the use cases, e.g. identify a product, register a user, that can have subfunctions themselves. These subfunctions are the tasks carried out by the user to accomplish his/her goal.

From an executive perspective, the strategical high-level use cases are the most important ones because they represent an overview of the system. In comparison, the responsible person for the implementation of the system will focus on the user goals and the subfunctions of the use cases. With this diversity of the goals, Cockburn (1999) defines three types of goals, represented in Figure 1:

- Strategic Level - "white" - Sky

When developing a system, the strategic goals have the aim of giving context to the services the system must provide, representing a sequencing of related goals and creating a framework of contents for the lower level case.

- User-goal Level - "blue" – Sea

Also described as the "elementary business process", the user-goal use case describes the individual's goals when operating the system. A list of blue level goals will justify the existence of the system by showing how the system supports the primary actors. It is also named as the sea level goals because these goals are the middle level that links the strategical and subfunctions goals.

- Subfunction Level - "indigo" - Water

The subfunction of the goals defines the tasks performed by the users of the system, and by the system itself. It is at this level that the system requirements are described.

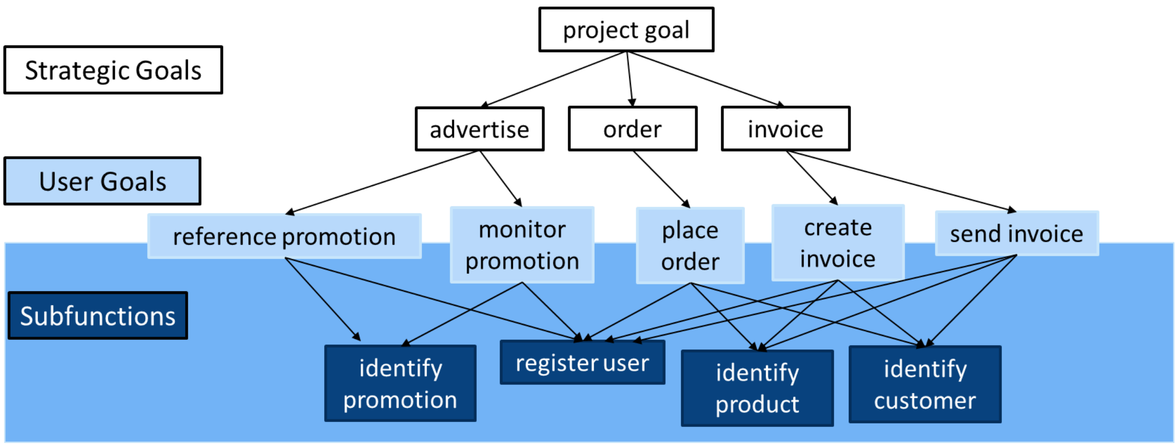


Figure 1 - Sailboat image of use case graph (adapted from Cockburn, 1999)

2.1.3. DATA QUALITY

The importance of data is increasing over time, from a by-product of IT systems, to "an organization's most valuable asset and resource" (Mahanti, 2019). The value of data is not only on itself but also on the way it is used and the insights and actions that the data provides. Data can be used several times, for example, "the product data [can be] used for sales, inventory forecasting, marketing, financial forecasts, and supply chain management" (Mahanti, 2019). As a source of several and diverse activities, it is important to guarantee the quality of the data.

Askham et al. (2013) defined six core data quality dimensions that can support assessing the quality of the data:

- Completeness: all the facts have a recorded value, "the absence of blank";
- Uniqueness: each data point is recorded only once;
- Timeliness: the time between the occurrence and recording of a certain event;
- Validity: the conformity of the data to a defined syntax;
- Accuracy: the data recorded represents the event correctly;
- Consistency: the data recorded in two different locations have the same value.

Having data to perform diverse actions and support decision-making processes can bring a lot of advantage to a company. At the same time, having bad quality data can have the opposite impact on the organization. The cost of bad quality data can be enormous when several decisions are made based on the information it provides (Mahanti, 2019).

2.1.4. MULTIDIMENSIONAL DATA MODELLING

Multidimensional data modelling is a method to structure data with the purpose of analysing it. It has three main applications: data warehousing, online analytical processing (OLAP) and data mining (Jensen et al., 2010, p. 1).

This model consists of three basic elements, facts, measures and dimensions.

The facts represent the subject of the analysis, such as events or processes that occurred. They can be distinguished into two types. The event facts, that represent the activities that can happen over time, such as selling an item and snapshot facts, that represent a specific state on a determined time, such as the stock level at the end of the day. The measures represent the numerical properties of the facts that the user wants to study. Dimensions are used to characterize the events represented by the facts. It allows the user to select and group the data on a certain level. The dimensions can be grouped in different levels, defining hierarchies.

The sales process is a common example of a multidimensional model. It consists of a fact table with the count of items sold as a measure. In order to analyse the items sold, more information about sales is needed. The dimensions time and product give additional information to characterize the sales that occurred with a specific product at a given time. With the dimension time and the hierarchy of hour-day-month, sales can be analysed per hour or can be aggregated by day or by month.

All these elements can be represented using different models. The most commonly used models are relational representations by using star, snowflake or constellation schemas (see Figure 2).

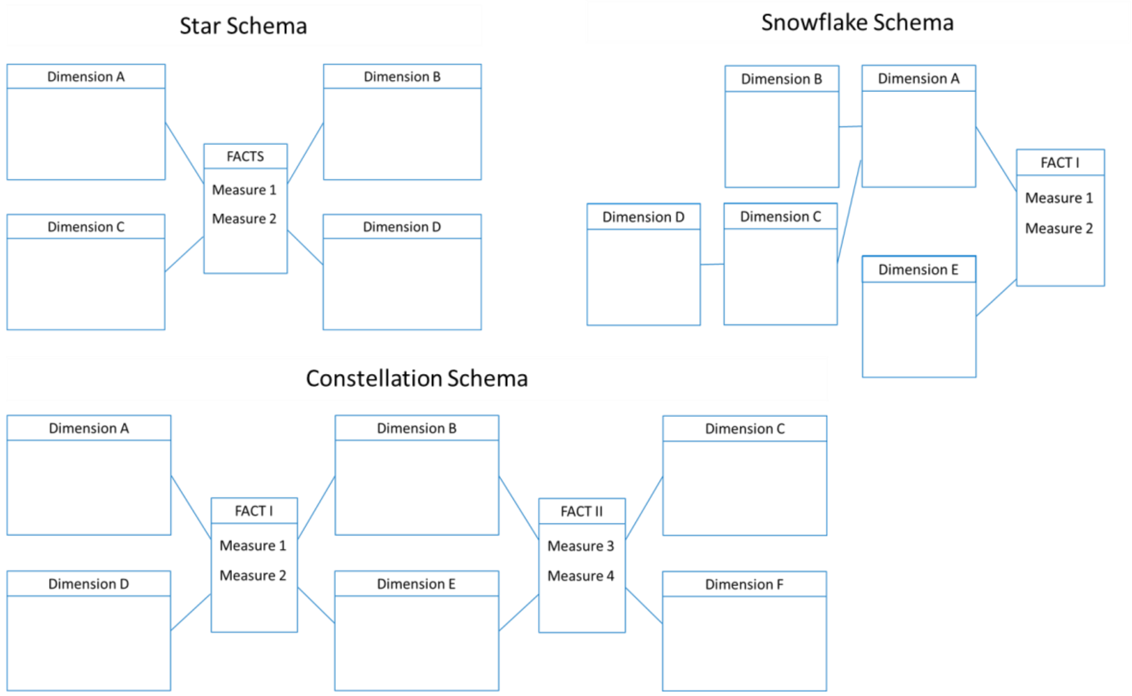


Figure 2 - Relation Schemas: (A) Star Schema; (B) Snowflake Schema; (C) Constellation Schema (adapted from Tutorialspoint, n.d.)

The star schema is the simplest model with only one fact table and one table per dimension. The snowflake schema uses several tables to represent a dimension, where each hierarchy level is represented separately.

The constellation schema is used when there is more than one fact table to be represented that share common dimensions. To develop the quality data marts, this schema will be used because for one product (dimension) there are several events (facts) to be analysed.

2.1.5. BUSINESS ANALYTICS

Business analytics is defined as “a scientific process of transforming data into insights for making better decisions” (Camm, Cochran, Fry, & Ohlmann, 2020, p. 4). It “is the application of the tools, techniques, and principles of analytics to complex business problems” (Dursun, 2014, p. 1). This encompasses different types of processes and activities to get insights from the data.

The analytics can be categorized considering their nature: descriptive, diagnostic, predictive, prescriptive and automated (Figure 3).

Most of the descriptive analytics activities are associated with building a report that describes, resumes and analyses the historical data. These reports consist of static snapshots of the business, representation of the key performance indicators and ad-hoc reporting (Delen & Ram, 2018, p 8).

Diagnostics analytics aim to identify the causes of the tendencies and results encounter on the data. It uses exploratory data analysis tools such as “ visualization, drill-down, data discovery and data mining” (Delen & Ram, 2018, p. 9).

When organizations have mature descriptive and diagnostics analytics, they look beyond the past into the future state. Predictive analytics focuses on forecasting future results based on previous events. The predictions can be classifications if estimating a categorical value, or regressions if estimating a numerical value. Furthermore, if the value is time-dependent, it is named time-series forecasting. (Delen & Ram, 2018, p. 9)

By applying heuristics, simulation and optimisation techniques, prescriptive analytics aim to recommend to the user the ‘correct’ and optimal actions and decisions to be taken considering the information available. These analytics enable the evaluation of ‘what-if’ scenarios, as a specific decision can be simulated, and the suggestion of services or products in real-time based on the client’s profile. (Delen & Ram, 2018, p. 9)

The last level is automated analytics. This type of analytics is applied when the model monitors, decides and acts in an autonomous or semi-autonomous way, dynamically adjusting the strategies based on the environment’s changes and improved forecast. Examples of these analytics are adjusting online prices automatically or deciding which email to send to a customer automatically. (Davenport, 2015). Is important to distinguish this concept from the automated creation of analytics by applying tools like machine learning (Davenport, 2015).

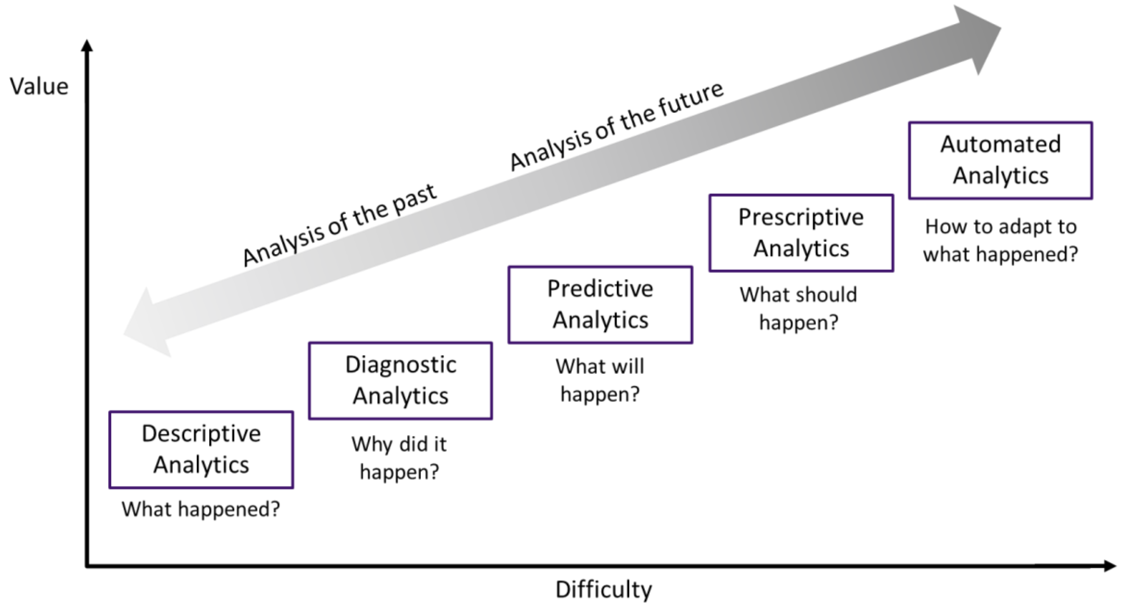


Figure 3 - Business Analytics' categories (adapted from Delen & Ram, 2018)

In the context of this study, the analytics performed focused on the first and second levels. The dashboard and its visualizations should provide the user with some descriptive information regarding the product’s quality and provide clues to the possible causes for deviations. As Davenport (2015) refers, “it is often a natural progression through the different types of analytics”. The aim with the quality data marts is to create the base, from the technical and information system perspective, to develop in a later stage more valuable and complex analytics.

2.1.6. DATA VISUALIZATION

Laszlo Bock (2015) states that “having all the information in the world at our fingertips doesn’t make it easier to communicate: it makes it harder” (Knaflic, 2015). Data visualization allows the data to be communicated more effectively (Kirk, 2012). The visualization is an interface between the data and its users, supporting them in identifying process improvements or potential causes of problems, by allowing them to detect patterns, deviations and outliers in the data (Celonis, 2020).

The aim of this section is to explore data visualization principles that are applied when building a dashboard. They will be summarized into four sections, based on the lessons presented by Cole Knaflic (2015):

- **Know the context**

Before starting to think or design the visualizations, it is crucial to understand the context of the report or the dashboard. Cole Knaflic (2015, p. 20) explains the relevance of identifying the who, the what and the how of the dashboard to gain a deeper view of its use.

The role of the data analyst is to identify the user of the dashboard, to define the goal of the analyses, to understand what are the questions the stakeholders have when using the dashboard and which visualization can help answer their questions (Celonis, 2020).

- **Choose the right chart**

The data can be represented in different formats communicating different information to the reader. These visualizations can vary from a simple text to complex geographical representations.

Table 1 shows the most common visualizations as well as their main goal and usage.

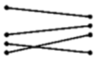
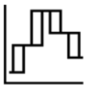
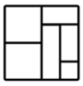
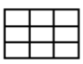
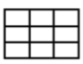
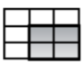
- **Think like a designer**

The elaboration of dashboards is like the creation of presentations. It “requires not only to select the appropriate content but also to choose the right way to display the selected content” (Ng et al., 2013, p. 96). In addition, each page, as each slide should communicate one message, to facilitate the user analysis and navigation to all the graphs and numbers.

Integrating a lot of visualizations can create an overload of information for the user to assimilate. It is important to build the dashboard’s pages as simple as possible. And to keep in mind the consistency of the pages, by displaying the information on natural order, from top to bottom and from left to right. It is also important to keep certain elements always in an expected position.

The colours have an important role to transmit a specific idea and should be used as an advantage to communicate a certain concept. The common example is to use the traffic light colour code: green for good, yellow for warning, red for not good (Celonis, 2020).

Table 1 - Representation of data visualization and their main goals (adapted from (Celonis, 2020; Knaflic, 2015)

Description	Visualization	Main goal/usage
Simple text		Highlight a specific number, the users do not need to look in a graph to get it
Charts:		
Gauge chart or speedometer charts		Compare a certain value to a range or target
Bar chart - horizontal		Comparison of categories and ranking
Column chart - vertical		Comparison of categories
Histogram		Represent the distribution of a quantitative variable
Stacked chart – horizontal or vertical		Comparison and part-to-whole
Line chart		Represent change over time
Slope graph		Compare two time periods
Waterfall		Represent the starting point, the increases and decreases and the result point
Square area or tree map		Represent numbers with different scales
Pie chart		Represent proportional parts of a whole
Scatter plot		Correlation of two quantitative variables
Bubble plot		Correlation of three quantitative variables
Geographical representation and maps		Spatial Representation
Tables:		
Table		Present several values related with one attribute
Pivot table		Summarize data, overview of main attributes
Heatmap table		Add information by colouring the cells of the table

- **Design dashboards, not reports**

Stephen Few (2007) defines dashboard as "a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance". In contrast, a report can be defined "as a document that contains data used for reading or viewing"(Alexander, 2016, p. 10).

By designing dashboards and not reports, it is intended to create a set of visualizations that support the user decision-making process by monitoring what is happening (Few, 2007). The dashboards should be dynamic, allowing the user to explore the data that is presented and does not need to impose a specific set of actions to them.

It is also important to define the "right level of aggregation/abstraction for the information displayed" (Ng et al., 2013, p. 97). The drill-down option, which displays more detailed data, is a common feature of dashboards. Nevertheless, the charts should display and highlight the information that triggers the user to explore at the first view. If this information is hidden on a deeper level, the user main not notice some aspect of the data (Ng et al., 2013, p 97).

Therefore, during the design of the dashboards, it is necessary that the dashboard developer has a close interaction with the user (Ng et al., 2013, p.97).

Besides these four main principles, an important aspect, when building reports and dashboards, is the manipulation of the data. Creating misleading graphics even to emphasize a message is not right (Knaflic, 2015).

2.1.7. DATA MINING METHODOLOGY: CRISP-DM

CRoss-Industry Standard Process for Data Mining, CRISP-DM, is a data mining process developed in 1996 by a consortium of industries with the aim of building an "industry-, tool- and application neutral" methodology (Chapman (NCR) et al., 2000, p. 1). The model represents the project life cycle composed of six phases. The sequence of the steps is not rigid, and it is common to go back to a previous phase when more insights and understanding are gained about the subject. Figure 4 shows the six steps and the most common dependencies between them, represented by the arrows.

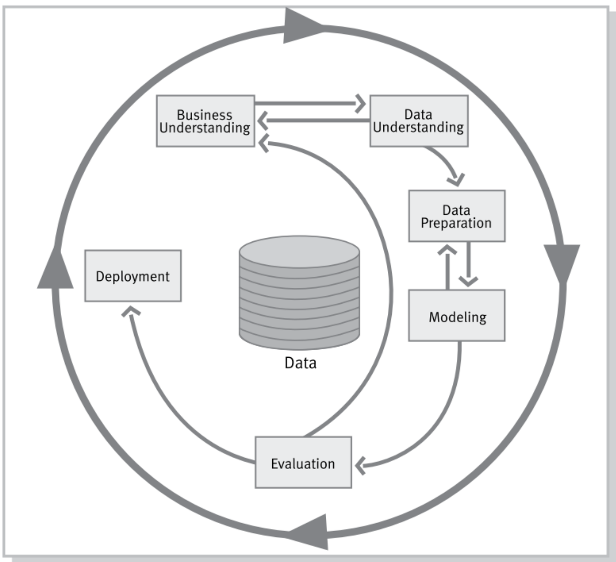


Figure 4 - CRISP-DM Reference Model (Chapman (NCR) et al., 2000, p. 10)

The first step is about getting to know the project. It is at this stage that the business requirements and the data mining goals are defined. The situation at hand is assessed and the project planned. With more knowledge about the business, the next phase deals with understanding the data to become more familiar with it. At this phase, the data is collected, described, explored and its quality is verified. As more knowledge about the context is obtained in this step, it may be necessary to go back to the previous one and upgrade the business understanding.

During the data preparation step, the tasks related to extracting-transforming-loading (ETL) are performed to build the final dataset. The "tasks include table, record, and attribute selection, as well as transformation and cleaning of data for modelling tools" (Chapman (NCR) et al., 2000, p. 11). At the next step, different modelling techniques are applied and tested in order to solve the data mining problem. Some of these models may require adjusting the data set and a need to go back to the previous step.

When the model built reaches a satisfactory quality, the evaluation step begins. At this stage, it is important to assess the performance of the model from a data point of view, but also from a business perspective. The goals and objectives defined in the first step should be reviewed. In some cases, this leads to findings that change the data mining project direction and requires a restart of the data mining project.

At the deployment stage, the defined model needs to be deployed in a way that integrates the decision-making processes of the company, for example creating a dashboard on a web page, together with a monitoring and maintenance plan of the model created. It is during this step that a review of the project is performed and a final report written.

2.2. QUALITY AND PROCESS CONTROL

Montgomery (2019, p. 6) refers that "quality is inversely proportional to variability" and believes that quality of a product increase if the variability of the product characteristics decreases and therefore that "quality improvement is the reduction of variability in processes and products" (Montgomery, 2019, p. 7). To ensure the quality of the products, the production must be stable and repeatable, in which the process operates with little variability at the dimensions of the quality characteristics (Montgomery, 2019).

Before looking for ways to reduce variability, it is important to distinguish between its two main types: (i) variability due to natural causes that are related to uncontrollable aspects that affect the processes, even the well designed and maintained and (ii) variability due to special causes that can be associated with machine settings, operator mistakes and material condition, among others. A process under statistical control is a process only influenced by natural causes, while an out of control process is also influenced by special causes of variation (Montgomery, 2019, p. 181).

In this subchapter, the first section focuses on quality tools used to reduce variability in the process. Then, it is presented two frameworks: the business process management life cycle and the DMAIC method.

2.2.1. STATISTICAL PROCESS CONTROL

Statistical process control (SPC) has the aim to reduce the variability of the process to improve the stability and capability of the process. For that several tools can be used to identifying the special causes of variance and study its causes, also known as “the magnificent seven” (Montgomery, 2019, p. 199):

- Histogram or steam-and-leaf plot
- Check sheet
- Pareto chart
- Cause-and-effect diagram
- Defect concentration diagram
- Scatter diagram
- Control chart.

The focus of this section is to present the use of control charts to monitor the process.

2.2.1.1. CONTROL CHARTS

The Shewhart control chart, developed in the 1920s, is an on-line tool that graphically represents a statistic related to a quality characteristic and compares it to defined control limits (Figure 5). The values presented with blue colour, represent the statistic (average, for example) calculated based on a sample retrieved from the production. The control limits are defined based on the natural variability expected for the characteristic and calculated by using statistical concepts. If a point is outside the control limits, it is an indication that the process is out of control and that a special cause occurred on the process. This cause needs afterwards to be studied and eliminated (Montgomery, 2019).

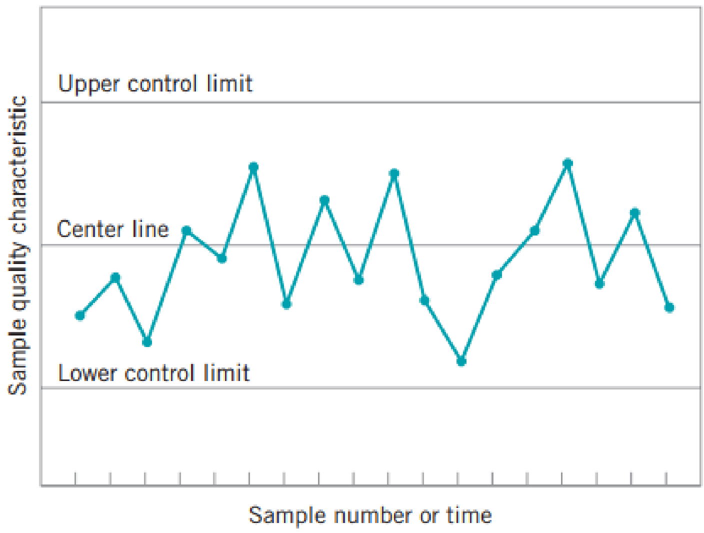


Figure 5 - Control chart (Montgomery, 2019, p.182)

There are several types of control charts. In this work, the individual values - moving range (I-MR) control chart are going to be applied. These two charts are used together, being the first for controlling the central tendency of the process, based on the individual values, and the second one for controlling the variability of the process using the moving range, that corresponds to the difference between the values of the point and the previous one (Figure 6).

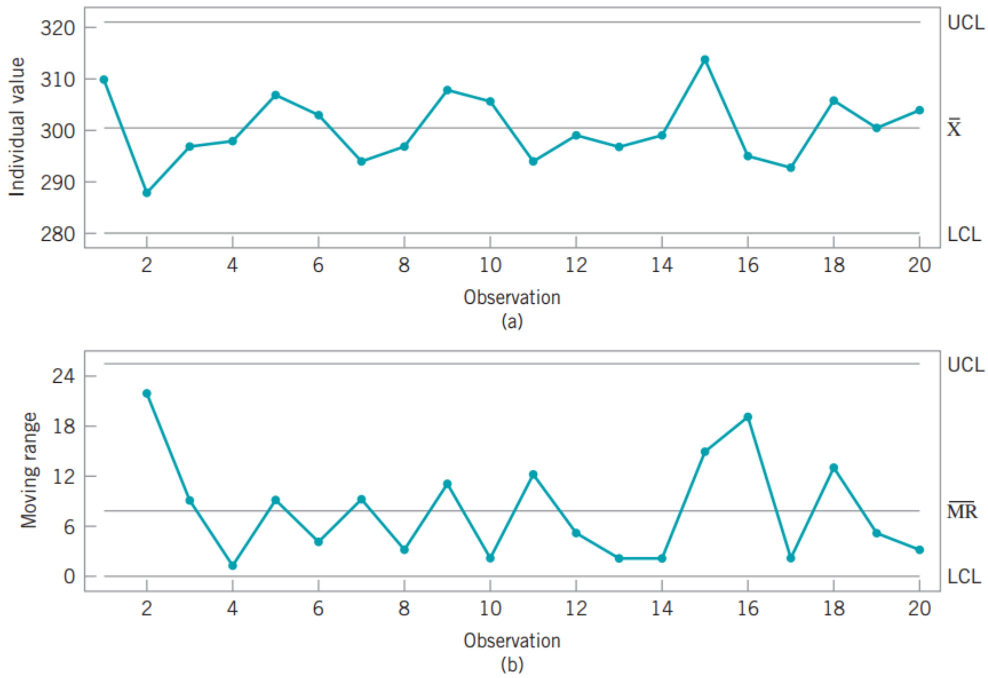


Figure 6 - I-MR control chart (Montgomery, 2019, p. 261)

The interpretation of the I-MR chart starts by observing if the MR chart is under control. In the lower graph, it is visible if any abrupted behaviour between two consecutive points occurs. Any detected deviations should be study and eliminated. Montgomery (2019, p. 244) alerts to "never attempt to interpret the chart when the [MR] chart indicates an out-of-control condition". After that, the individual value chart should be analysed. These analyses should not consist only on the points out of control, but if some cyclic pattern, a trend or a shift in the process level is present (Montgomery, 2019).

2.2.1.2. PROCESS CAPABILITY ANALYSIS

Process capability analysis consists of "analysing [the process] variability relative to product requirements or specifications" (Montgomery, 2019, p. 345). The specifications are the limits defined by the customer and should not be confused with the control limits. If the product is outside the specification limits the customer will not accept it and it will be considered a loss.

Two main indicators are used to represent the capability of the process:

$$Cp = \frac{UCL - LCL}{6\sigma} \qquad Cpk = \min(Cpu = \frac{USL - \mu}{3\sigma}; Cpl = \frac{\mu - LSL}{3\sigma})$$

C_p is the ratio of the allowed variation and the real variation and does not consider the location of the values relative to the specification's target. C_{pk} ratio makes the same evaluation taking into consideration the centre of the process. It commonly established "that C_p measures potential capability in the process, whereas C_{pk} measures actual capability" (Montgomery, 2019, p. 356).

2.2.1.3. SPC IMPLEMENTATION

To implement SPC, a methodology consisting of two phases should be conducted. The first phase aims to estimate the population parameters and to determine the control limits. During this phase, the historical process data is analysed, considering its central tendency and variability. The points considered out of control are then identified and their causes studied and eliminated, improving the process under study. For this improved process, new control limits should be defined (Montgomery, 2019).

The second phase focuses on monitoring the process by using new data in real-time and it is assumed that all of the special causes presented on the process were detected and eliminated on the previous phase. The control limits should be periodically reviewed, especially if some change occurs, but must not be constantly recalculated considering the new data (Montgomery, 2019).

2.2.2. BPM LIFE CYCLE

A business process is defined by Dumas, Marcello, Mendling, & Reijers (2018, p. 6) "as a collection of inter-related events, activities and decision points that involve a number of actors and objects, and that collectively lead to an outcome that is of value to at least one customer". Several authors affirm that organizations' survival depends on the good understanding of their business processes (Ouali, Mhiri, & Bouzguenda, 2016).

Business Process Management (BPM) is a broad field that focuses on improving the performance of business processes with the aim of enhancing the organizational operational performance, increasing productivity and reducing costs. It applies knowledge from different areas, such as information technology and management (Chinosi & Trombetta, 2012; Dumas et al., 2018; Geiger, Harrer, Lenhard, & Wirtz, 2018; Van Der Aalst, 2013).

Dumas et al. (2018, p. 28) clarify that "BPM is a body of principles, methods and tools to discover, analyse, redesign, implement and monitor business processes". The BPM life cycle supports organizations to better managing their processes and consists of the six phases presented in Figure 7.

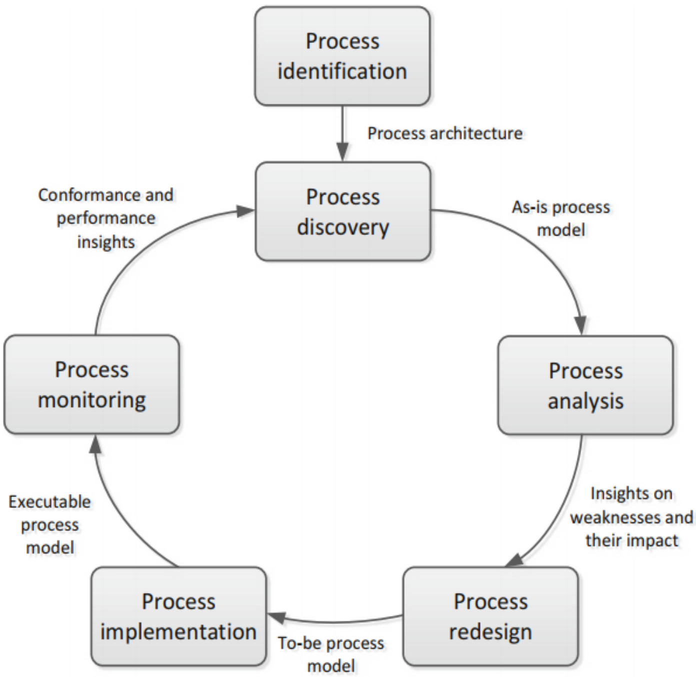


Figure 7 - BPM life cycle (Dumas et al., 2018, p. 23)

BPM life cycle starts by identifying the processes to be studied. It is important to define the problem to be solved and to identify the processes involved before starting to analyse them. Besides that, the scope and the relations with other processes need to be defined. The performance indicators should be identified to give quantitative information of the state of the problem and the process. Occasionally, this step is part of the analysis phase since the data is more relevant at that moment. The second phase is the process discovery, where a deeper understanding of how the work is done is acquired. As an outcome, one or more as-is models of the process are done. It is in this phase that process modelling techniques are applied. In the third phase, process analysis is done with the goal of assessing possible issues and opportunities to improve it. The next phase focuses on "[identifying] and [analysing] potential remedies for these issues" (Dumas et al., 2018, p. 20). It results in a redesigned process to be implemented in the next phase. The implementation phase consists of making the necessary changes to reach the to-be process.

These changes address mostly two complementary areas: (i) organizational change management, that deals with adapting established working methods and (ii) process automation, that requires an investment on the organization's IT level (Dumas et al., 2018, p. 23). After the implementation phase, the process needs to be continuously monitored in order to ensure its performance. After the monitoring and controlling phase, a restart of the life cycle and a new discovery, analysis and redesign of the process are performed, as it is shown in Figure 7.

2.2.3. DMAIC PROCESS

The DMAIC process is used as a roadmap for projects with the aim of improving a process and consist of five phases: Define, Measure, Analyse, Improve and Control (Council for Six Sigma Certification, 2018). The American Society for Quality defines it as "a data-driven quality strategy for improving processes" (ASQ, 2020). Although it is mostly associated with six sigma projects, the DMAIC method is a very flexible and general problem-solving procedure and can be applied in different contexts (Montgomery, 2019).

Even though it is mostly presented as a linear process, DMAIC has an interactive problem-solving approach allowing to get back to earlier steps, which brings to this method a generalized and powerful framework to think about problems (Smith & Phadke, 2005).

Each phase has its focus and a set of recommended tools to be applied. Two of the characteristics of this solving problem method are the application of statistical tools and the purpose to bring data to the decisions and validation of ideas. "The DMAIC framework utilizes control charts, designed [of] experiments, process capability analysis, measurement systems capability studies, and many other basic statistical tools" (Montgomery, 2019, p. 29).

The DMAIC process starts by defining the problem to be addressed. First, a framework for the project is done by defining the goals, the resources needed, the team involved, the process and the environment where the problem occurs. To map the process, tools such as value stream mapping and SIPOC analysis are applied. To understand the customer's expectation towards the project, tools as the voice of the customer (VOC) are used. All this information should be used to create a project charter, a one-page document that summarizes the project plan and main objectives.

The Measure phase aims to assess the current performance of the process. Therefore, critical to quality (CTQ) characteristics of the process are identified and measured. Output and quality performances are also measured by conducting Pareto analysis and capability studies, to understand, for example, defect frequencies. The initial situation is described and a baseline performance is specified providing a base understanding of the initial situation.

During the Analyse phase, the focus is on identifying influencing factors of the CTQ and the root causes of their behaviour. For the root cause analysis, failure mode and effect analysis (FMEA) and hypothesis testing are some of the tools that can be applied.

During the Improve phase, the root causes identified are going to be addressed. Adjustments are designed and implemented in order to improve the process's performance. In this phase, the ideas to improve the process are validated. Payoff effort matrix, design of experiments (DOE) and kaizen events are applied during this phase.

At the last step, the outcome is controlled and revised. Quality control plans are constructed to support the monitorization of the improvements made. Statistical Process Control, visual control with 5Ss, and mistake-proofing tools are applied.

2.3. QUALITY 4.0

Quality 4.0 is defined as the application of Industry 4.0 technologies into the quality field (Sisodia & Forero, 2020). It is about "the users of that technology, and the processes they use to maximize value" (LSN Research, 2017).

"This emerging Industry 4.0 concept is an umbrella term for a new industrial paradigm that embraces a set of future industrial developments regarding Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing and Augmented Reality" (Pereira & Romero, 2017). "Industry 4.0 can be also perceived as a natural transformation of the industrial production systems triggered by the digitalization trend" (Rojko, 2017).

These developments are mostly presented from the technology perspective and implemented by IT teams. However, the Quality 4.0 framework presents them as organizational issues. The quality professionals need to reposition themselves as the owners of these changes. As process management experts, they should be the ones defining how to use the data and why (ASQ, 2018; Sisodia & Forero, 2020).

Zonnenshain & Kenett (2020) discuss several opportunities in the quality field to leverage these new technologies, such as "quality as a data-driven discipline, modelling and simulation for evidence based quality engineering, prognostics for quality, integrated quality management (…)" and more.

The concept of Quality 4.0 is presented in this project by supporting the implementation of this reality by providing the quality teams with the systems that distribute and analyse the data about the quality of the production.

3. DESIGNED METHODOLOGIES

The project has consisted into (i) studying the problem that the needed data is not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production and (ii) the execution of the cases where the quality data mart are developed. In this chapter, the methodologies (i) to study the problem and (ii) to execute the cases are described. Figure 8 presents the timeline of the methodologies steps and how they integrate with each other.

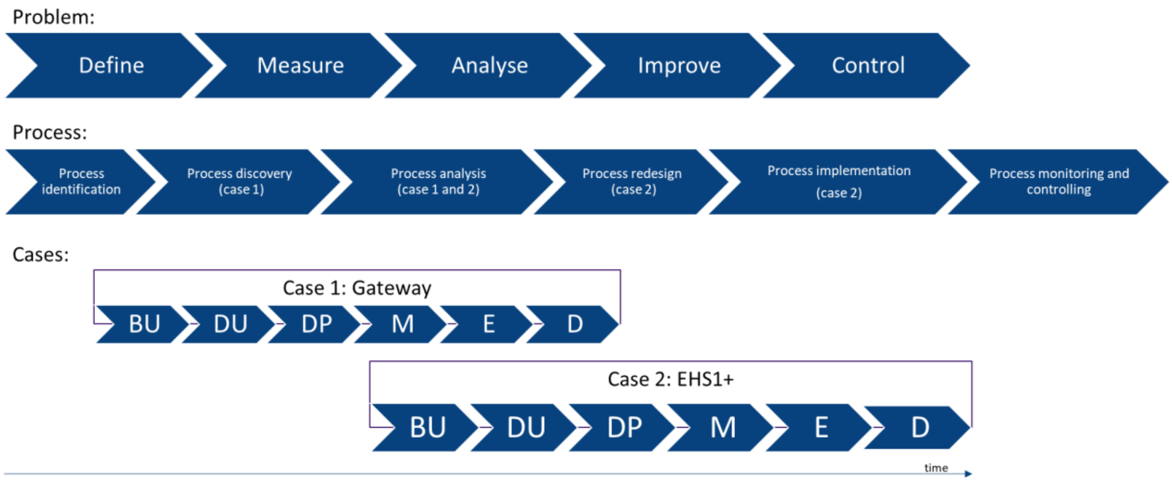


Figure 8 - Methodology's timeline

3.1. PROBLEM-SOLVING METHODOLOGY

To design the methodology to study the problem two frameworks were applied: DMAIC and BPM life cycle (see chapter 2).

Although the DMAIC method is mostly known for its usage on lean six sigma projects that aims to reduce variance on a process, this method can also be applied to a big variety of structure and semi-structured problems. In their study, De Mast & Lokkerbol (2012, p. 10) conclude that "DMAIC is suitable for rather extensive problem-solving tasks, requiring all of the components of problem definition, diagnosis and the design of remedies". Therefore, the DMAIC was chosen to be the problem-solving method.

Integrated with the DMAIC framework, the BPM life cycle was applied in order to develop the process of creating quality data marts. The activities performed in each phase are described next.

The first phase aims to define the problem at hand. Before addressing the problem itself, an initial onboarding period took place, with training sessions about the work dynamics at Bosch Ovar. After that, the project opportunity was further presented, which also corresponded to the process identification step. The goals and scope of the project were defined. The methodology to follow during the project was then studied and the plan of activities, its milestones and timeline were designed.

At the second phase, the aim is to assess the current situation by defining and measuring key points of the problem. Therefore, during this phase, a characterization of the current conditions is done, together with the definition of the baseline state and the desired state. It is also during this phase that the process discovery phase happens together with the beginning of the first case.

Afterwards, at the analysis phase, several points of the problem related to IT, the quality and the execution perspective are going to be analysed. The aim of these analyses is to gain a better understanding of the problem and the causes of it in order to solve it.

At the improvement phase, the ideas and solutions to the problems identified earlier are implemented. It is during this phase that the process redesign and implementation are performed, simultaneously with the beginning of the second case.

In the last phase, the impact of the improvement actions is evaluated. The use of dashboards should also be assessed. And a revision and conclusion of the project are also done with the presentation of the results and the end state compared with the desired state defined at the beginning.

3.2. DASHBOARD METHODOLOGICAL APPROACH

For each case, several activities about identification, acquisition, handling, analysis, visualisation and display of data are conducted in order to build the dashboards with the relevant information for their users. These cases presented in chapter 6 are objects of study among the full project.

For this, a methodology based on the CRISP-DM reference model (see section 2.1.4) will be applied. The subsections 3.2.1 to 3.2.6 describe the activities done in the six phases.

3.2.1. BUSINESS UNDERSTANDING

The first step of the model is to gain a deep understanding of the case at hands. After the identification of the team involved and the motivation for the dashboard, information about the product and the production process is gathered. All the support documents to the project, like failure mode and effect analysis (FMEA), control plans (CP), value stream mapping (VSM), customer support requirements (CSR), among others should be collected and analysed. Also, a more hands-on approach to explore the environment is achieved through observation of the production steps and by interacting with the production teams.

In this step, the identification of the critical to quality (CTQ) characteristics is done with the quality engineer. The CTQ characteristics are the base to define what are the goals and expectations of the dashboard, and the functional requirements for it.

Therefore, during this phase the following outcomes are expected:

- Team identification;
- Product description (should include the main functions);
- Production process mapping;
- CTQ characteristics identification;
- List of inspection methods;
- Goals for the dashboard;
- Identification of the users and
- Requirements mapping.

3.2.2. DATA UNDERSTANDING

With the goals for the dashboard defined and the information requirements identified, the second step is to focus on the data. The first part is to identify for the requested information, the needed data and to compare it with the data that is already being collected and stored. A data strategy plan is defined in collaboration with the IT responsible. This plan should consist of the mapping of the data flow, and the definition of the format and structure in which the data is going to be accessed.

Besides this, data analyses are done in order to gain sensibility to the data, to its quality and to investigate hypotheses.

At this stage it is expected to have:

- An identification of the data;
- The data strategy plan and
- The data analysis.

3.2.3. DATA PREPARATION

The data preparation phase consists of the integration of the data into the model. For this study, the tool for modelling the data is MS Power BI. This tool has the capability to gather different sources on the same platform, to create a relational model and to perform ETL tasks.

At this phase the following outcomes should be completed:

- The data model and
- The ETL tasks on the MS Power BI file.

3.2.4. MODELLING

After having the data imported to MS Power BI, at the modelling phase the visualizations of the data are created. In this phase, visualization principles should be applied, together with statistical techniques and process control tools.

It is crucial to keep in mind who are the stakeholders and how they would use the information and how they would interact with the dashboard.

For this phase, the outcomes are:

- The identification and selection of data visualizations and statistical analysis techniques;
- The creation of the pages with visualization in MS Power BI.

3.2.5. EVALUATION

After creating the visuals, they are presented to the quality engineer and the main users for feedback and details adjustment. With this new information, the work developed in previous phases may suffer some changes. These alterations should be presented again to the quality engineer for further feedback. After this feedback loop, a trial period with the users is defined in which the usage of the dashboard is tested.

It is expected to complete this stage with the final version of the dashboard ready to be deployed.

3.2.6. DEPLOYMENT

When the dashboard is ready to be launched, the deployment of the dashboard is done at the company server. This publishing server is able to define some settings, as the refreshing schedule and visualization rights. In this stage, a final meeting is organized, where the project is reviewed, and the lessons learned are documented for further projects.

Following all the phases a report is written, in order to document the main outcomes of each step.

4. PROJECT CONTEXTUALIZATION AND INITIAL STATE

In this chapter, the main aspects related to the environment of the project are described. It starts with a presentation of Bosch and the current situation about the data usage in the factory in Ovar. After that, relevant processes and frameworks of quality data marts are presented. Based on this characterization, indicators are defined in the last section to describe the baseline state and desired state of the project.

4.1. ABOUT THE COMPANY

This project is conducted at the Bosch factory located in Ovar, Portugal. With the motto *invented for life*, Bosch is a global company that develops a huge variety of products with a big range of applications, focusing not only on production excellence but also on research and development (R&D). It all started in 1886, in Stuttgart, Germany when Robert Bosch opened a workshop for precision mechanics and electrical engineering (Bosch Global, n.d.).

Currently, Bosch has more than 460 plants and four business units: Mobility Solutions, Industrial Technology, Energy & Building Technology and Consumer Goods. Figure 9 presents the divisions under each business unit (BU) (Bosch, 2019b).

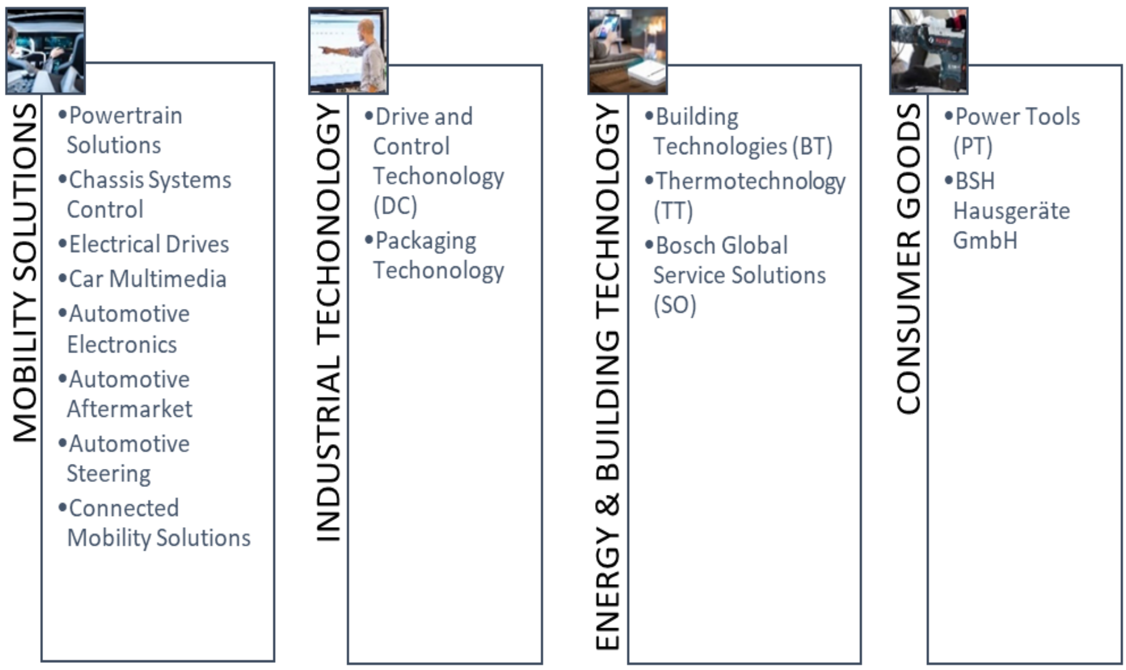


Figure 9 - Bosch Business Units Divisions (adapted from Bosch (2019b) and Bosch Global (2019))

4.1.1. PRODUCTS

Bosch Ovar is part of the Energy & Building Technology unit, as a major plant of the Building Technologies (BT) Division. Its focus is on the production of electronics solutions.

The product portfolio is characterized as highly diverse, complex and flexible, with roughly 700 finished goods and low production volume. The products are divided into four main areas: Security (BT-SC), Communication (BT-CO), Fire (BT-FIR) and Other (NON-BT) (Figure 10).

Figure 10 - Bosch Ovar product portfolio (Bosch, 2019a)

The product range for the BT unit includes video surveillance cameras; audio products for conference's, congress' and critical communication systems; fire detection systems and access control systems.

The other category (non-BT) contains the products outside the BT division, for which the Ovar plant provides manufacturing of products or sub-products (TT, PT, BSH) and development of software, mechanics and optical processes. This was a decision made recently in order to increase the production volume of the plant, by working for other BUs. Also, there is a focus of Ovar plant management to have more R&D opportunities (Bosch, 2019a).

Besides its end product portfolio, Ovar plant is also responsible for the production of printed circuit board assembly (PCBA) and uses several different technologies as surface mount technology (SMT) and through-hole technology (THT) assembly with selective and wave soldering.

Globally, different plants of Bosch are considered as an expert in certain fields and are assigned as a centre of competence, being contacted to give support to other plants in certain subjects. Ovar organization is the centre of competence for the manufacturing of electronic boards and optical block assembly (Bosch, 2019a).

4.1.2. STRATEGY

The 2022 strategy of Bosch Ovar is to focus on five main fields: (i) Manufacturing Engineering Process, (ii) Supply Chain, (iii) People Management, (iv) Technology, Equipment & Infrastructure Management, (v) Development Services – R&D. (Bosch, 2019a)

These areas were identified after defining the aim of providing excellence in connected solutions (see Figure 11). The factory eagerness for excellence led them to be recognized several times and most recently with the EFQM Global Excellence Award 2019 (Bosch, 2019a).

Figure 11 - Bosch Ovar 2022 (Bosch, 2019a)

4.1.3. ORGANIZATIONAL STRUCTURE

The Ovar factory is organized as follows. The plant manager is responsible for the organization together with a board of directors accountable for their specific areas. Integrated with this hierarchy structure, there is a process approach, where the teams are formed based on the value stream they are working for, creating a matrix structure as presented in Figure 12. The values streams teams are PCBA production (MOE1), security (MOE2 –SC), contract manufacture (MOE2 - CM) and communication and fire (MOE2-CSI).

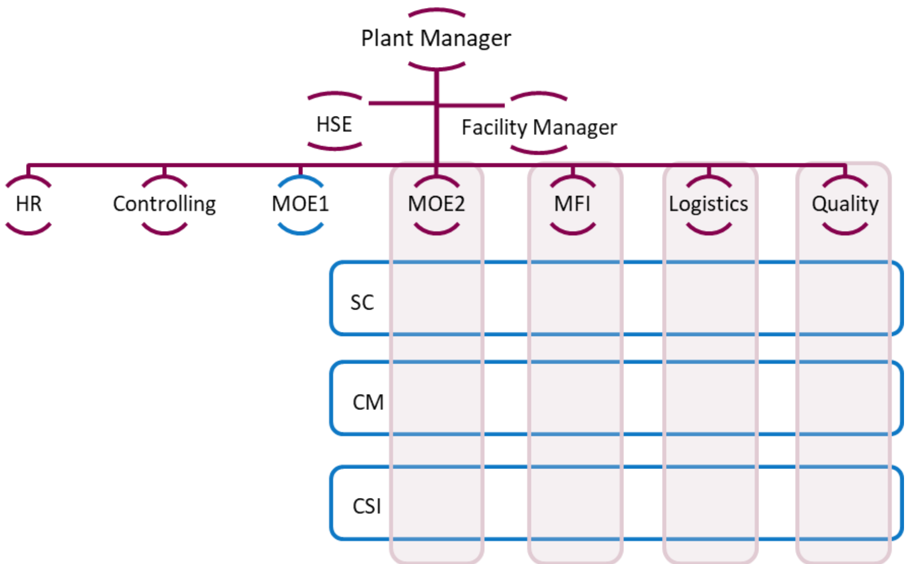


Figure 12 - Bosch Ovar Value Stream Organization (Bosch, 2019a)

In the course of the project, the organization is facing structural changes. Before, the support function's collaborators (logistics, quality, manufacturing (MOE), industrialization (MFI)) were allocated to a functional department and assigned to a value stream. Now the production and support function's collaborators are allocated to a certain value stream team with a certain functional responsibility. This causes some changes in the leadership level and how teams support each other, enforcing the links inside the value stream team.

The structural re-organization leads to a natural resistance to change. The adaptation to the new working structure started during the project timeline and is expected to last until or even after the end of this project.

4.1.4. QUALITY DEPARTMENT

The project is integrated on the area of quality engineering but is related to the other areas of quality and the industrialization and manufacturing processes.

The quality department is separated by focus areas: product audit; process quality; quality engineering; purchasing quality; tool trace engineering.

The role of the quality engineer is to improve the quality of the products and production by analysing the manufacturing system being expected to incorporate the use of quality methods and tools. The quality engineer also has an important role to communicate with the client to ensure the quality of the production and when quality deviation or complaint appears (Bosch, 2020).

4.2. USE OF DATA IN THE ORGANIZATION

4.2.1. DIGITALIZATION OVERVIEW TOOL

Nowadays, Industry 4.0 technologies and concepts are known by any industry, but not all the factories are at the same maturity level when implementing them. Companies need to adapt and invest their efforts to make the change to implement Industry 4.0 principles. These tools should support and enhance already established routines.

Recently, Bosch Ovar started a digitalization initiative, where a platform named digital overview tool was implemented to support the daily meetings of the teams. During these meetings, the multidisciplinary teams gather to evaluate their production performance and discuss the main difficulties and next points to tackle. With this new online platform, it is possible to evaluate the production performance of the previous days and keep track of open points that need to be discussed and which task still need to be done. Several interactive boards were installed on the job floor next to the production lines to facilitate the collection and report of the data during the daily meetings, making it also available to everyone at any time.

Not only the daily performance is available, but the companies KPI Tree, with the key performance indicators, is represented, which is mostly used by the management. In Figure 13 the page with the KPI tree at the digital overview tool is presented. Each department is responsible to define, use and monitor its related indicators.

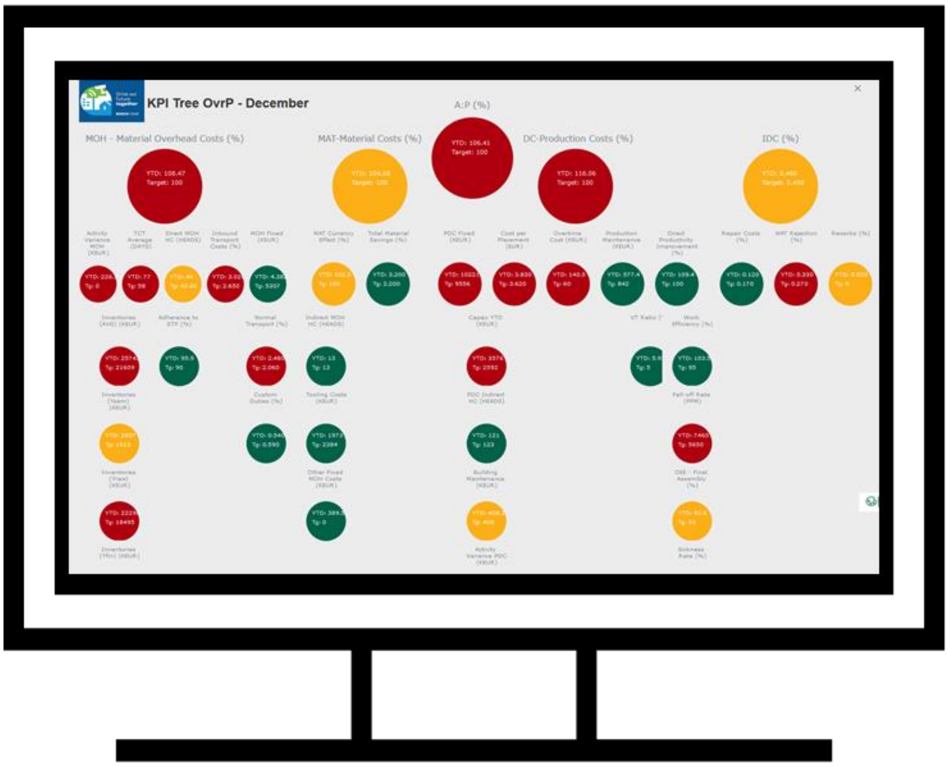


Figure 13 - Digital overview tool

The idea of using data and making a data-driven decision is still being implemented on the day to day tasks and how people approach their decisions and challenges with the support of the information given by the data. Thanks to the conducted project, some of the data is easily accessed by the production, however not all the needed data is there. This tool is not yet providing relevant insights to the support teams, with the relevant information that they need. This digitalization tool is a work in process project, therefore more interactions are planned to improve the platform.

4.2.2. USE OF DATA BY THE QUALITY DEPARTMENT

The KPIs for the quality department are the ones related to the product performance at the customer level, claims and returns, and the quality aspects at the production level.

The most important indicators are the following ones:

- Dead on Arrival (DoA) – the ratio of products that failure at the customer.
- Master Plant to Master Plant (MP2MP) – the ratio of internal failure product from one Bosch plant to another Bosch plant.
- Customer Acceptance Test (CAT) – the amount of products that fail on the test that simulates the normal usage of a product.
- Fall of Rate (FOR) – the ratio of products (mainly the PCBAs) that need to be repaired before continuing the manufacturing process.
- Corrective Actions Request (CAR) – time need to develop a response by studying the causes and action to contain and improve the process for recurrent or severe quality problem.

The role of the quality engineer is to discuss with the customers and with the production about quality problems that arise. It is also his/her responsibility to ensure that the problems are being studied and solved. To understand the root cause of a claim, the quality engineer needs data about the production of a specific product. In this case, he/she needs to request the IT team to file a report.

Currently, this involves asking the test engineer for the specific log file. In this file, the data from the test equipment of a specific serial number (S\N) is stored. The time that the test engineer takes to answer varies and can take up to three weeks to have access to a single log file.

4.3. PRODUCTS INDUSTRIALIZATION PROCESSES

When a new Bosch product is developed, the development team needs to design and define the product features that ensure the satisfaction of the customers and the market needs. When a product is designed, a manufacturing plant needs to be assigned accordingly to produce it. Two main processes support the transition from development to mass production, which are described next.

4.3.1. INDUSTRIALIZATION PROCESS

The product engineering process (PEP) also known as the industrialization process, is a standard procedure for the transfer of a product from the development phase to the production. This is a well-established process at Bosch. Several phases and milestones (Quality Gates (QG)) need to be completed as shown in Figure 14.

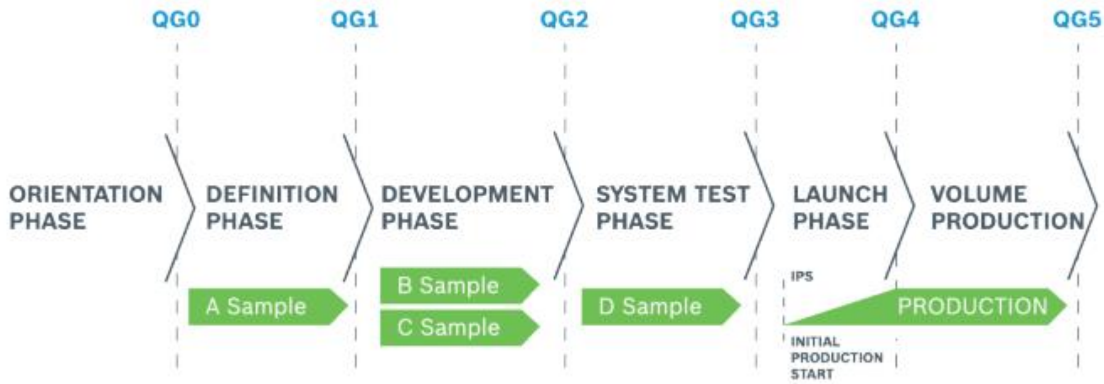


Figure 14 - Product Engineering Process (Bosch, 2019c)

Both development and manufacturing teams get together to define and adjust the product and the manufacturing process. In most cases, these two teams work at different locations. During this process, several production trials and small quantities of products are manufactured (X-samples) to test the production process, the inspections methods and to perform some design and reliability tests. During this time, other documents are created based on discussions between the different parties, such as product requirements, the list with critical to quality characteristics and product and process FMEA, among others.

4.3.2. MANAGEMENT OF CHARACTERISTICS

The central directive quality: management of characteristics (CDQ) (Bosch, 2019d) was recently developed as integration and replacement of other directives with the following topics: special characteristics classification; inspection planning, capability and process control and control plan.

Management of characteristics (CDQ) (Bosch, 2019d) is described as the process of identifying the characteristics of the product and classifying them based on its functionality and the robustness of its production process. Additionally, the quality control loops for the characteristics with inspection plans and monitorization methods are defined. This process aims to ensure that the customers' requirements are fulfilled, ensuring the quality of the manufactured products.

The CDQ is divided into two parts: characteristics classification and integrated quality planning, with defined steps shown in Figure 15.

	„Characteristics classification" (incl. Special Characteristics)
1	Agreement on special characteristics between BOSCH and customer
2	functional robustness analysis
3	manufacturing method robustness analysis)
4	Identification of confirmed special characteristics (capability analysis)
5	Process relevance analysis
6	Allocation of Characteristics Classification

	Integrated Quality Planning (IQP)
7	Definition of Inspection Strategy
8	Definition of Inspection Method
9	Planning of the Test/ Measurement Process Capability & Control
10	Definition of the Inspection Data Recording and Evaluation
11	Definition of Reaction and Corrective Action Plans
12	Documentation and release of the Method "Management of Characteristics"
13	Reviews of the Management of Characteristics

Figure 15 - CDQ steps (adapted from Bosch (2019d))

The first part focuses on studying the characteristics of the product and has as a result a list of classified characteristics. The classification consists of three groups based on the functional and manufacturing robustness, analysed from the second to fifth step:

A. Confirmed special characteristic,

B. Not confirmed as special characteristics (not robust and/or not functional),

C. Robust and functional or not relevant.

It is based on these categories that the inspection strategies are defined during the second part of the CDQ. In order to guarantee the product quality, more resources and efforts are dedicated to monitoring the characteristics classified as A and B.

As a new reformulated directive, it is not fully followed by all development teams. There are some difficulties to have a clear list of classified characteristics, what is the base for the creation of the quality data marts since the stakeholders want to get insights about these characteristics' performance. Several initiatives have taken place on the BT business unit to have classified lists of characteristics and the organization of the Ovar plant is involved in these efforts, with the current project as an example of it.

4.4. QUALITY DATA MART FRAMEWORK

At Bosch, the term quality data mart consists of an information system that collects, analyses, and distributes data and information regarding the quality of a product, which result in the creation of a dashboard. Since these ideas are recent at Ovar plant, there are not many projects and success stories on how to create the quality data marts, neither a correct nor structured way to do it.

At the start of the project, there were two pilot dashboards implemented for product A and B. Until then, the benefits for the users are not clearly shown to everyone in the organization, therefore the projects and quality data marts are not given the necessary priority and needed attention as well as resources. Since it is a multidisciplinary initiative, it is important to have a common strategy and to align everyone with the main goal.

In a previous project which dealt with the technical construction, the quality data mart concept and its frameworks were developed. Below the relevant outcomes are be presented. They will serve as a base for this work about the implementation of quality data marts.

4.4.1. DRIVING FRAMEWORK

The concept was developed within the CDQ process (Figure 16). Based on the study of the product characteristics, the quality features to be monitored are defined. It is in the second phase of the CDQ that the quality data mart is executed. The quality data mart should be created to store the data from the inspections' activities and provide the monitorization of the process in a simple and accessible way. The necessary visualizations can be compiled on a dashboard that is used to distribute the information across the stakeholders.

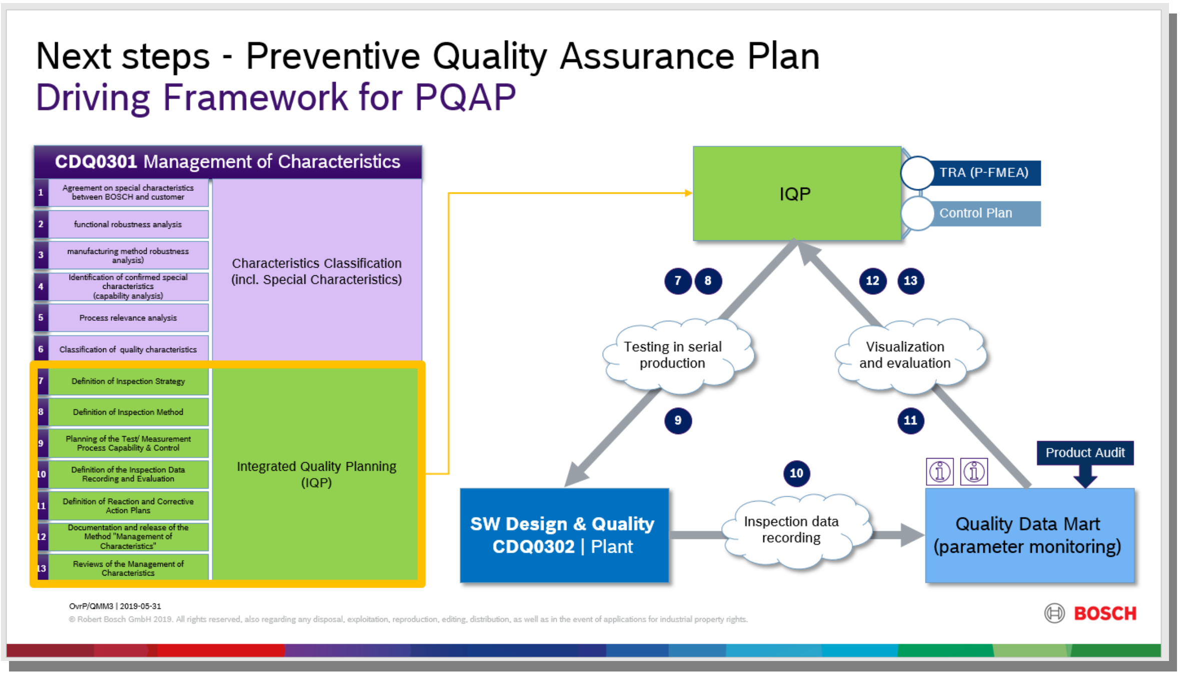


Figure 16 - Driving framework for the Quality Data Mart (Bosch, 2019f)

4.4.2. PUBLISHING FRAMEWORK

The publishing framework, presented in Figure 17, represents the process where the data and information flows are described. This process shows how the data generated at the production lines need to be stored in a database, which is used and analysed at the dashboard. This dashboard is later published at the Bosch server and distributed to the network in different digital platforms.

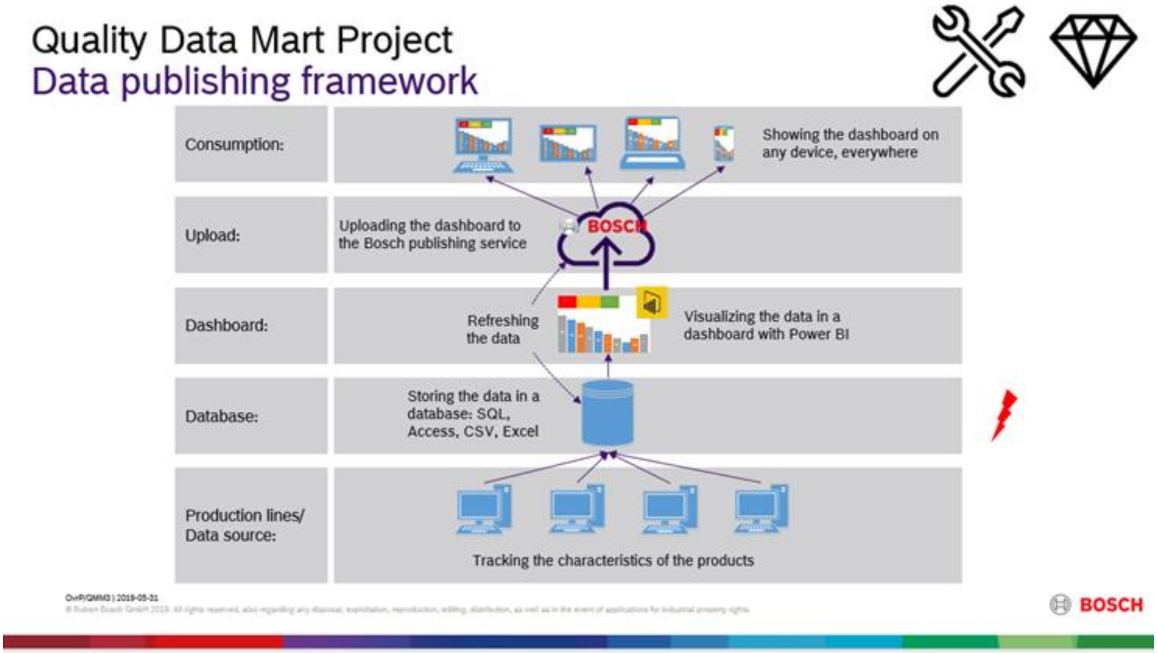


Figure 17 - Data Publishing Framework (Bosch, 2019f)

The software considered for this publishing framework was the MS Power BI since its usages for the quality engineer is fairly straightforward without the need to apply complex programming skills. Moreover, MS Power BI can connect diverse sources of data on one single dashboard.

This software has three main modes: model, data and report. In the first its where the data model can be defined, by defining tables and relations between them. In the data mode, the detail data presented in each table can be visualized. Lastly, it is on the report mode that the dashboard pages are designed (Microsoft Power BI, 2020).

MS Power BI is also being used globally in the organization to share and visualize information, therefore there is a dedicated central team for it and the possibility to upload the work on a common server. It also gives an easy platform to share the dashboard across the organization.

4.5. BASELINE AND DESIRED STATE

Based on the initial situation described above, dimensions and metrics were defined to build a baseline. The definition of these indicators is aligned with the study goals and supports the project's monitorization (see Table 2).

Table 2 - Baseline Table

Indicators	Current State	Desired State
Number of product dashboards created	2 (product A and B)	4 (product A, B, Gateway and EHS1+)
Access data	'fight for data'	Several easier options discussed and tried
Request for data -Difficulty	Need to ask IT when something happens Reactive approach	Automated (no need to request the IT team) Proactive approach
Request for data -Time	Takes around three weeks to get the log file of the requested S\N	Near real-time (daily or updated three times a day)
Request for data -Format of the data	Log file	Analysed and contextualized data Relevant information Visuals and graphics of the data
Information available -Amount of data and info available	Log file of a specific S\N that is asked	Access to required production data Data is analysed
Production monitorization	Mostly focus on output and not on quality features	Dashboards with information about the products' quality
Management of characteristics -CDQ implementation	CDQ mostly not implemented	Have a list of characteristics for all new products
Inspection methods and quality tools used - The methods used to define the tests to be performed	FMEA and CP implemented in all products at the industrialization phase and revised when needed	FMEA and CP and list of characteristics created during the industrialization process
Dashboard standards - Defined process and other support tools available	There is not a clear process	Proposal of a process
Quality data mart concept	New idea	Clear concept, ready to present and pilot

The gap between the desired and current state emphasizes the lack of data analysis and process monitorization regarding the quality of the products. This happens mostly due to the difficulty to access the data in an easy way and the lack of clearly identified critical to quality characteristics from the customer's side. With this gap, the already mentioned problem emerges: the needed data is not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production.

It is important to focus on improving the current state. However, this should be done in a way that leads to keep a sustainable improvement. In the next chapter, the measures to reach that desired state will be presented.

5. PROBLEM STUDY

In this chapter, the analyses conducted to further explore the problem are presented.

Considering the situation at the plant and the proposed challenges the following questions have been raised:

- Why is the data not available?
- What does it mean to have the necessary insights and how can they be identified?
- How can the data be analysed to create meaningful information? Which statistics should be used?
- How can the quality engineers use the information in their daily business?
- In which way should the information be provided and visualized?

From these questions, several analyses were conducted and divided into three categories. The first is related to the quality perspective, the second to the technical perspective and the third one to the execution of the quality data marts. For each category, the analyses and work developed are presented and discussed along with possible solutions. Furthermore, the outcomes of the solutions that were implemented are presented. In the last section, the final state of the project is presented, by reviewing the indicators defined in subsection 4.5.

5.1. THE QUALITY PERSPECTIVE

To better understand the work developed by the quality department an assessment on how the department uses the data at their daily tasks was done. Later, it was analysed how to identify the product characteristics with the use of CDQ procedure, presented in subsection 4.3.2.

5.1.1. ANALYSIS OF THE USE OF DATA BY THE QUALITY DEPARTMENT

Informal interviews and shadowing observation were the tools used to better understand how the quality engineers used data in their work. It can be concluded that the different value streams teams work differently, due to different products, processes, and customers that they have. Therefore, their use of data differs and three different scenarios were identified during this assessment:

A. The quality engineer does not have access to the data.

Since the data needed is mostly managed by test and IT engineers, the access to this data can be sensitive and the quality engineer may not have clearance to access it. In these cases, even if the quality engineer is willing to have a data-driven approach, he/she is faced with some barriers that need to be shattered.

B. The quality engineer has access to the data, but not in a friendly user format.

In some cases, the data is available, but its collection and analysis are not automated or simple to perform. This creates some difficulties for the quality engineer to have the needed information from the data. Also, he/she needs to spend valuable time analysing and make the data useful.
Another aspect is the trustability of the data. Some of the data, mainly regarding repair, needs to be inserted by the collaborator. This may lead to some failures on the data that is collected and give incomplete or false information to the quality engineer. There is also some waste due to the effort dedicated to manually confirm and correct the data.

C. The quality engineer has access to the data and analysed information but is not using it to its full potential.

This situation occurs when the behaviour and the working methods need to shift from a reactive approach to a proactive one. The quality engineer uses the information available when it is questioned by some abnormal situation but does not use the data as a trigger for creating measures to prevent further consequences.

Changing to a new way of working to have a more data-driven decision mindset is not an easy process and does not happen without consistent work. It is also important to create conditions to develop this behaviour. Besides the recent work done to make the data more accessible with the creation of quality data marts, there is an effort to increase the competencies of the quality engineers to analyse data, by providing MS Power BI training.

5.1.2. IDENTIFICATION OF QUALITY CHARACTERISTICS TO MONITOR

When industrializing a new product, one of the key steps is to ensure the quality of the production, by studying the critical to quality (CTQ) characteristics. The analysis of characteristics should be done by the development team. If this work is not done during the development phase, it is more complicated to clearly know what to monitor and consequently to develop the quality data marts.

It was observed that not all the development teams create the list of characteristics in the same way. There are different interpretations of how to create and document it. Therefore, the first part of the CDQ, a directive that describes a procedure to classify the characteristics (see Figure 15), is an important tool to develop the quality data marts.

When the CTQ characteristics are identified, the inspections methods to monitor them are determined. The way to inspect is defined with the support of process FMEA and control plans documentation. The outcomes of these inspection methods (pass/fail or a certain measure or attribute) are the raw the data used in the analyses and dashboards.

As a way to get closer to the work developed by the quality engineer and to support the use of the characteristics list, the idea is to reverse engineer the creation of the list. And to use the product of case one to build the characteristic list from the quality engineer point of view. And then to see the gap between what the development team presented and what the production team was expecting to have.

Is important to highlight that this list and the CDQ steps are intended to be developed in cooperation by both teams, but at the moment this is not yet well established. Thus, currently, both teams assess the criticality in their own way. The already created support documentation of the CDQ also reveals to be essential to gather the information and the reasoning for classifying the characteristics and selecting the inspection methods.

5.2. THE DATA PERSPECTIVE

The IT approach to data storage is to focus on the technical optimization of resources instead of the usability of the data for analysis. From a technical perspective, the main frameworks were developed in a previous study, introduced in section 4.4. The main constraints identified during the first study were at the database level and focus on five gaps: access, cost, connectivity to MS Power BI, management, and structure. With these gaps in mind, different solutions and strategies were proposed in the referred study, but nothing was effectively implemented. Therefore, the gap between IT and the way the data is stored and its accessibility are still barriers that need to be analysed. In the next subsections, these gaps are discussed. Additionally, an analysis of the quality of the data is performed. To understand better the IT perspective a data workshop was conduct and its outcomes are present in the last subsection.

5.2.1. THE ACCESS GAP

The main struggle is to clear the access to the data for the quality department. The access is not given by the IT department due to possible interference with the production data upload, so there is a need to limit the number of people that have access to it.

Two solutions were suggested: (i) to have a virtual server that would be a copy of the production data, where no interference with the production would happen, which has the problem of the high costs associated with the virtual server. And (ii) to use powerful and free open source solutions like PostgreSQL, which would not be optimal due to some constrains when connecting with MS Power BI server. Moreover, the management does not support having open sources options due to its lack of security reliability.

With the different solutions and options presented before, no clear strategy was defined. As a result, quality data marts are created case by case. Different easy options are explored having in consideration not to demand too many IT resources, enabling further creation of dashboards.

5.2.2. DATA STRUCTURE GAP

Currently, most of the data is uploaded in a teststand standard schema, which is not the preferential schema when analysing data. To optimize the database's queries, the structure of the data must be built for that purpose. When building a data mart, the use of a star schema is recommended. (Jensen et al., 2010)

There is also the situation that the needed data is spread over different places within the organization, with different data formats, without a standard way to interconnect them. The quality data mart would play a crucial the role of a connector of the diverse data sets (production database, CAT inspections, extra testing, complaints record, ...).

This data usually has different formats, so it is important to consider which software to use to create the dashboard and for more complex products to use multidimensional data modelling techniques.

5.2.3. DATA QUALITY ANALYSIS

While assessing the way the quality engineers used data (see session 5.1.1), the not trustability of the data was identified as a pain point. This leads to a need to assess the quality of the data that it is used. The data available at the different values streams were analysed, considering the quality data dimensions (see subsection 2.1.3).

In most cases the inspection of the products is done with test equipment at the production line, that assures a good data quality. The equipment performance is also ensured by capability studies and measurement system analysis (MSA) studies. With this equipment, the data obtained is complete, valid, accurate and with low delay on the time from the inspection to the entrance of the data on the database. It should be noted that the same unit can be tested more than once, therefore the results for a single product are not unique. Nevertheless, the result of a unique test on a given time to a specific unit is singular.

The main constraints identified were related to the inspections done by an operator and at the reparation level, where the operator needs to insert manually the inspection or reparation data. This affects the timeliness, due to sometimes the collaborator does not introduce the data immediately and can only insert it later in the shift or at the next day, or to completely forgets to do it, especially if he/she is overloaded. Even though there are some efforts to confirm and double-check the data that is inserted, there is still a lack of quality related to the accuracy of the data.

Regarding the uniqueness, at the PCBA production value stream (MOE1), there is an automated optical inspection (AOI) machine that provides the repairer with information about the component that may have quality problems. For the same PCBA, there is data available from the AOI machine and from the repair collaborator. In some cases, both sources do not match what brings confusion and distrust to the system.

At the x-ray inspection, since the evaluation is performed by the CAT operator and collected on an excel file, some of the values may not follow the pre-defined data format, which affects the validity dimension.

Taking into account that the system has to be fed with the correct data, it is important to consider analysing and solving any data quality deviations that may be occurring. This depends on the product itself and its process and value stream. The main deviations usually occur when there is a need to insert the data manually.

5.2.4. OUTCOME

Considering the scope of the project, in order to tackle the situation, it was decided to have a case-by-case approach, since having easily executed pilot cases, with successful implementation, can highlight what needs to be done to support the quality department’s work. The aim is to create win-win situations, where the IT resources are not highly demanded and the quality department can have access to the data. Two pilot projects were addressed, case one: Gateway and case two: EHS1+.

Furthermore, the source of the barriers has to be analysed. Throughout the execution of the second case, a meeting was carried out with the test and IT engineers, in order to understand the IT perspective to the quality data mart topic. During this workshop, the work developed until that point was presented, along with the concept and framework of the quality data mart.

From everything presented, the main concern pointed out was the use of the MS Power BI software. Mainly because of the way it operates on the backstage of the software and how it accesses the production database. After some discussion, a consensus was reached that the software Grafana would be better because it is possible to control and define how the software communicates with the production database.

So, it was decided to have the second case developed using Grafana and to study the use of the two different software's (Grafana and MS Power BI).

5.3. THE DASHBOARD EXECUTION

A big focus for the project is the process of creating quality data marts. One of the main pain points identified was the lack of standardization. In order to understand and define this process, a SIPOC analysis was done. Moreover, based on the cases developed the role of the quality engineer was analysed. Lastly, as outcome, a proposal for a process to develop a quality data mart is presented.

5.3.1. THE PROCESS AND STANDARDIZATION

Even though in previous work, frameworks were developed (see subsection 4.4), there was no clear way on how to execute and create quality data marts. Neither the steps, nor who is responsible for executing them or when should each one be performed were defined. This situation led to difficulties related to the ambiguity on the way of working. One of the focus of this project is then to study and propose a procedure on how to build a quality data mart in the future.

In order to study the process, the approach will be, as already mentioned, to work by pilot projects, developing two quality data marts and keeping track of the steps taken, while refining it by taking into account improvement points. Also, documents and templates will be created to support the execution of the process in the future.

On the other hand, the aim is to work towards defining the roles of the different departments in other to create tasks' responsibility and a common strategy on how to execute similar projects in the future.

5.3.2. SIPOC ANALYSIS

While previous analyses were being done, a need to analyse the process in detail, its inputs and stakeholders emerged. The SIPOC method was applied, which stand for suppliers-inputs-process-outputs-customers. This analysis consists of (i) defining the process steps, (ii) determining the output and customers, and (iii) identifying the suppliers and inputs (ASQ, 2019).

In the first SIPOC analysis phase, it is important to define the boundaries and scope of the process. In this study, the focus is on the execution of the quality data mart, from the need to have it developed until it is ready to be deployed. The analysis does not focus on other responsibilities and activities related to the quality or industrialization teams.

Based on the methodology defined in section 3.2 and the experience from the first case, seven high-level steps were defined as presented in Figure 18. It starts by identifying the dashboard aim, followed by understanding the product, the characteristics to be studied and how they are monitored. Then the availability of the data is studied in order to start data analyses and to extract, transform and load the data into the MS power BI. In this software, the visualizations are designed, and later published into the Bosch server and distributed to the stakeholders.

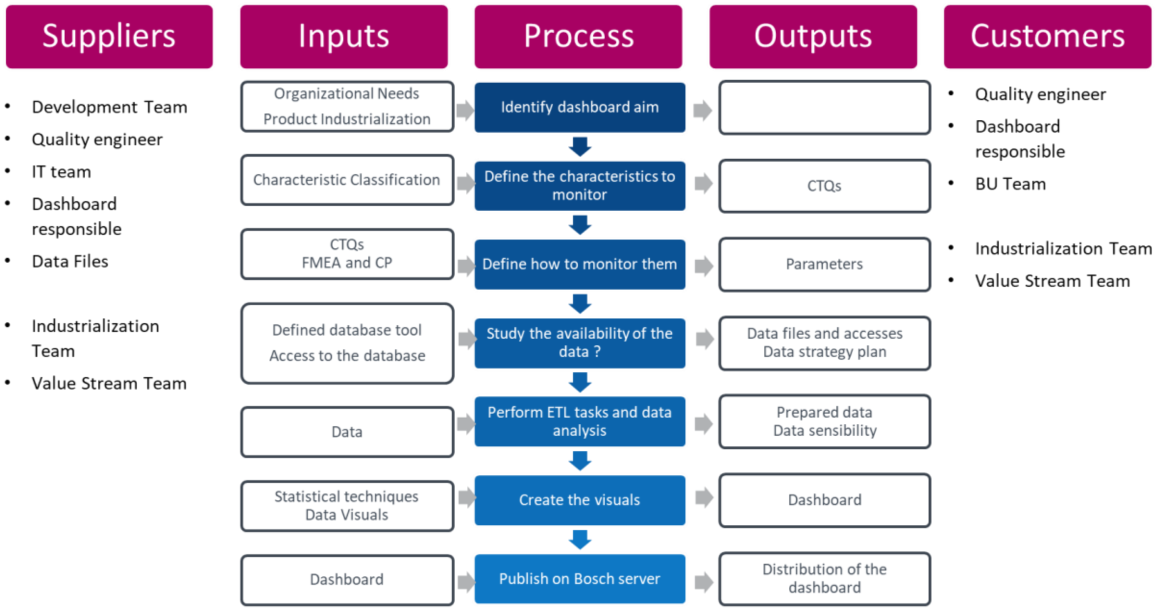


Figure 18 - SIPOC diagram for the dashboard's creation

The outputs and inputs were described for each step giving a detailed analysis. From the output list, it is observable that the dashboard itself is not the only result of this process, but better data understanding and preparation are also obtained. By observing the inputs list, it is detailed what it is needed for each step. This list also supports identifying the suppliers, by defining who or what can provide each input.

By describing the customers, it was possible to identify not only the direct teams but also indirect customers, the industrialization and value stream teams that should also use the dashboard. It was through this reflection that a broader view of who will use the dashboard was obtained. The same happens with the suppliers. By identifying them, it was clear that they should also be engaged in developing the quality data mart in order to easily support its creation.

5.3.3. THE QUALITY ENGINEER ROLE

To create the quality data mart for a certain product, the involvement of different teams is necessary. In this section, the contribution of both teams is analysed and the role of the quality engineer in this scenario is discussed.

- Development team

This team is one of the stakeholders of the product that is produced by Ovar plant, and it is also for them that the dashboard is created, so they can, in near real-time, monitor the production even if they are not on the plant. An identified difficulty was that sometimes they did not have well defined what they wanted from the dashboard. The communication point is done through the quality engineer and it was observed that with good documents, like the characteristics list, it is easier to define more objectively what needs to be done.

- Industrialization team

This team is composed of Ovar plant's associates. The dashboard should be built also to support their work, therefore it is important to understand their needs. They also play a role on the technical side and should support how to collect and access the data on the best way possible and to develop the inspection methods when necessary.

- The quality engineer

The quality engineer is the main communication person that can gather the requirements from the development and industrialization teams. He/She should ensure that the dashboard developed is aligned with the needs of both teams and facilitate the data analyst work. The challenge faced was sometimes due to the lack of clear expectations from both teams since the building of dashboards is something relatively new to everybody.

By studying the influence of both teams and the quality engineer, a better understanding of the environment where the quality data marts are executed was gained. This awareness supports and contributes to a more brought view of the process when studying it.

5.3.4. OUTCOME: QUALITY DATA MART PROCESS

Based on the work developed during this project, a process to create the quality data marts was defined. It is based on the CRISP-DM methodology and it takes into consideration the PEP and CDQ procedures presented in section 4.3.

The procedure of developing a quality data mart can be divided into four main steps: project definition, data provision, dashboard design and deployment. Each step represents a project milestone, as presented in Figure 19.

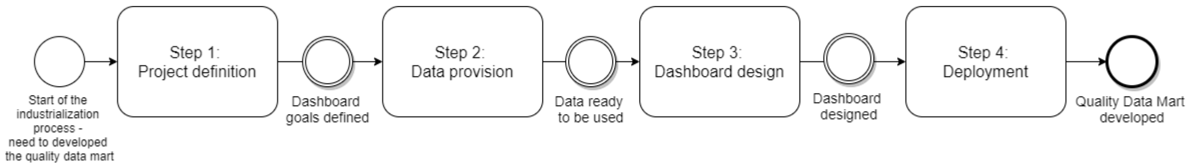


Figure 19 - Quality data mart process steps

In the following sections, each step is going to be described in detail, where the business process modelling notation developed by Object Management Group, BPMN 2.0 is applied (Object Management Group, 2011).

Three actors are represented horizontally by lanes, the quality engineer, the dashboard responsible and the test engineer to illustrate their responsibilities trough out the development of the quality data marts. It is important to note that the detail chosen had in consideration the aim of the representation, that is to illustrate the activities needed to develop the quality data mart. In the descriptions below more context is presented. The complete representation is presented in Appendix 1, which include the PEP and CDQ procedures representations.

5.3.4.1. STEP 1: PROJECT DEFINITION

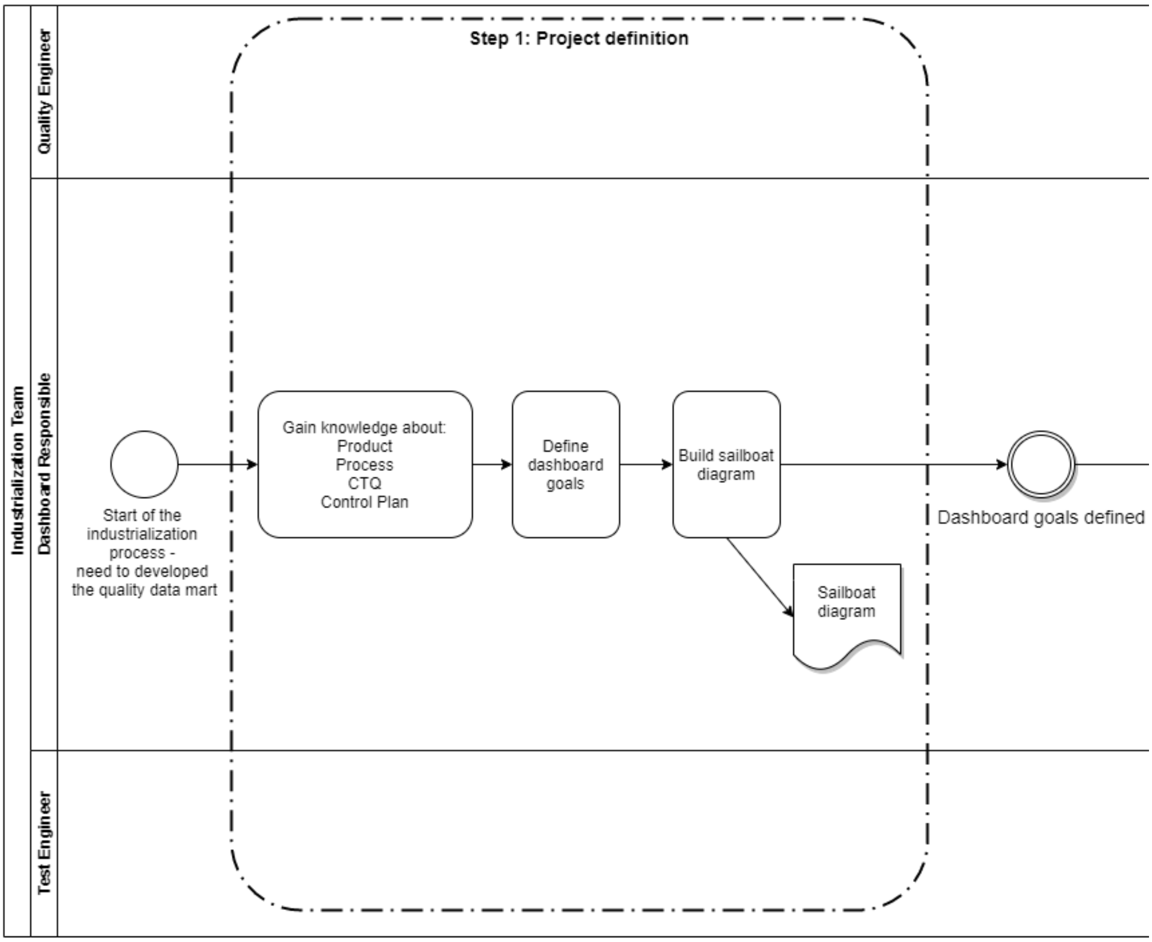


Figure 20 - Step 1: Project definition

The process starts with the need to develop the quality data mart that comes from the industrialization of a new product. The first main step, shown in Figure 20, is about the definition of the project. The person responsible for developing the dashboard should obtain knowledge about the product, by reading the available documents, being at the process workstations and interacting with the teams. Here the quality engineer has the role to support the dashboard responsible to gain the necessary insights about the product and its production. With all the insights gathered, the goals for the project, as the timeline and team involved are defined. Then the sailboat diagram is built, by defining the strategical, the user goals and the subfunctions use cases. This main step is finished by having the goals and the sailboat diagram defined and approved by the quality engineer.

5.3.4.2. STEP 2: DATA PROVISION

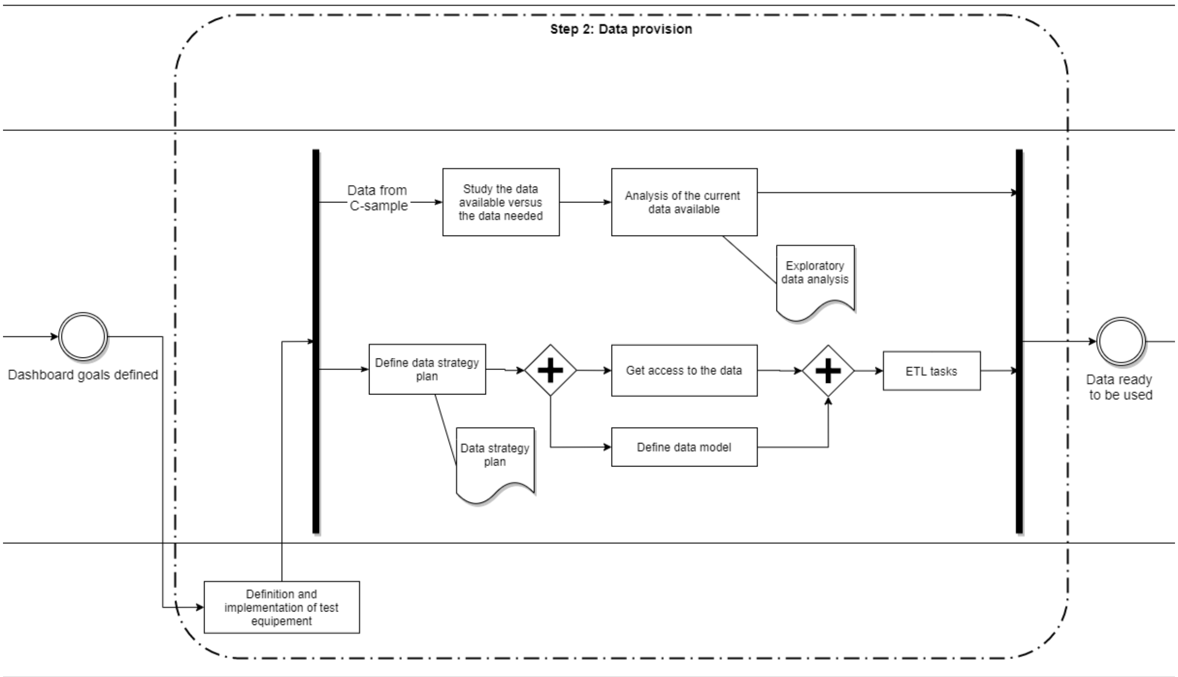


Figure 21 - Step 2: Data provision

The second step, shown in Figure 21, is about the data. After the test equipment being developed and the data starting to be stored, the dashboard's responsible has the conditions to explore the data available. In one hand, an evaluation of the data collected should be done to ensure its quality and to ensure the data is sufficient for the analyses needed. An exploratory data analysis should be conducted, giving to the dashboard's responsible more sensibility and understanding of the data. Simultaneously, the data strategy plan should be developed by defining the data access and flow from the production to the MS Power BI, or equivalent software. After having this plan defined, it has to be executed in order to get access to the data and to define its structure. After these two activities, the extract-transform-load (ETL) tasks can be performed, ending the second step with the data prepared, connected and modelled, ready to be used in the dashboard.

5.3.4.3. STEP 3: DASHBOARD DESIGN

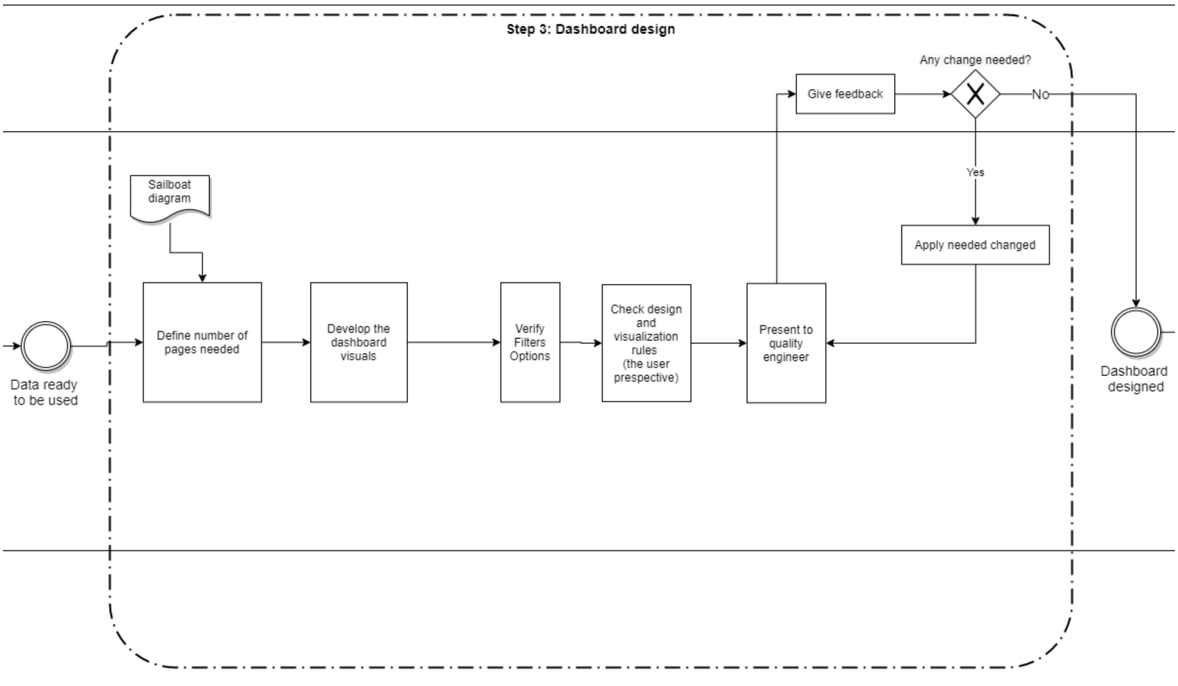


Figure 22 - Step 3: Dashboard design

From the second step, the data is prepared and ready to be used in the design of the dashboard, which is performed in the third phase, shown in Figure 22. It starts with the definition of the number of required pages, based on the needs and goals defined at the sailboat diagram during the first step. Then, each page visuals are created. This stage consists of selecting the right graphs, measures and indicators which are made with code at the MS power BI, followed by the definition of the filters for the page and their integration on it. Once a first design for the page is created, the responsible for the dashboard needs to consider the user experience and the application of design and visualization principles. The first draft is presented to the quality engineer for feedback and when all the needed feedback loops are concluded and both the quality engineer and the dashboard responsible are satisfied with the developed dashboard, the third step is concluded.

5.3.4.4. STEP 4: DEPLOYMENT

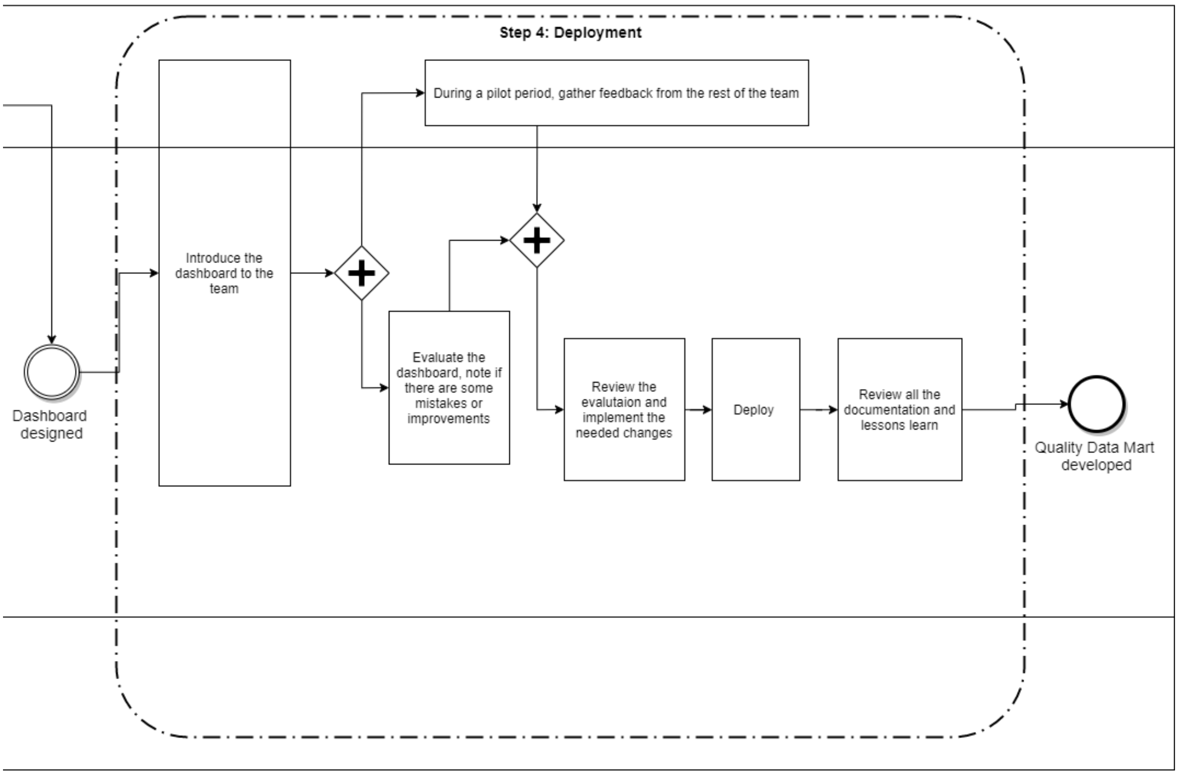


Figure 23 - Step 4: Deployment

The last step, presented in Figure 23, focus on deploying the dashboard to the team. It consists of presenting the dashboard, gather feedback and evaluate its usage and overall experience, making the necessary adjustments before publishing it. At this step, the documentation of the project should be finalized, concluding the project.

5.3.4.5. REMARKS

During the execution of the quality data marts, its main developments should be documented. Therefore it is suggested that an executive summary is elaborated along the process, where all the documents and progress are recorded.

Another point to mention is that the responsibility to develop the dashboard is not assigned to a specific person. Even though the tasks needed are defined, it is needed to within the teams decide who should take responsibility for the tasks defined.

Lastly, the process presented is based on the work developed during the internship. Due to some limitations, it was not possible to refine the process with the experience from the second case, since it was not concluded, therefore the process may not accurately represent the optimal procedure.

5.4. FINAL STATE

The work presented along this chapter 5 contributed to explore several aspects of the problem and look towards answering the emerged questions. By exploring the role of the quality engineer and the IT department to develop the quality data marts, a better understanding of the quality and IT teams working was obtained. The main outcome, besides the use cases presented in chapter 6, was the proposal of a process to build the quality data marts. To present the impact of the project's development, in Table 3 the indicators defined before were re-evaluated. In general, progress was made in all the indicators.

Table 3 - Initial vs Final vs Desired State

Indicators	Initial State	Final State	Desired State
Number of product dashboards created	2 (product A and B)	3 (product A, B and Gateway)	4 (product A, B, Gateway and EHS1+)
Access data	'fight for data'	More involvement of the IT department to develop suitable solutions for everyone	Several easier options discussed and tried
Request for data -Difficulty	Need to ask IT when something happens Reactive approach	During industrialization, the system to get the data should be discussed and built to have the data automatically available	Automated (no need to request the IT team) Proactive approach
Request for data -Time	Takes around three weeks to get the Log file of the requested S\N	Near real-time	Near real-time (daily or updated three times a day)
Request for data -Format of the data	Log file	Analysed data presented in a dashboard	Analysed and contextualized data Relevant information Visuals and graphics
Information available -Amount of data and info available	Log file of a specific S\N that is asked	Access to all the production data	Access to all production data Data is analysed
Production Monitorization	Mostly focus on output and not on quality features	Quality related information also available	Dashboards with information about the products' quality
Management of characteristics -CDQ implementation	CDQ mostly not implemented	Initiatives and efforts to implement the CDQ	Have the list of characteristics for all new products
Inspection Methods Quality tools used - The methods used to define the tests done	FMEA and CP implemented in all products at the industrialization phase and revised when needed	FMEA and CP are done to all products at the industrialization phase and revised when needed	FMEA and CP and list of characteristics created during the industrialization process
Dashboard Standards - Defined process and other support tools available	There is not a clear process	Process presented in section 5.3.4	Proposal of a process
Quality data mart concept	New idea	Clear concept, ready to present and pilot	Clear concept, ready to present and pilot

6. QUALITY DATA MART IMPLEMENTATION

As presented in the third chapter of this report, in parallel with the application of the DMAIC phases, the two cases are executed, where quality data marts are developed. Each played a role in the study of the project. The first case was used to discover the process and to understand how the quality data mart should be performed, being used as a valuable input to develop the process. The second case was used to validate the designed process and to refine and note differences in the process. Both also served as a support for the analyses and studies developed during the project.

Regarding the execution of the cases, they follow the six-phase methodology presented in subsection 3.2: business understanding, data understanding, data preparation, modelling, evaluation and deployment. In the next sections, the work developed within both cases is presented, including discussions, reflections and recommendations faced while executing them.

6.1. CASE 1: GATEWAY

In this subsection, the work developed during the case one is presented. It starts with an introduction to the product and its CTQ characteristics, then the goals of the dashboard are presented. After that, an exploratory data analysis is conducted. Later the data strategy plan and data schema are presented. The dashboard pages are described and its visualization detailed. Lastly, the lessons learned and the next steps of the case are presented. The executive summary of this case is presented in Appendix 2.

6.1.1. PRODUCT AND PROCESS

The product is named Gateway (Figure 24) and was developed with the aim “to replace the obsolete LSN (LSN = Local Security Network Classic) wireless trade good portfolio” (Bosch, 2019e).

Figure 24 – Gateway product

This product belongs to the CSI value stream as part of a fire detecting network. It will serve as a communication portal between Siemens devices and Bosch control panels as schematized in Figure 25.

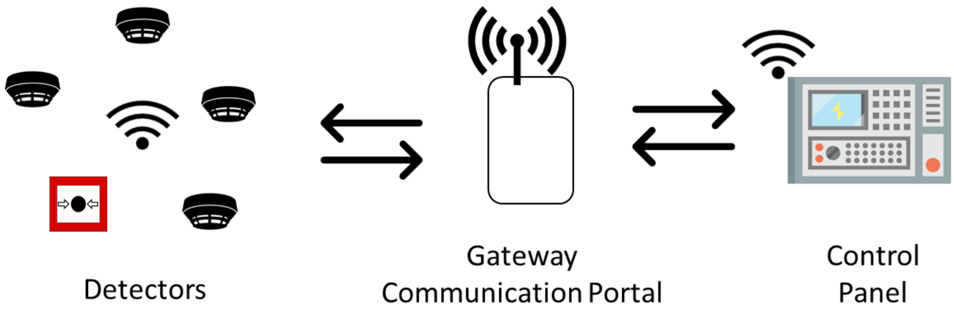


Figure 25 - Gateway communication between Bosch Fire Panel and Siemens wireless portfolio (adapted from Bosch, 2019e)

The Gateway product consists of the following main parts: the radio module developed by Siemens, the antenna, the housing, and the PCB produced at Bosch Ovar. The production process, presented in Figure 26, consists of the production of PCBA, using surface mount technology (SMT) and through-hole technology (THT) technologies, followed by the application of coating protection on the PCBA and by the milling process. At the final assembly station (FAS), the PCBA is submitted to a functional test, then the antenna's and the audio jack's pins are manually soldered to it and assembled on the housing. Then a final test is performed to the product, where several functionalities are tested including the signal of the RF module. If the product passes the test, it continues to the last FAS activity which is the packaging. There are also additional inspections, an x-ray test to evaluate the soldering quality and a customer acceptance test (CAT) (Figure 26).

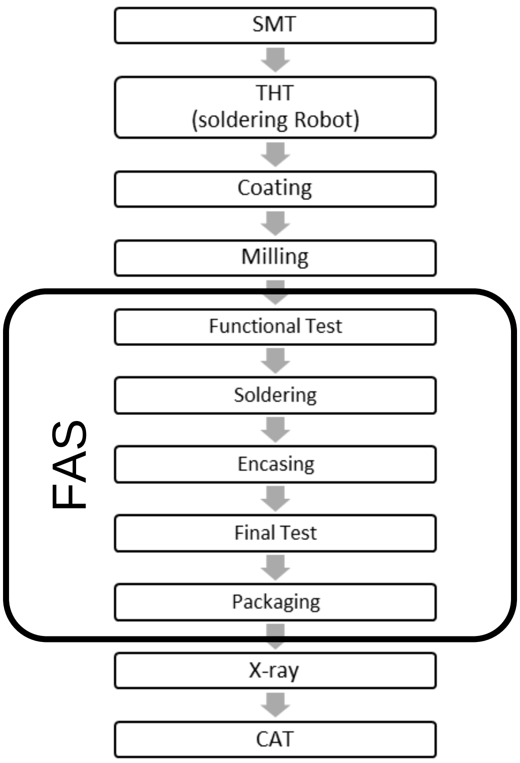


Figure 26 - Gateway production process

6.1.2. CRITICAL TO QUALITY CHARACTERISTICS IDENTIFICATION AND INSPECTION PLAN

Based on the functions of the product and the knowledge regarding the production process, the following characteristics were identified as critical to quality:

- The RF signal strength as the main function of the device
- The soldering process, which must comply with the norm IPC-1-610

At the production site, several inspection methods are applied in order to ensure the product's quality. Common to the most production processes in Ovar plant there is a functional test and a final test (EOL: end-of-line) performed on the product, followed by a CAT. Besides these tests, an inspection at the x-ray is done to evaluate the filling rate of the soldering pins.

6.1.3. GOALS FOR THE DASHBOARD

During the first kick-start meeting, the goals for the dashboard were discussed with the quality engineer. Complementing these initial meetings, some documents were analysed including FMEA and commercial requirement specification. From these analyses, another characteristic worth monitoring was identified, LED light, due to reported importance for the customer to be able to identify that the product is working. However, it was considered out of scope for this dashboard, due to its stable performance.

Besides monitoring the characteristics, the quality engineer presented the need to monitor the production pass/fail rate and the reasons for the failure by analysing the step fails of the EOL test.

The quality engineer also expressed that the use of the visualization of the data is going to be used when communicating with the client, the BU. It was then identified the need to have all the information regarding a unit, sorted by its S\N, in a single view.

It is also desirable that this dashboard supports the quality engineering on the analysis of the causes of the failures and other production-related events. Therefore it was proposed to integrate into the dashboards DoA, CAR and CAT information.

With this information, as explained in section 2.1.1, a sailboat graph was designed to map the goals, objectives and functionalities of the dashboard (see Figure 27).

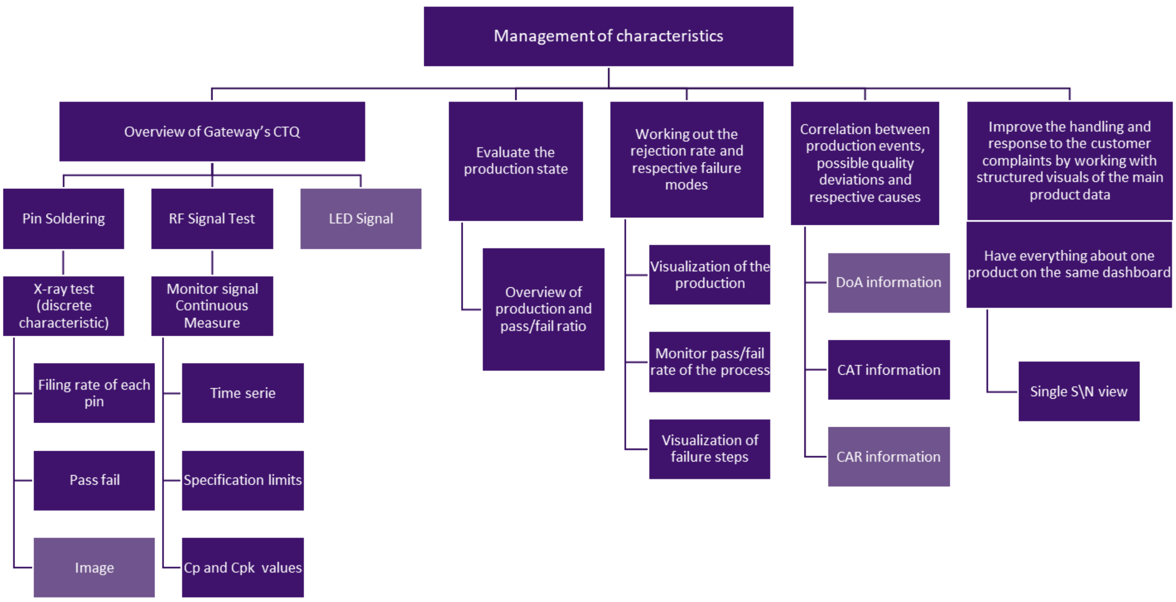


Figure 27 - Gateway dashboard sailboat graph

The strategical goals identified are: overview of the CTQ, evaluation of the production state, analysis of the rejection and failure modes, correlation with other events and having a single product view.

Then, the user goals for the team were described. These consist of information that is expected to be on the dashboard, such as the pin soldering, the RF signal and the overview of the production.

For the CTQ characteristics, the subfunctions were detailed. For the pin soldering, there was a possibility to show an image, but the collection of the images did not pay off, due to the extra effort for the inspector to take the picture and upload it.

6.1.4. EXPLORATORY DATA ANALYSIS

To understand the product's data, an exploratory data analysis was performed considering the data related to the first three months of production, which corresponds to 174 units.

The analysis starts with a quick view of the production rate, then a further analysis regarding the data from the EOL test, with pass-fail analysis and cause analysis. Later the identified CTQ characteristics are studied. First, regarding the soldering performance and lastly about the signal strength, where the warning limits to be used for the signal are determined.

6.1.4.1. PRODUCTION OUTPUT

The first step was to analyse the manufacturing rate. The output per week is presented in Figure 28, in which the weeks without production were not deployed. It can be observed the instability of the production output, that is due to the fact that the production plan depends on the forecasted demand, which can change substantially.

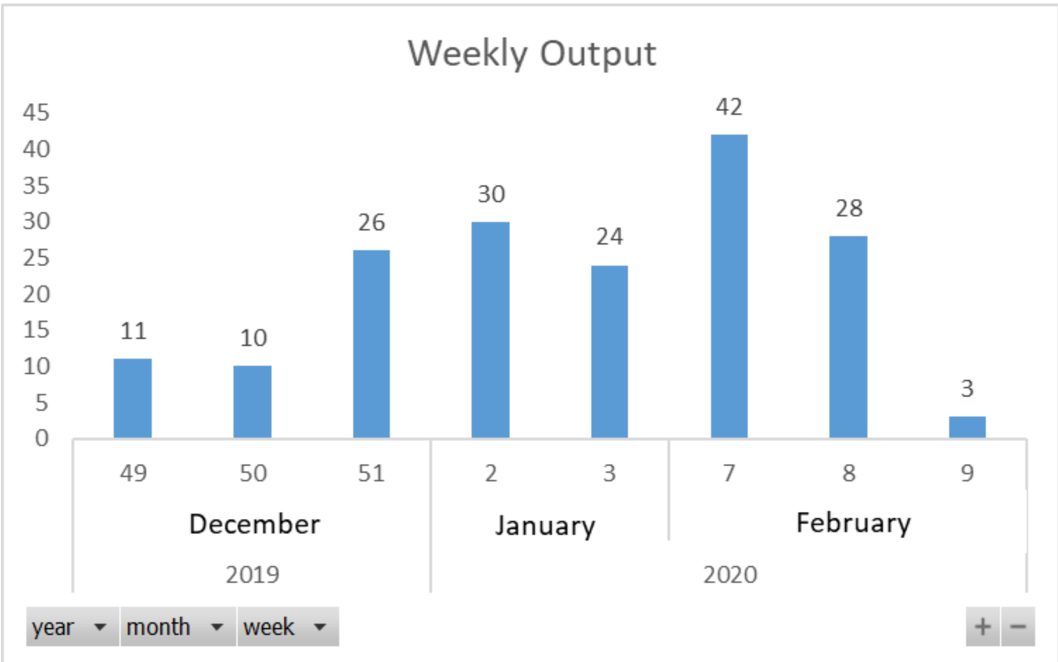


Figure 28 - Gateway's weekly output

All the products are submitted to the EOL test at the FAS and need to pass once to be considered ready to be used by the customer. Nevertheless, some problem related to test can happen or some extra reparation leads to the same product being tested more than once. Therefore, the analysis considers the units tested and the tests done.

During the first three months, as observed in Figure 29, twelve of the 174 S\N, seven per cent of the products failed at least once on the test and 20 of the 204, ten per cent of the tests that were performed failed. It can also be concluded that the twelve products failed in 20 tests and that the 174 products were tested 204.

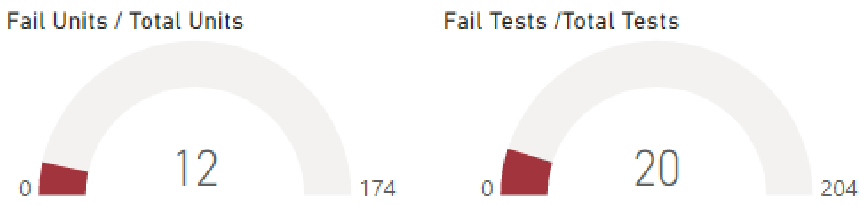


Figure 29 - Snapshot from the dashboard: EOL test performance

For each fail test, the step fail is recorded. Figure 30 presents the number of times each failure type occurred during these months. It was also analysed if there was some time pattern concerning the failures' occurrences. Though, no significant conclusions were reached. The step fails will then be continuously monitored to proactively address some deviation, but at the moment no action will be taken.

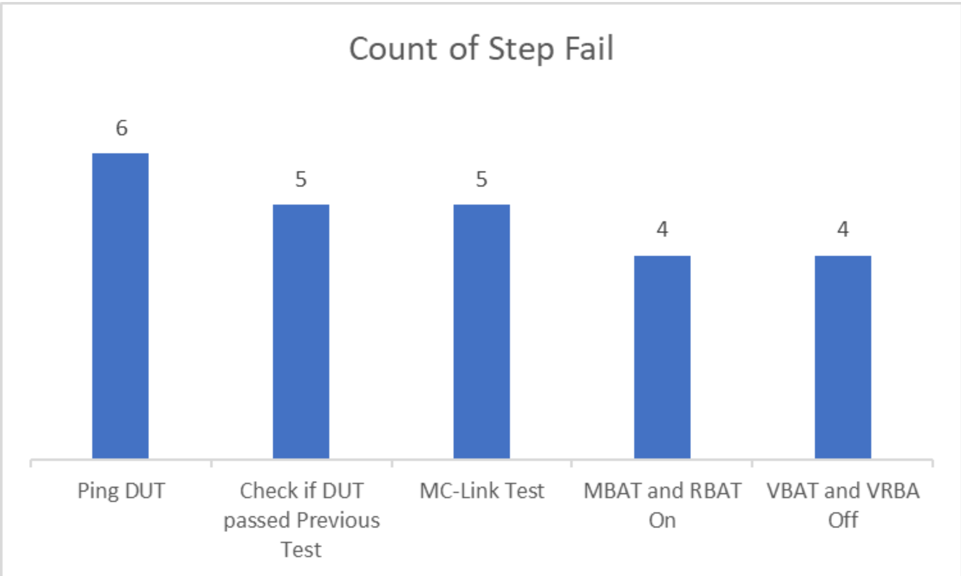


Figure 30 - Count EOL Step Fail

6.1.4.2. PIN'S FILLING RATE

The pin filling rate is a critical characteristic that must comply with safety norms. The product has five pins that are filled by a manually soldering process. It is later evaluated by a visual x-ray inspection (Figure 31).

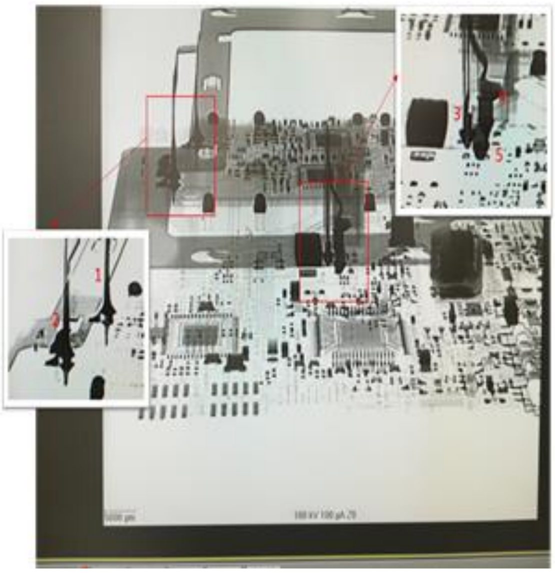


Figure 31 - X-ray Inspection: 1 And 2 pins for the antenna and 3,4 and 5 pins for the audio jack

The inspector registers the percentage of filling rate at each pin. Later each pin is categorized in four classes: A. < 75%; B. 75%- 100%; C. 100%; D. >100%.

The ideal is to have all the pins in class C. If the pin is in class A it is underfilled and there is not a connection. If the pin is in class D, the pin in overfilled and can cause a short circuit. If the pin's filling rate is in class A or D, the product needs to be rectified. If the pin is in class B is still accepted but not ideal.

The results for the production data regarding the filling rate are presented in Figure 32.

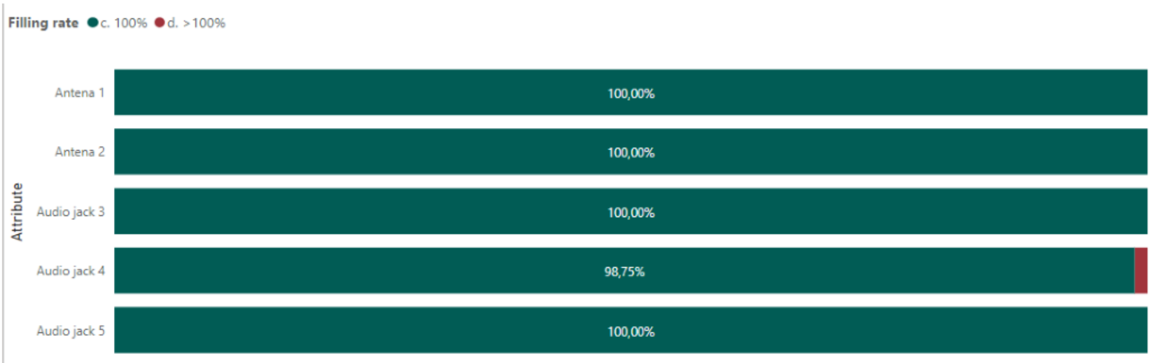


Figure 32 - Snapshot from Dashboard: Filling Rate

Only one product at pin four was classified as class D and the rest at class C. Therefore, no extra action or analysis is taken. These results are not surprising since, at the moment, it is always the same collaborator assembling this product. Due to some underfilling problems detected early in the industrialization period, there was more attention given to the soldering process. This characteristic will continue to be 100% monitored and to actions will be taken when some deviation occurs.

6.1.4.3. SIGNAL STRENGTH

The product main function is to communicate with the control panel and the fire detectors. This communication is done via radio frequency signals that are transmitted (DUT to FDUZ – from device to tester) and received (FDUZ to DUT - from tester to device) by the product. To ensure product capacity to send and receive signals, during the EOL test the signals received by each product and the tester are recorded. The specification limits for the signals levels are between -82 dB and -60 dB.

From the 204 tests recorded, 192 were apt for this analysis, since, at some fail tests, the measurement of the signal strength was not recorded. Even if the test's result is failed, the signal would be considered to this study. To analyse the signal a first generic plotting was done, together with an outlier analysis. After that, the time series of the signal and the capability was analysed. Lastly, the control limits were determined.

The plot of both signals, transmitted (DUT) and received (FDUZ), gives an overview of the behaviour of the signals (Figure 33). It should be noted that the data recorded is rounded to the unit, so it appears to be a discrete number. It can also be observed that the signal that is transmitted should be in the same range as the one that is received.

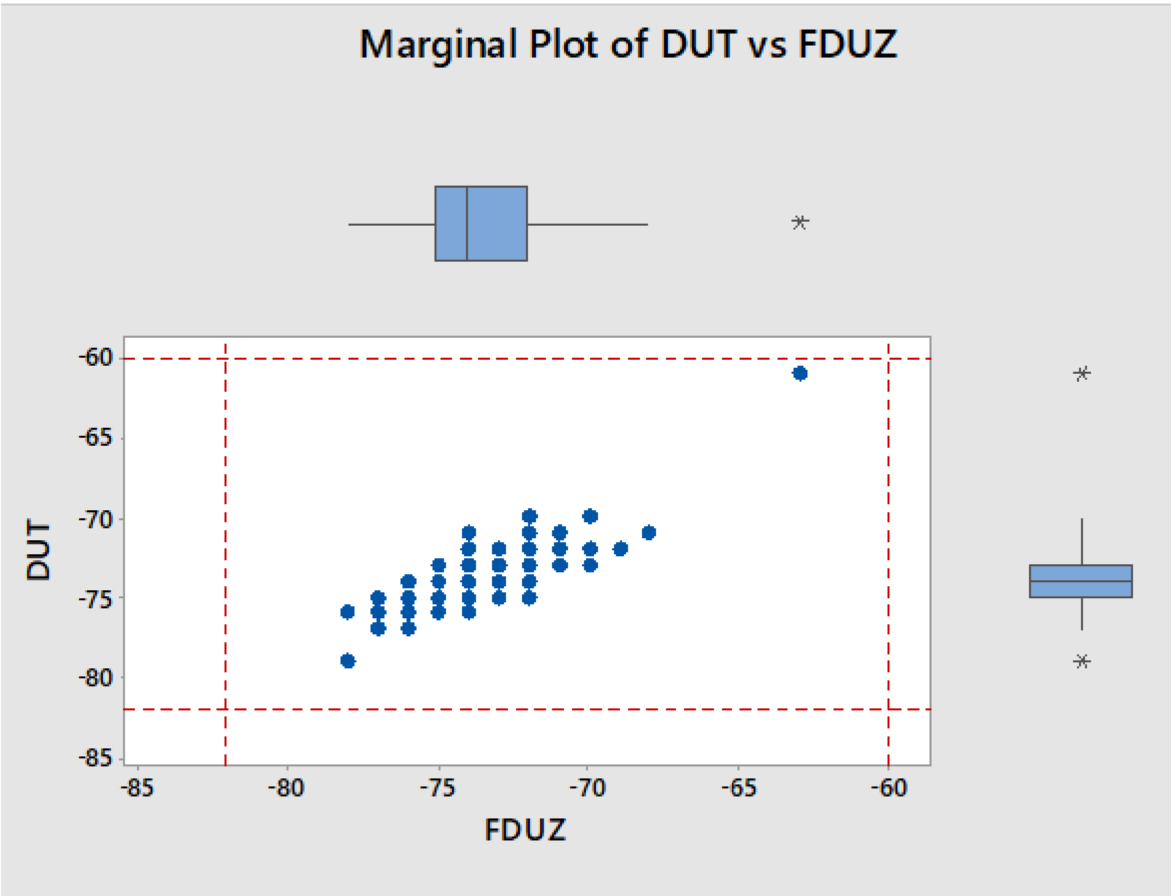


Figure 33 - Marginal plot (transmitted (DUT), received (FDUZ))

Table 4 presents the data statistics from the signals and it can be observed that the values are highly concentred between -75 dB and -73 dB for transmitted (DUT) and -75 dB and -72 dB for received (FDUZ), representing 50 per cent of the values (from Quartile 1 to Quartile 3).

Table 4 - Descriptive statistics of data from transmitted (DUT) and received (FDUZ) signal strength

	DUT	FDUZ
N	192	192
min	-79	-78
Q1	-75	-75
median	-74	-74
Q3	-73	-72
Max	-61	-63
Mean	-73.729	-73.714
StDev	1.87	1.957

Analysing Figure 33 and the individual plotting of the signals, it is possible to identify an outlier. The data regarding this unit is shown in Table 5. This unit was tested four times, the first three failed due to the same test failure mode.

Table 5 - Outlier data

Traceability ID	Data	Column3	S\N	FDUZ	DUT
049016000000641338	09/01/2020 08:10	Failed	043112003708101013	-76	-75
049016000000641338	09/01/2020 08:15	Failed	043112003708101013	-63	-61
049016000000641338	09/01/2020 08:17	Failed	043112003708101013	-78	-76
049016000000641338	09/01/2020 08:33	Passed	043112003708101013	-75	-75

Since the same S\N was tested multiple times in a row, the second test, which corresponds to the outlier identified, was removed from the data points. No other outliers were identified after removing this point. In Table 6, the updated values about the signal are presented.

Table 6 - Descriptive statistics of data without outlier from transmitted (DUT) and received (FDUZ) signal strength

	DUT	FDUZ
N	191	191
min	-79	-78
Q1	-75	-75
median	-74	-74
Q3	-73	-72
Max	-70	-68
Mean	-73.796	-73.76
StDev	1.63	1.8

The next step of the study was to analyse the behaviour of the signal over time. In addition to simply verifying the time series correspondent to the signals, control charts for individual values and moving ranges (I-MR) were implemented in order to monitor the stability of the process, corresponding to the first implementation phase of statistical process control. Figure 34 presents both charts I-MR for DUT and FDUZ signals. As in the individual value control chart each sample consist of one value, the same chart, without considering the control limits, also represents the time series of the values measured. In Figure 34, it can be seen the change of the signal strength along the time, the determined control limits of the referred charts and the identification of the out of control points.

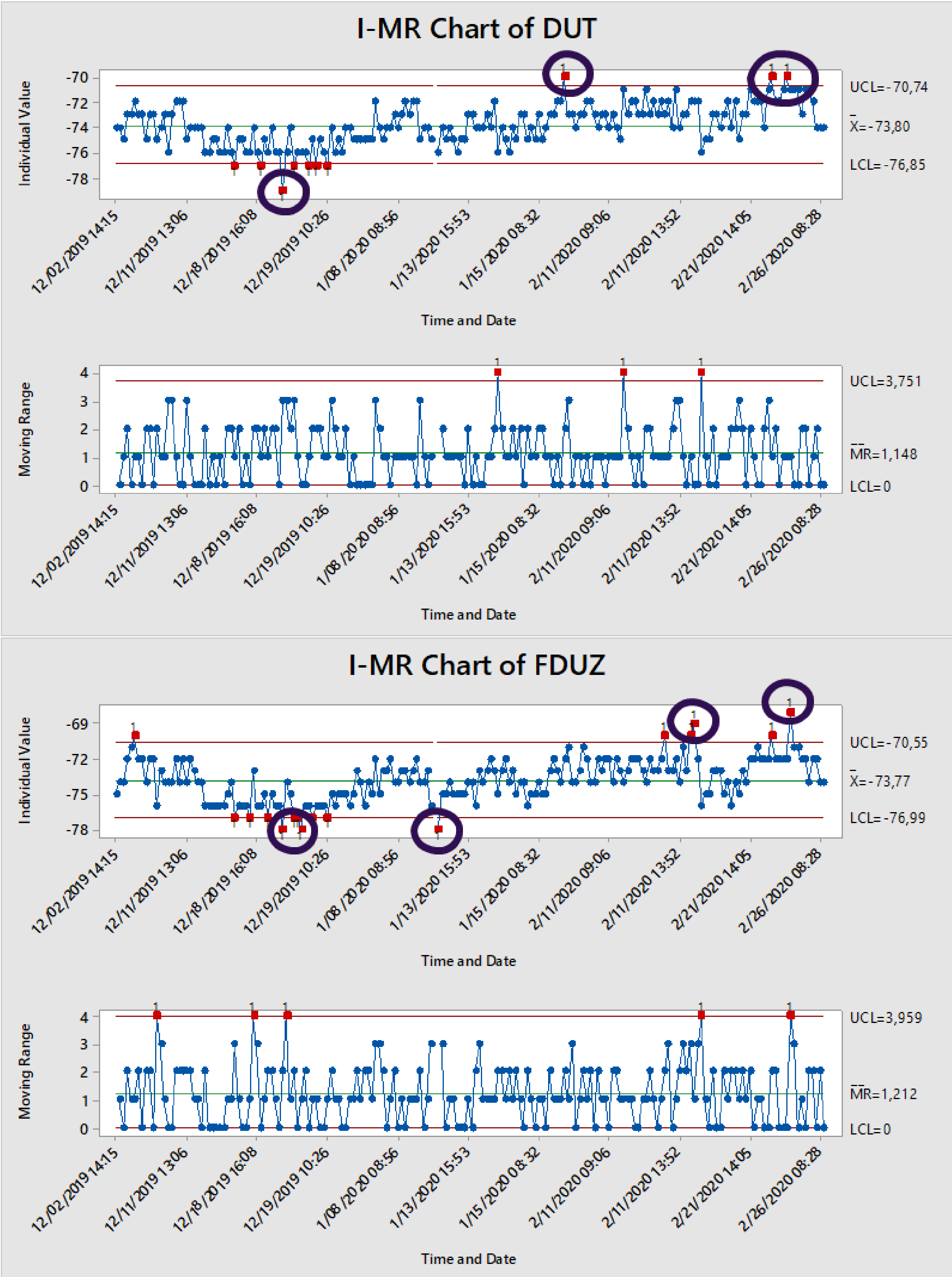


Figure 34 - I-MR control charts for transmitted (DUT) and received (FDUZ) signal strength

Due to the data discretization, the control limits were approximated to the unit, as presented in Table 7.

Table 7 - Individual values control limits

	Transmitted (DUT)	Received (FDUZ)
UCL	-70,74 =-71	-70,55 = -70
LCL	-76,85 = -77	-76,99 = -77

For both sets of signals, the moving range chart upper control limit is defined as 4, therefore no point is considered out of control. In the individual values charts, several points are identified and presented in Table 8 and Table 9.

Table 8 - DUT out of control points

DUT out of control points			
S\N	FDUZ	DUT	Date and time
049016000000638626	-78	-79	19/12/2019 08:33
049016000000655927	-72	-70	11/02/2020 07:06
049016000000655871	-70	-70	21/02/2020 14:42
049016000000655867	-72	-70	21/02/2020 15:15

Table 9 - FDUZ out of control points

FDUZ out of control points			
S\N	FDUZ	DUT	Date and time
049016000000638626	-78	-79	19/12/2019 08:33
049016000000638630	-78	-76	19/12/2019 09:12
049016000000641338	-78	-76	09/01/2020 08:17
049016000000655894	-69	-72	11/02/2020 14:22
049016000000655948	-68	-71	21/02/2020 15:25

All the units and test that correspond to these points were discussed with the quality engineer in charge of the product in order to investigate possible assignable causes, and no clear reason for the deviations was found. Since in all the cases the signals were between the specification limits, it was decided to pay attention to the future evolution of the signals, but not to take any action considering the past points.

Nevertheless, an analysis where the points out of control were removed and the control limits recalculated was done. The result was that the control limits for both transmitted (DUT) and received (FDUZ) signals to be -71 dB and -77 dB. In Figure 35, the updated I-MR charts are represented.

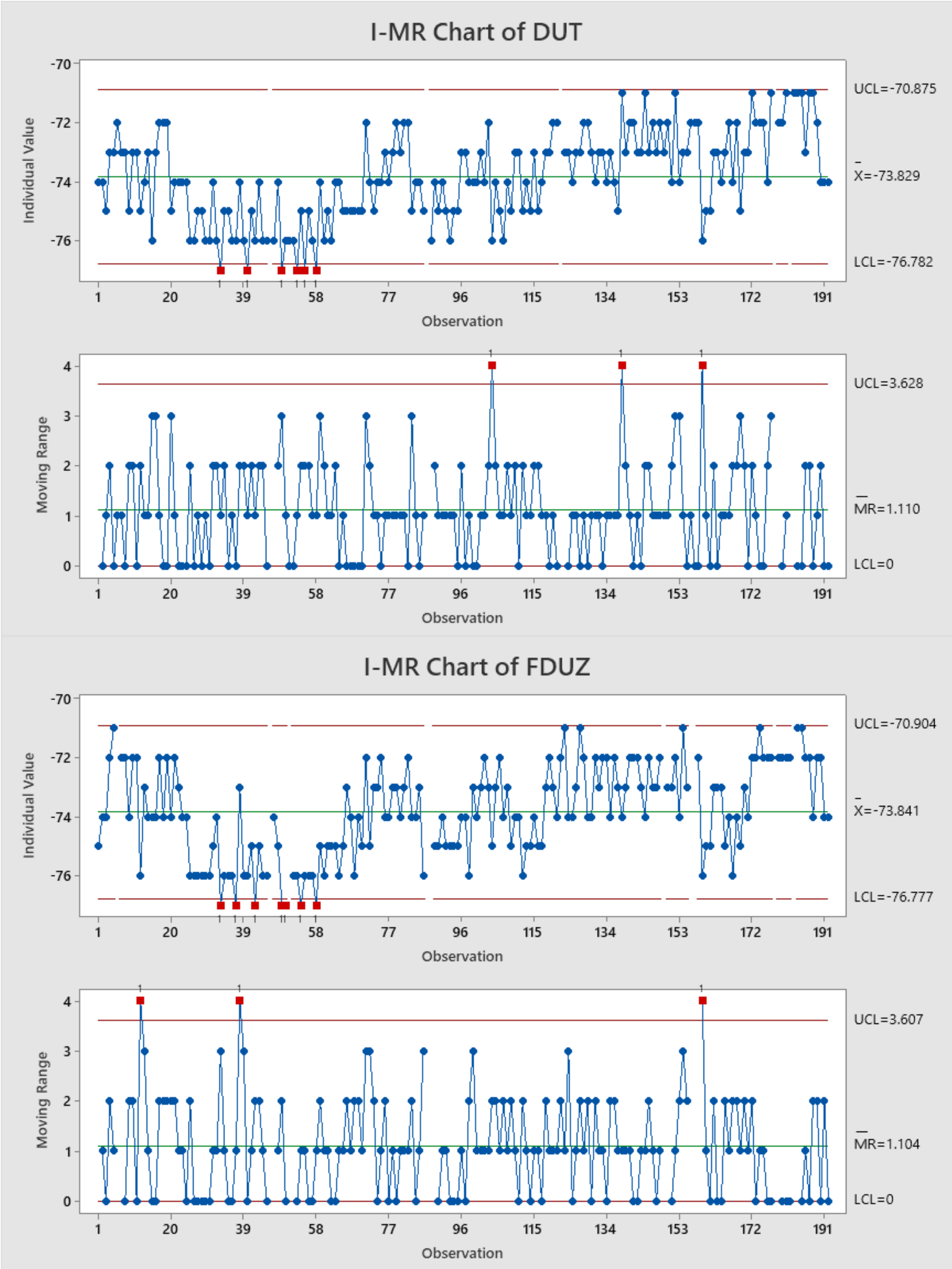


Figure 35 - I-MR control charts without points out of control for transmitted (DUT) and received (FDUZ) signal strength

After analysing the stability of the process over time, a capability analysis was done. First, tests to evaluate the normality were performed. It can be concluded that the distribution of both transmitted (DUT) and received (FDUZ) signal strengths can be considered approximately normal, so the indices C_p and C_{pk} can be used to measure the capability of the process.

By observing Figure 36, it can be concluded that the processes are capable to perform between the specification limits, showing high capability indexes ($C_p > 2$ and $C_{pk} > 1,5$).

From the C_p values being higher than two, it can be concluded that the specification limits ranges are twice larger than the process ranges, which gives confidence regarding the dispersion of the values. The C_{pk} values indicate a small deviation from the centre of the process at the -71 dB. It is visible on the graphs some tendency to have signals centred between -73 dB and -74 dB. Overall it can be concluded that the process as a high capability.

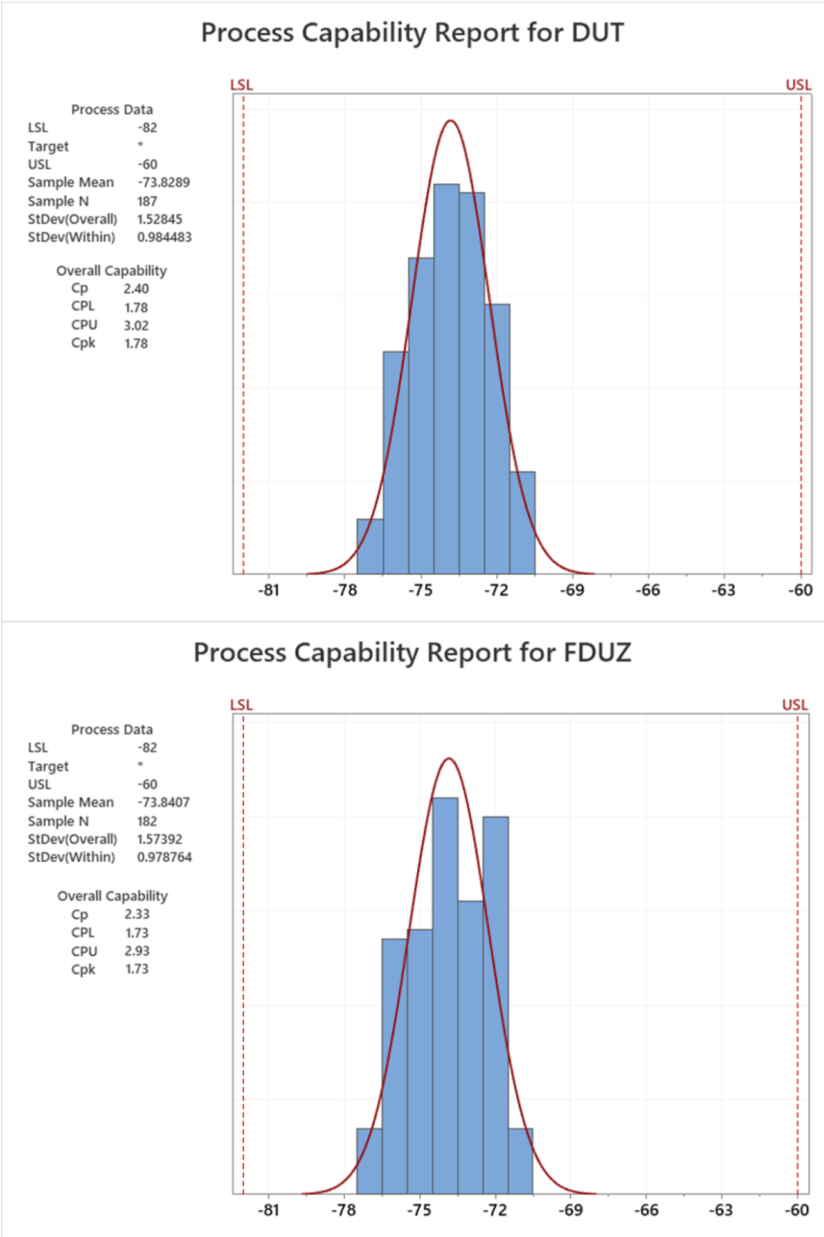


Figure 36 - Capability Analysis transmitted (DUT) and received (FDUZ) signals

This exploratory data analysis allowed the team to have a better knowledge about the process Simultaneously, this activity provides the data analyst with more sensibility and context about the data that he/she is working with.

6.1.5. DATA STRATEGY PLAN

Based on the goals and the different tests done to the product the data needed was collected from the following sources: the EOL test, that provides the result pass-fail of the production and the RF signals strength, the x-ray inspection, and the CAT inspection. For all the sources the quality of the data was analysed. As also presented in subsection 5.2.3, the main concerned would be with the x-ray and CAT inspection since both are performed by a collaborator. It was ensured that it is clear how the inspection and the collection of the data need to be performed.

In Figure 37, the data strategy is presented. It can be observed the data flow from the inspection method to the MS Power BI file. To access the production database an executable file was created by the test engineer to extract the needed data to CSV files stored in a folders network. For the x-ray and CAT inspection, the data is stored in excel files that are easily accessed because they are stored in the network folders.

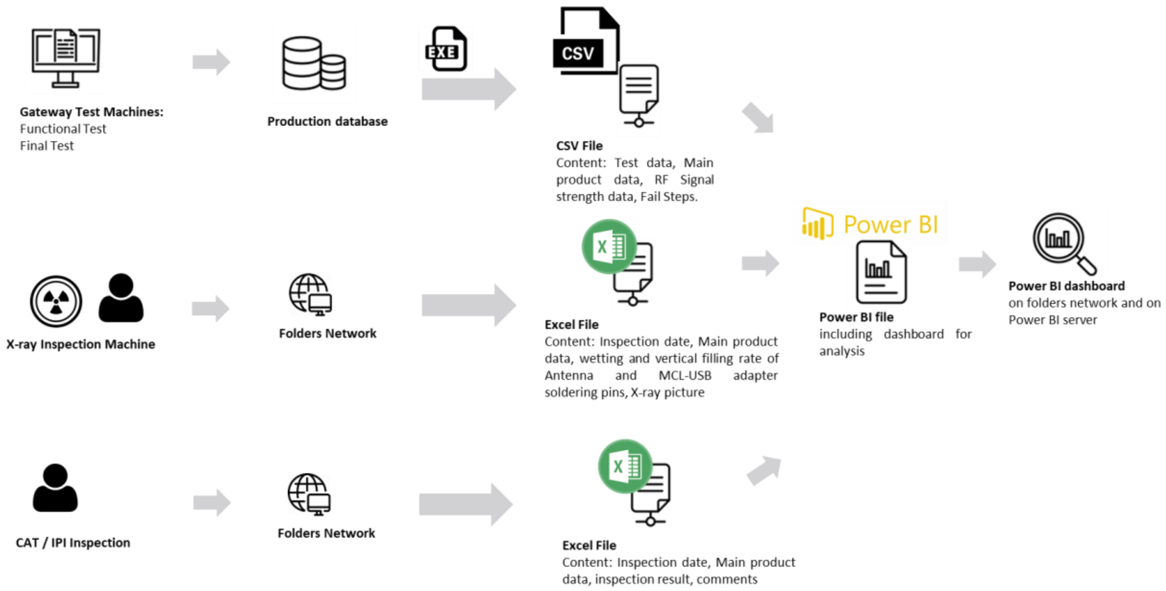


Figure 37 - Gateway Data Strategy Plan

6.1.6. DATA SCHEMA

The data schema is defined by applying multidimensional data modelling. MS Power BI has a feature that allows defining the data structure of the dashboard. In Figure 38 the data schema is presented.

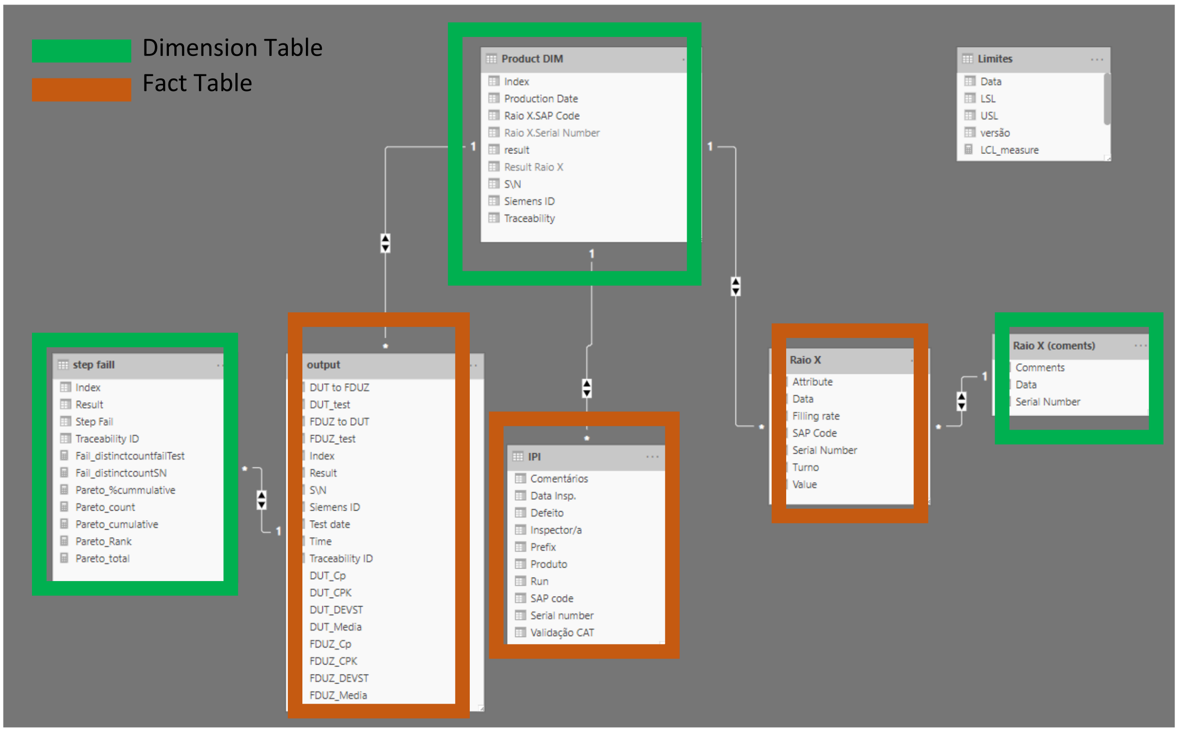


Figure 38 - Gateway Data Schema

The analysis focuses on three main activities, the EOL test, the x-ray inspection and the CAT inspection. Each has a separate data source as presented in the data strategy plan. From the three main activities, three fact tables were defined, named ‘output’ for the EOL test, ‘IPI’ for the CAT inspection and ‘raio X’ for the x-ray inspection. A common dimension to all of them is the product. For each unit, all the ID numbers and production date are stored in the dimension table named ‘product dim’. This table is created with the data from different data sources. From the EOL test data set, the serial number, the traceability ID and the siemens ID are obtained. The production date corresponds to the first test date for each S\N. The SAP code is obtained from the x-ray data source. The ‘product dim’ table has a one to many relations with the fact tables since any unit can be tested more than once.

The ‘output’ table contains the result (pass/fail), the values of the signals received and transmitted and the time the EOL test occurs. It was decided to not create the dimension time, because the MS Power BI already provide another mechanism associated with the time dimension, facilitating its analysis. Another dimension related to the EOL test is the step fails, which has a many to one relation with the output table since one test can have more than one failure mode. It was also observed at the x-ray data source that some comments were collected, therefore a dimension for this event was created.

An extra table was created to store the control and specific limits.

6.1.7. DATA VISUALIZATIONS

Based on Figure 27 - Gateway dashboard sailboat graph and with the data needed prepared, five pages were created to display the information about the product: Overview, X-ray: Soldering performance, RF Signal Performance, Final Test Failure Analysis, Single Unit Overview.

In subsections 6.1.7.1 to 6.1.7.5, the elements of each dashboard page will be explored.

6.1.7.1. OVERVIEW

The first dashboard page presented in Figure 39 aims to provide a quick view of all the aspects related to the product. Any user can find the production process on the left and can get more information about the product. It is possible to see the production during a certain period, by adjusting the time filter on the top left. This filter will be presented on all pages. The performance of the production can be seen by the EOL test bar. Extra and more detailed information about CAR, DoA and CAT it is displayed at the bottom of the page. Because this dashboard corresponds to the beginning of the production, there is not any data regarding CAR and DoA, therefore it was decided to include it later in the dashboard. With the data schema defined, it would be easy to add more fact tables with this information and link it with the product dimension table.

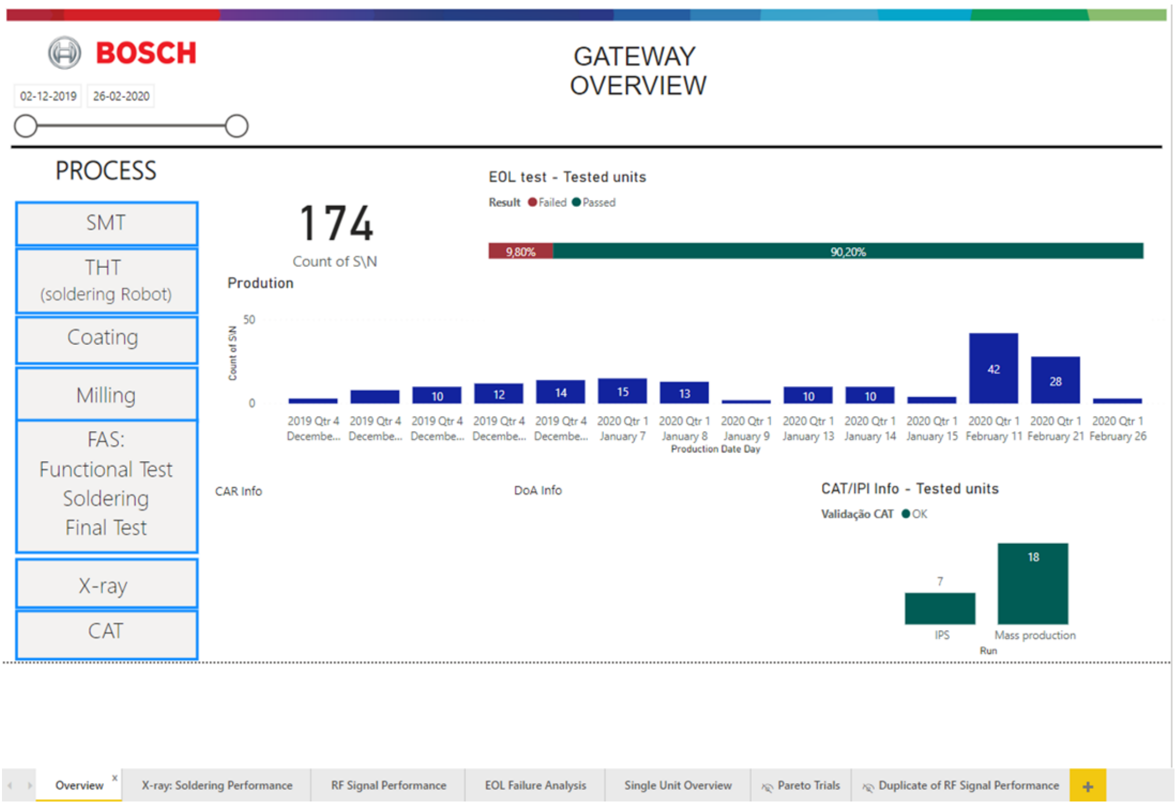


Figure 39 - Dashboard Gateway Overview

6.1.7.2. X-RAY: SOLDERING PERFORMANCE

During x-ray inspection, five pins are evaluated, as presented in Figure 31. This page aims to evaluate the soldering performance (see Figure 40). The result per pin can be seen on the left. At the top, the results per unit are displayed by production date. A product would be considered not good if any of its pins are at a class a or d. At the bottom, a detailed view of all the products inspection can be found. The bar and colour can quickly indicate if there is some deviation regarding the filling rate.

The dashboard allows interaction between the graphs, by selecting one of the dates the graph in the bottom and left will only show the information about the products that were produced on that specific date. On the top right is also possible to search for a specific serial number (S\N).

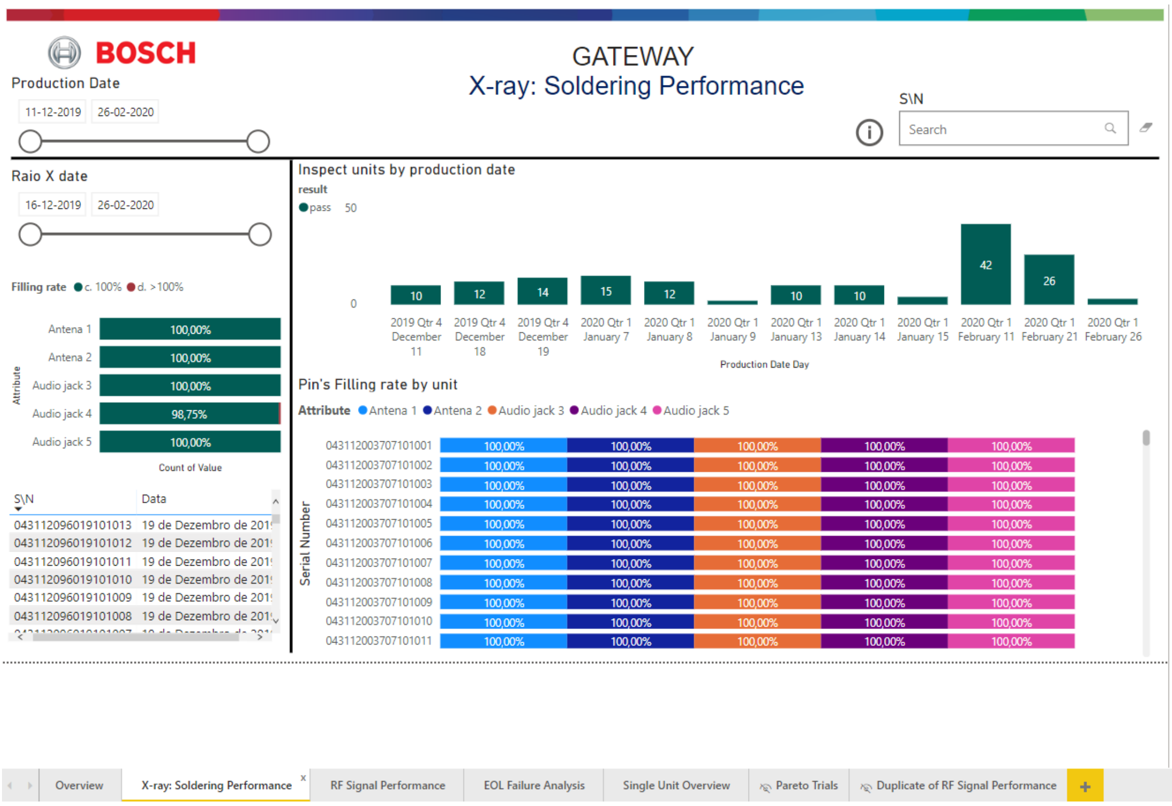


Figure 40 - Dashboard Gateway X-ray: Soldering Performance

6.1.7.3. RF SIGNAL PERFORMANCE

The aim of RF signal performance analysis page presented in Figure 41 is to monitor the signal. For that, the process capability, C_p and C_{pk}, and a categorization of the points as (i)under control, (ii) out of control and under specification and (iii) out of specification will serve as indicators and are presented on the top. This bar can also be used as a filter and easily identify the points out of control or out of specification.

On the bottom, the time series of the signals are displayed. The normal setting is to present the signal average of the production of the day with the black line, that can be compared with the reference line, that now is set to be the mean of all points. With the grey bars, the standard deviation for the day is presented. These two representations give the user information regarding the location and dispersion of the values. It is possible to analyze the data by visualizing each point individually with the drill-down option on the graph. It is also possible to know which product a specific point belongs to, by clicking on it and verifying its S\N on the top left of the screen.

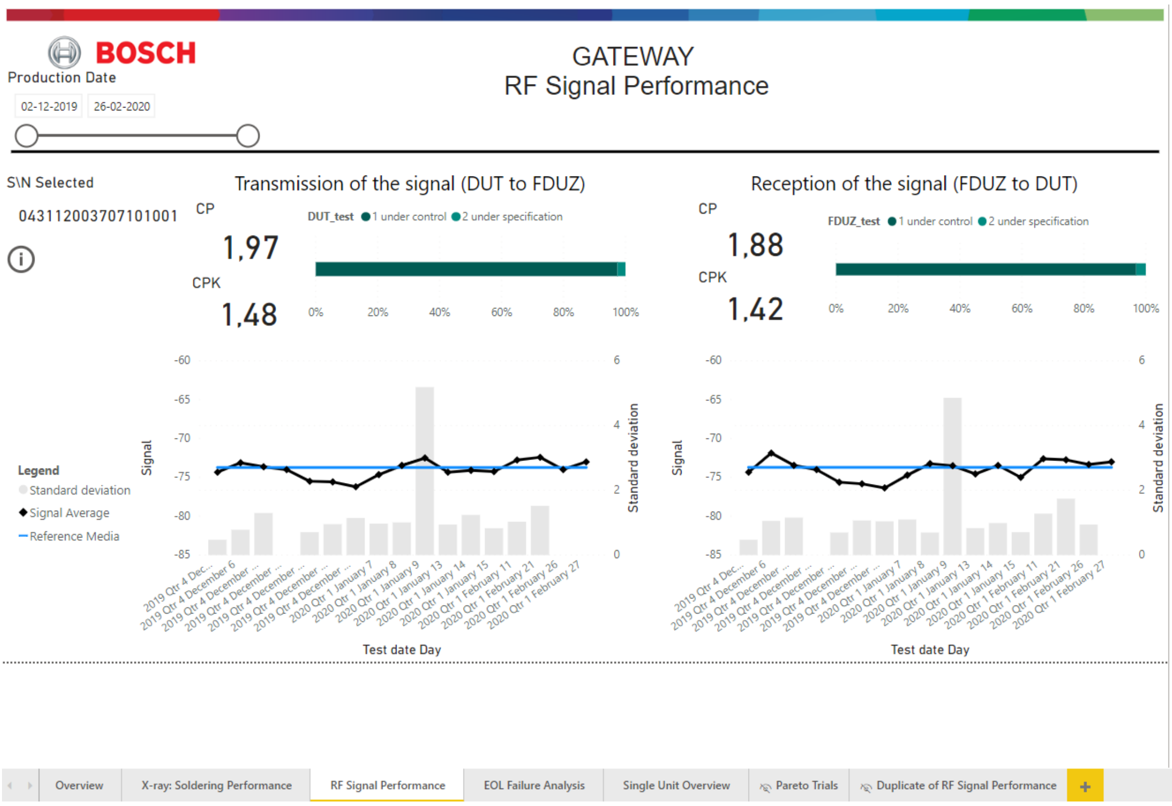


Figure 41 - Dashboard Gateway RF Signal Performance

6.1.7.4. FINAL TEST FAILURE ANALYSIS

Figure 42 presents the dashboard page with the final test failure analysis. On the top left, two gauge graphs show the number of failures per total units and per total tests. On the top right, the time distribution of the failed tests is shown, allowing also to select a specific day. On the bottom left, the counting of the various failure modes is presented. On the bottom right, detailed information about the tests can be found. It is also possible to search for a specific S\N.

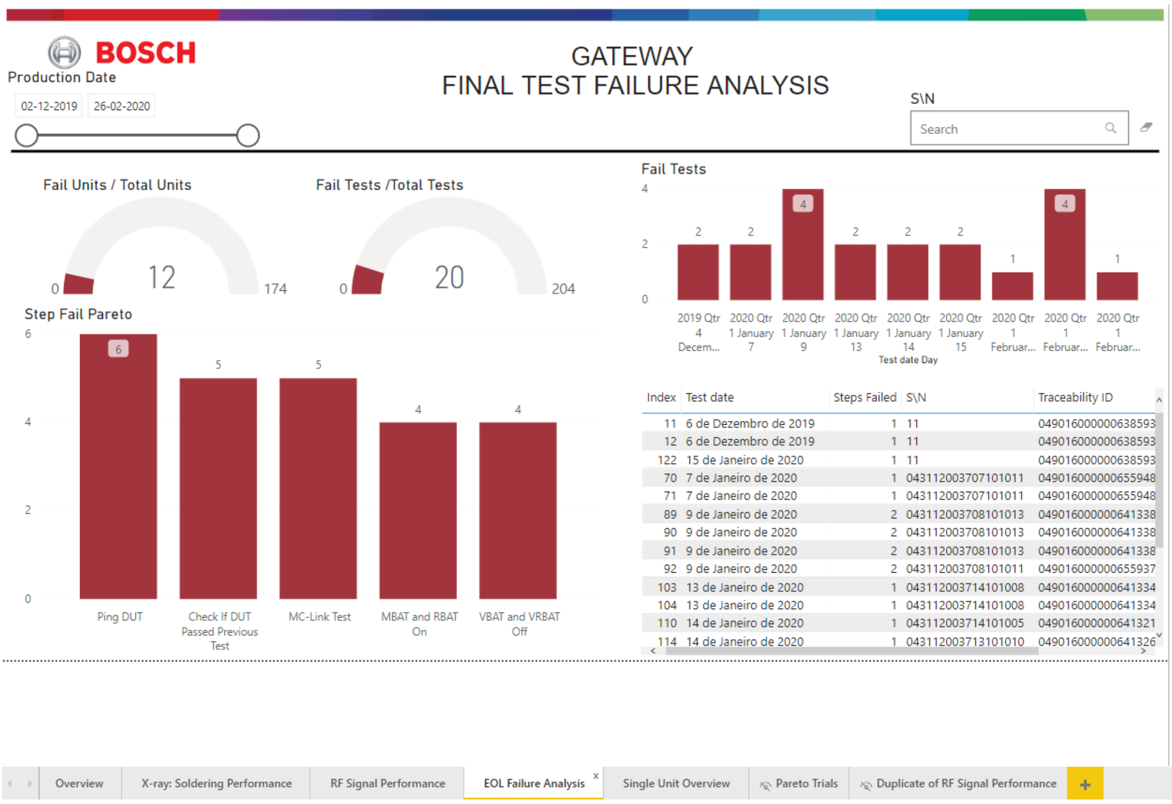


Figure 42 - Dashboard Gateway Final Test Failure Analysis

6.1.7.5. SINGLE UNIT OVERVIEW

On the last page, represented in Figure 43, the information regarding one unit is presented. On the top left, the user can introduce the S\N code, not all the numbers need to be there, because below on the table all the possible units are shown as well as their production date. It is then possible to select a specific product. On the top right, a time filter can support the identification of the S\N desired. On the middle top, all the EOL tests and the signal data values are presented and below the failure steps that occurred are also shown. By selecting a specific test, the step failures graph filters EOL test results and vice versa. On the left, the information regarding the x-ray inspection and the CAT inspection is presented.

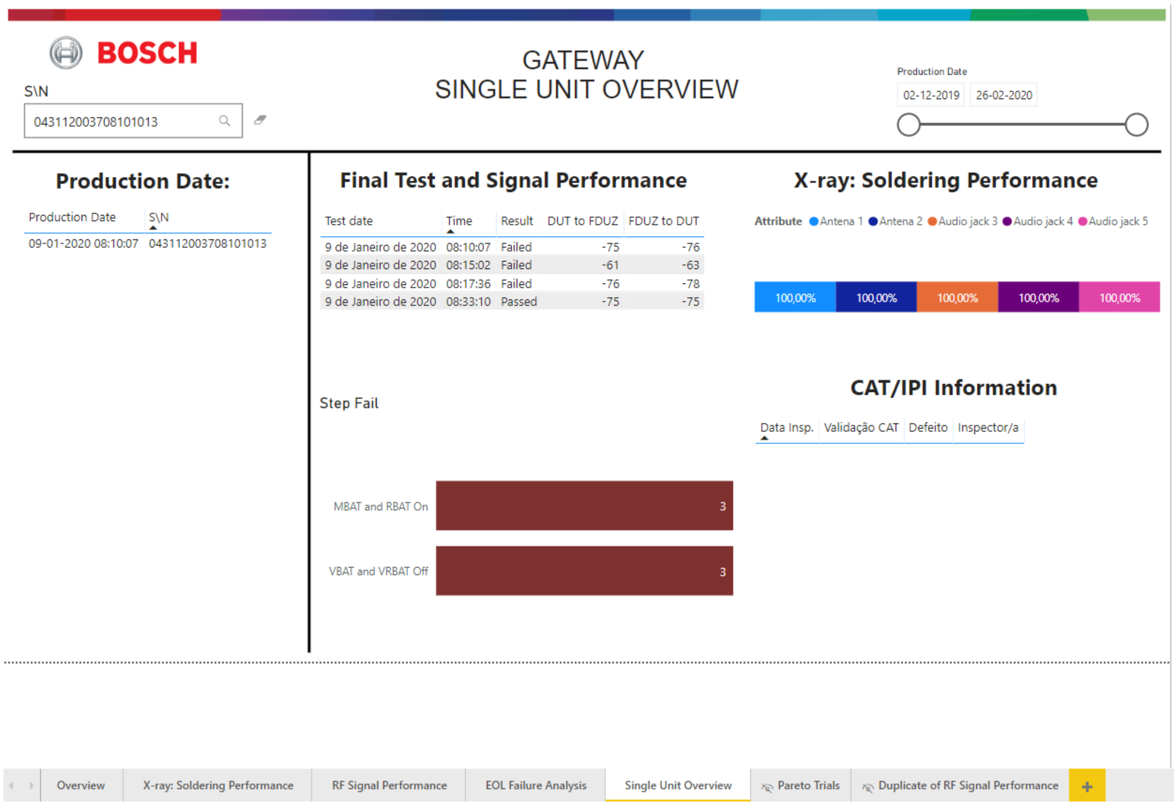


Figure 43 - Dashboard Gateway Single Unit Overview

6.1.7.6. REMARKS ABOUT THE DATA VISUALIZATION

During the process of creating the visualizations, the principles presented in section 2.1.1 - know the context, choose the right chart, think like a designer, design dashboards not reports - were kept in mind and will be discussed in this section.

Regarding the ‘know the context’ principle, one of the difficulties was to imagine the role of the quality engineer and the other users in order to predict how the dashboard would be used. It was also complicated to ask them how do they intend to use it since having these dashboards and analyses, that are built to specifically fulfil their needs are not usual. The challenge when building the dashboard that should be used by others was not being entirely familiar with their work.

In general, selecting the right graph to use in each situation is easy when there is a good understanding of the data and the purpose and use for it. In this case, the time-series graph for the RF signal (see Figure 41) was the more challenging one, because there is a lot of information that could be displayed on that graph, such as control and specification limits, and different ways to represent it. In the end, it is the user, in this case the quality engineer, that should decide which approach is best suited for his/her work. And the aim is to keep it as simple and intuitive as possible.

To ensure a good user experience it is important to create the dashboard with some design consistency and rules. An important configuration of all pages is to follow the normal reading pattern from top to bottom and from left to right. Therefore, many of the filters are at the left and top of the dashboard. Another point to consider is the main reason the user goes to a certain page and highlight that information in a way that there is the first information they found.

The dashboard is made to be explored. The user should, from the macro perspective, filter and chunk down its analyses. This gives more flexibility and empowerment to the user to make his/her own analyses and conclusions. For example, at the x-ray soldering performance page (see Figure 40), it is possible to analyse the soldering performance in the production daily and by pin. If the user wants to know more about a specific situation, he/she can filter the data and analyse only the units under that situation. It is also possible to know more about a specific unit at the single unit overview page.

The aim of the dashboard is not to give a direction, but to support the decision-making process of their users.

6.1.8. LESSONS LEARNED AND NEXT STEPS

In this section, reflections about the creation of the dashboard for the gateway product are presented as well suggested next steps.

This case was the first case of this project. It was used as a playground to test the possibilities of building the dashboard and to learn about the software. It was also a base to define the work presented in section 5.3.4: Outcome: Quality Data Mart Process.

One of the first approaches was to explore the MS power BI by trying different graphs. This led to some bold drafts to be made, such as display of images and the integration of data from CAR, DoA and CAT. For the quality engineer, it was refreshing to have someone only focusing on the development of the dashboard and the visualization of the information in the best way, instead of building a quick fix on the side to display some data.

By trying different visualizations without preparing the data, some mistakes at the data modelling level were made. This experience highlighted the importance of, what may look like the “backstage” of the dashboard, the preparation and study of the data. And how the mistakes at that level can later on the development of the quality data mart bring problems.

Regarding the data access, the quality engineer and the test engineer had most of the arrangement planned before the beginning of the project. In one way, facilitated the earlier access to the data, but when it was suggested to include the data from the functional test, what would request the creation of another executable file, difficulties were presented. These barriers were mostly related to IT resources and the low priority for this project.

Another challenge was to manage the data and the analysis without being its direct user. In the beginning, graphs and analyses were made without having the context to evaluate its meaning. The quality engineer had a crucial role to fill the knowledge gap about the product. Only after the Exploratory Data Analysis (subsection 6.1.4) that the information presented by the data started to be more trivial, however, it was not expected to not have an explanation for the out of control situations, and the lack of action from the quality engineer to explore further.

As next steps, first it is to present the dashboard to the team and start a pilot period and evaluation of its usages. After concluding this evaluation and implementing some adjustments, the dashboard should be published on the Bosch server. Lastly is important to keep evaluating and to consider upgrade the dashboard, by adding other features such as more information regarding DoA and CAR.

6.2. CASE 2: EHS1+

The second case was developed later into the project with the aim to support the validation of the quality data mart process. The product selected was more complex than the one from the first case and from a different value stream, which allowed to gather different perspectives and to face other challenges.

The worked develop during this case is presented in the following subsections and Appendix 3 contains the executive summary of the case.

6.2.1. PRODUCT AND PROCESS

EHS1+ (Figure 44) is an electro-hydraulic valve and it is a component of a valve with the functional aim to create a closed-loop control of valve spool position. It is an automotive valve that, by electro-hydraulic actions activate a specific position that leads to a set of activities on the vehicle. This new product belongs to the contract manufacture value stream.

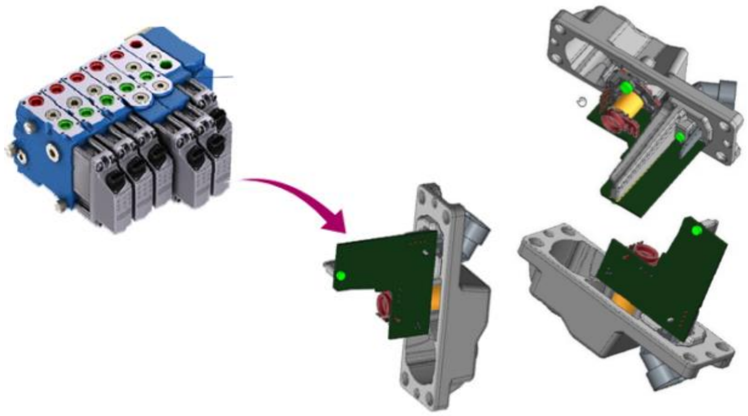


Figure 44 - EHS1+ product

The single valve is a complex product on itself and consists of several parts that are represented in Figure 45.

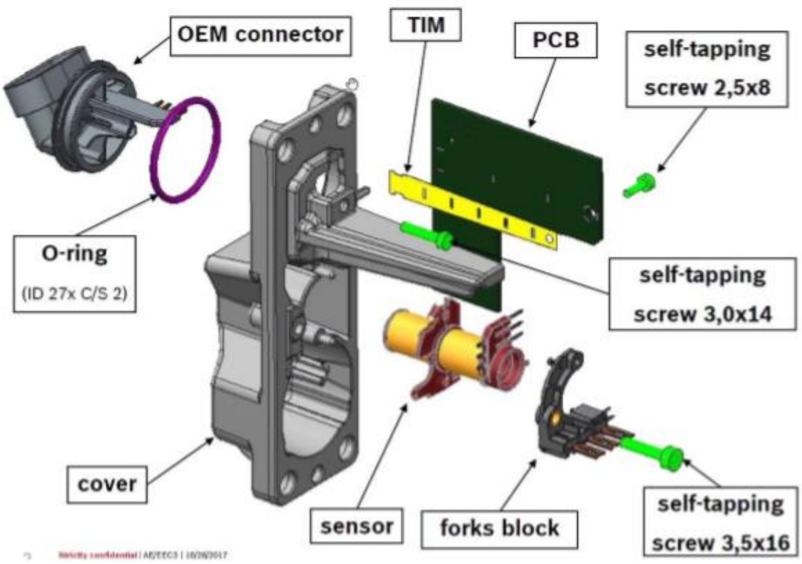


Figure 45 - EHS1+ components

The production process is represented in Figure 46. It starts at the supplier level (blue boxes) where most components are bought, except for the PCBAs that are produce at Ovar factory. To make the PCBAs, first, the multi-board is marked, then, at the SMT line, the components are soldered on both sides and inspected using an automated optical inspection (AOI).

The final assembly station (FAS) is divided into five working stations (WS) (green boxes). On the WS0 the multi-board is separated and submitted to a functional test. At WS1, the original equipment manufacturer (OEM) connector and the O-ring are pre-assembled together and then assemble into the cover. The force done when pressing the OEM connector and the O-ring into the cover is important to ensure that no liquid or oil can be transfer from the inside of the cover to the outside. After that, the sensor and the forks block are preassembled and two screws are applied into the cover (screw 3,0x14 and 3,5x16).

At the WS2, a personalised machine dedicated to mix and apply the thermal interface material (TIM) can be found. This material needs to have a specific consistency and to be applied in the right place at the cover. After dispending the TIM, the PCBA is assembled on top of the TIM and another screw is applied (screw 2,5x8).

Next, at WS3, the soldering of ten pins for three components takes place. There is a soldering robot dedicated for this line. On the last WS, there is an end of line (EOL) test and the packaging of the EHS1+. External to the FAS, an x-ray inspection is done to ensure the soldering performance and a CAT inspection is done.

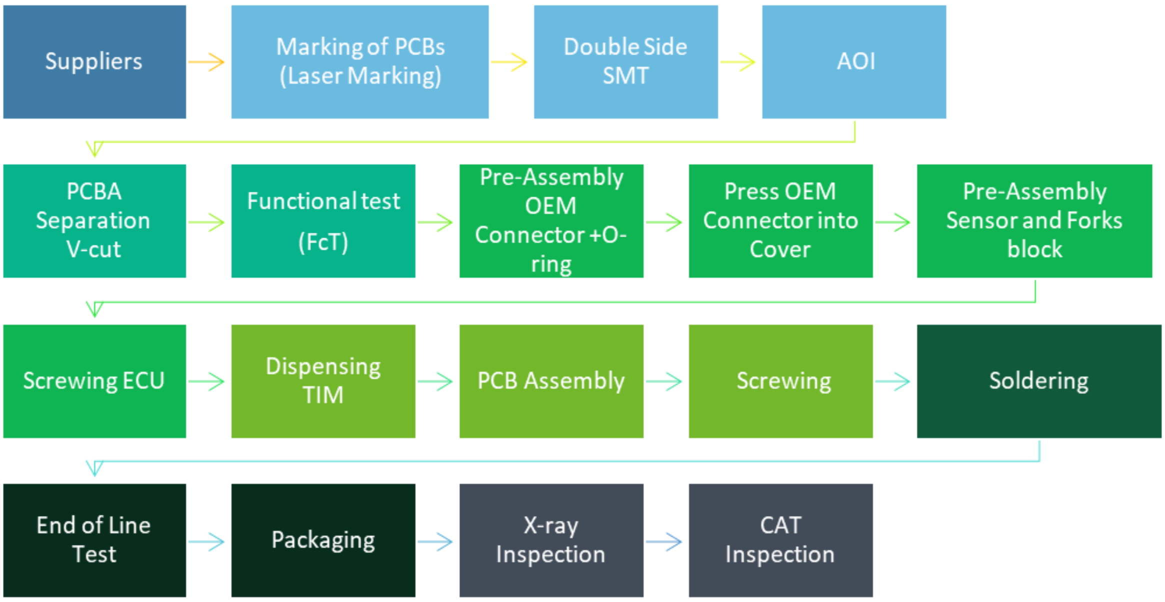


Figure 46 - EHS1+ production process

6.2.2. CRITICAL TO QUALITY CHARACTERISTICS IDENTIFICATION AND INSPECTION PLAN

Being an automotive component there are some rules and standards that this product needs to follow. After discussion with the team and analysing its process the following characteristics were identified as critical to quality:

- **Soldering requirements:** solder joints must comply with IPC-A-610 class 3 requirements (100% hole filling with menisci on both sides, free of defects).
- **Thermal interface material (TIM) dispensing:** this material is responsible for the heat dissipation from PCBA to the cover, and crucial for the functionality of the product. It is required to dispense homogeneously the defined TIM quantity on cover's "finger“.
- **Original Equipment Manufacturer (OEM) connector and O-ring:** these two components need to be assembled correctly in order to isolate the valve from liquids and oils.
- **Screwing**: the process of screwing is fundamental for the product to guarantee its robustness since the product is exposed to vibration during its normal use.
- **Purchased material**: some of the characteristics that are critical for the functionality of the product are monitored and ensured by the supplier.

To ensure the quality of the product, several inspections need to be performed at different stages. Figure 47 schematizes the control plan, with the definition of inspections done at each stage.

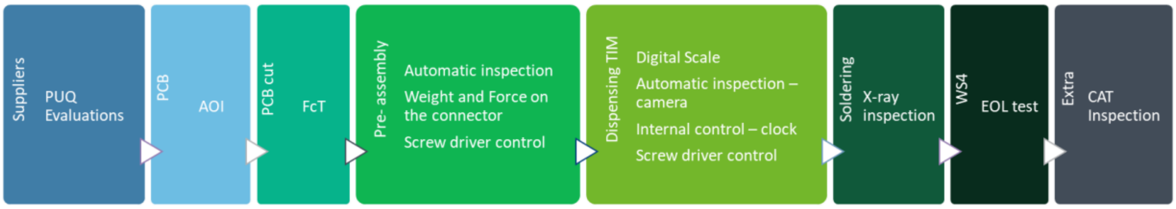


Figure 47 - EHS1+ control plan

At least one inspection is done at each production step. At the supplier level, there are a set of evaluations done to the purchased material performed by the PUQ team. The normal set inspections are done, to the PCB with the AOI inspection, the functional test (FcT), the EOL test and CAT inspection. At the WS1, there is an automatic inspection for the assembly and the weight and force done to the connector is controlled to ensure the correct assembly. The screwdriver control is done at WS1 and WS2, by controlling the torque and angle. Regarding the dispensation of the TIM, there is a digital scale and internal clock that calculate the dispending rate (grams per minute). There is also a camera that automatically inspects the position of the TIM into the cover’s "finger“. To inspect the soldering, the units are submitted to x-ray inspection.

6.2.3. GOALS FOR THE DASHBOARD

From the Gateway case, it was previously assessed that the quality data mart should serve five main goals. After some discussion about this case, the following areas were identified: (i) to allow the team to have an overview of the CTQ characteristics, (ii) to evaluate the production state, (iii) to know the rejection state and the failure modes, (iv) to allow evaluating some association between events and (v) to support the communication with the customer (Figure 48).

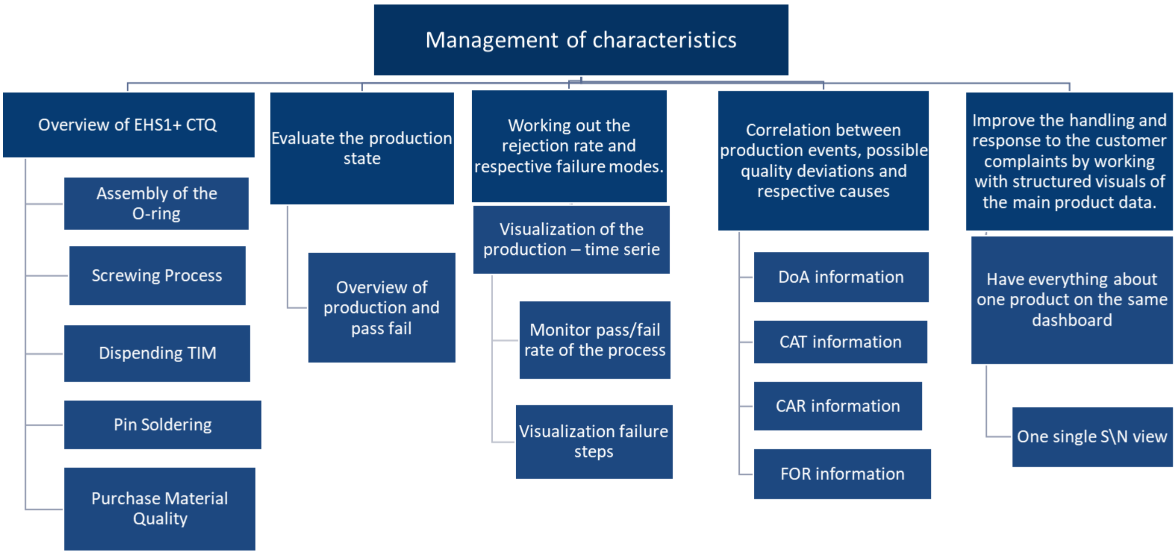


Figure 48 - EHS1+ Dashboard sailboat graph

With the complexity of the product and the larger amount of CTQ characteristics, the branch diagram of the overview of EHS1+ CTQ Characteristics was built separately (Figure 49).

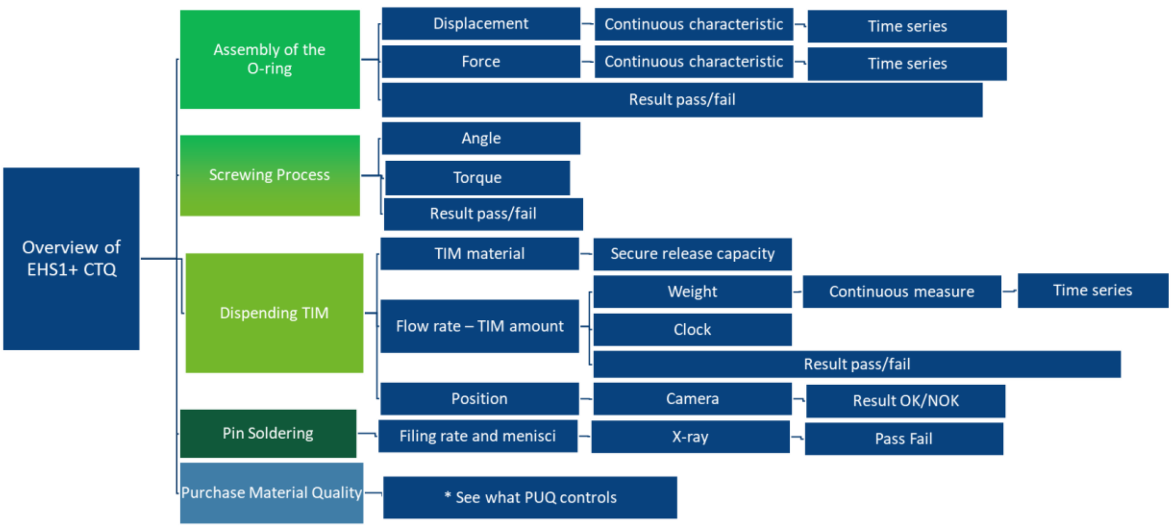


Figure 49 - EHS1+ Dashboard sailboat graph: overview of CTQ characteristics

For each, the data available to monitor the characteristics were identified, then evaluated if it should be used and how. For the assembly of the O-ring, the force and displacement during the assembly are the two value recorded, that are continuous characteristic and should be represented on the dashboard using a time series. Regarding the screwing process, even though the data related to the angle and the torque are collected in the database, considering the needs of the users, it was decided to not use these values and instead to only have a view of pass/fail results. Regarding the dispensation of the TIM, three aspects need to be monitored, the material, the flow rate and the position. For each, it was studied how to track the process. The pin soldering will have a similar approach to the previous case, to use the x-ray inspection results. It was discussed to explore the possibility of incorporating the information from the purchased materials, but it was not defined as a priority.

6.2.4. DATA STRATEGY PLAN

Based on the goals defined above, it was identified three main sources: the production database, x-ray inspection document and the CAT inspection document (Figure 50).

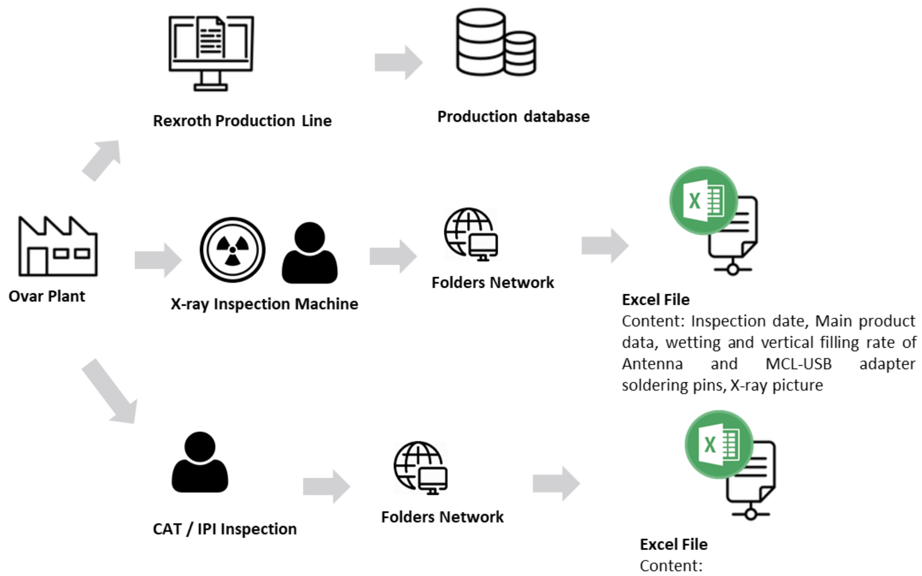


Figure 50 - EHS1+ Data Sources

During the data workshop with the test and IT engineers, it was discussed the best strategies to develop the quality data mart and it was concluded to use of the Grafana Software (see subsection 5.2.4).

6.2.5. LESSONS LEARNED AND NEXT STEPS

Due to time limitations, it was not possible to create the quality data mart and develop the dashboard for EHS1+. Reflections about the work developed, including a comparison with the first case execution, and the next steps to be followed are described in this section.

In comparison with the product of the first case, EHS1+ is a more complex product, with more components and a more extensive production process, what resulted on more data to be recorded and more characteristics to monitor. When the quality data mart started to be developed, in the first case the industrialization process was almost at the end, at the launch stage, in contrast to this case that was at the end of the development phase. There were some detail and tasks done by the industrialization team. On the one hand, slow down the development of the quality data mart, which highlighted the importance to have the development of the dashboard aligned industrialization procedure and the team. On the other hand, provided the study with a close look at the industrialization tasks and how the quality data mart could be more brought and benefit everyone.

This second case was intended to be used to validate and refine the quality data mart process proposed at subsection 5.3.4. Although it was not possible to improve much on the process mapping task, this case was directed to get a better understanding of the IT perspective on how to access the data. The discussion ended up about which software to use considering its connection to the production database. The next step would be to explore and use the Grafana software to build quality data marts, and to compare it with MS Power BI.

During the development of this case, it was clearer the misalignment from the high-level management regarding how to proceed with the development of quality data marts due to the fact that the quality and IT departments were developing different solutions. One of the key points, presented by (COTEC Portugal, 2020) when implementing industry 4.0 initiatives and transformations, is the importance of having a common strategy for the company in order to prevent different projects to be developed without alignment.

The last aspect to be considered at Ovar plant is that the various value stream teams work differently, and both teams and business units would expect different outcomes from the quality data mart. Considering the dashboard responsible perspective, it is important to assess the similarities and differences in the working dynamics in order to produce the best result.

The next steps to be performed in this case are to finish the quality data mart, that would generically consist of (i) assigning the responsibility to develop the quality data mart to a collaborator, (ii) connecting the data to the Grafana software, (iii) conducting data analysis and evaluating the fitness of the data to the monitoring needs, (iv) designing the graphics, (v) evaluating the use by establishing a testing period within the team and (vi) sharing the dashboard with the team and reviewing the work.

6.3. REFLECTION

In this section, a reflection about the implementation of the quality data marts, the usage of MS Power BI and the use of supporting tools that were created are presented.

6.3.1. IMPLEMENTATION

During the development of the cases, one of the main challenges was to understand the product in the analysis. Considering that at Bosch Ovar there are several values streams and different types of products and manufacturing processes, little knowledge about the product is expected to be transferable from case to case due to their different characteristics.

It was also important to get familiar with the industrialization process, but it was not possible, in this project, to follow the process for one product from the beginning to the end, since it usually takes more than a year to execute. The same happens with the management of characteristics process, also because at the moment it is not being fully applied. The execution of the quality data mart should follow the other processes and be aligned with their stages.

Another struggle was the perception of the implementation of the quality data mart as something develop only by and for the quality engineer. But the quality data mart is a tool that supports the industrialization and production teams and should be presented as a task that the industrialization team is responsible for.

6.3.2. SOFTWARE

The experience with the MS Power BI was a good one. It was easy to learn how to navigate to the different modes since it applies the same principles of Microsoft programmes.

Microsoft defined MS Power BI as "a business analytics solution that lets you visualize your data and share insights across your organization, or embed them in your app or website. Connect to hundreds of data sources and bring your data to life with live dashboards and reports." (Microsoft Power BI, 2020)

The possibility to connect different sources with different types and data formats was a key point to develop the quality data mart. Also, for being able to perform ETL tasks and to build the data model in the program itself were facilitating aspects.

In terms of visuals creation, the software gives the flexibility to present the data in different ways and to construct the necessary indicators. For the user, the dynamic dashboard serves the different stakeholders that are looking for different insights.

Some relevant features were missing, such as alarm or notifications when a certain value is reached. There are other powerful business analytics solutions that would be interesting to explore and can serve as equal or better as the Microsoft option, but it was not within the scope of the presented work to explore it.

6.3.3. SUPPORTING TOOLS

Several tools were applied and developed during this project, bringing benefits not only to the case where they were applied but also to the quality data marts to be developed in the future, given that some structure was stipulated in the execution.

The sailboat diagram serves as a graphic way to represent the different goals and uses cases. Not only supports to structure the goals but also to define what are the functionalities needed for the dashboard in order to fulfil the goals. It also serves as a communication tool for showing the purpose of the dashboard, presenting not only the high-level goals but also to present the functionalities and the data needed by IT engineers, when building the data strategy plan.

The data modelling performed by applying multidimensional data schemes is crucial to develop data marts since it allows to optimize the querying data tasks performed by the model.

The executive summary serves as a communication tool to gather all the work developed during the case. It serves as a tool for the quality data mart responsible to manage the project by having all the information in one document and by keeping track of the status of the project, what was already done and what needs to be done. It is also used as a communication tool because it can easily be adapted to contain the relevant information when discussing or presenting the quality data mart. Lastly, it serves as a knowledge management tool and can be used for future projects to benchmark how quality data marts can be built.

The proposed procedure presented in section 5.3.4, was defined based on the experience from the case one and was planned to be pilot and refined by the execution of the case two. The integration of the PEP and CDQ process when mapping and building the quality data mart process, gave more context on how these three processes relate to each other. The clear separation of the different stages with concrete outcomes and milestones also contributes to adapting when each stage is occurring.

All these tools are relevant not only to support the building of a specific quality data mart but also to support the creation of future ones.

7. CONCLUSIONS AND REFLECTIONS

In this final chapter, the main conclusions of the project are presented. First with a summary and reflecting of the work developed. Afterwards by answering the project questions initially defined. Lastly by presenting the project limitations and future work.

7.1. STUDY'S SUMMARY AND REFLECTION

The project developed at Bosch Ovar was about the implementation of quality data marts which are information systems that collect, analyse and distribute the data regarding the quality of the product with the creation of a dashboard. The quality data marts should be developed during the industrialization of the product, together with the definition and implementation of the production process.

The project combines the fields of data mining and analysis, quality and process monitorization techniques. The issue faced was that the needed data was not available for use in a meaningful, easy and fast way to give to the stakeholders the necessary insights about the quality of the production.

The main goals of the study were to develop two quality data marts and to propose a standard for the development of quality data marts at Bosch Ovar. Therefore, the project was divided into two areas: (i) the study of the problem and (ii) the implementation of the quality data marts. To study the problem, a methodology based on DMAIC was designed, integrating the principles of the BPM life cycle for the definition of the process. Regarding the execution of the use cases a data mining methodology, CRISP-DM, was used.

Although the DMAIC methodology is not usually applied in this project context, it was verified that helped to define a clear set of steps to be developed in order to improve the issue presented. DMAIC has a set of quality tools associated with the methodology that supports the execution of each stage. It is also a data-driven problem-solving methodology, what pushed and ensured that data was taken into consideration when defining, analysing and solving the problem, mostly with the indicators developed.

The BPM life cycle was integrated into the implementation of the cases. The first case supported the understanding and the definition of the process as-is while the second case would support the concept's validation of the proposed procedure.

After defining the scope of the project, its goals and methodologies, an assessment of the initial situation was done. It resulted in the definition of the baseline state and the desired state considering several indicators.

Afterwards, several analyses were done in order to get more knowledge about the problem and the situation, looking for the root causes. There were not clear proven root causes found due to the nature of the analysis and the problem. However, it was possible to identify three main categories: quality, data and execution. For each area, solutions were designed and implemented, with the aim to improve the situation. The main results were the development of a procedure to develop the dashboard, considering the already existing procedures and tasks for the industrialization team. Also, documents and tools were introduced to support the creation of quality data marts.

Considering the practical cases, the CRISP-DM method provided a structured procedure to develop the quality data marts, preventing going directly to get insights and analysis allowing to first gather knowledge about the product and the data and to define users' requirements.

Due to time limitations, the second case was not finished, but as it was proposed a standard procedure to develop a quality data mart, it is believed that the conclusion of this case will not be difficult to perform.

7.2. ANSWERS TO THE PROJECT QUESTIONS

At the beginning of this study, three questions were defined to be explored. In this section, the answers will be presented as they can be concluded from the work presented.

- What is meaningful data regarding the products' and processes' quality for the different stakeholders?

Stakeholders', such as the quality engineer and the BU responsible, aim to ensure the quality of the production and to make the best decisions and actions to guarantee a certain level of performance. For them, it is crucial to monitor the production, especially in its critical points. At Bosch, there is a focus on defining procedures that support the identification of the critical characteristics and their monitorization. The quality directives as Management of Characteristics supports the standardization of what is meaningful data and how to define it for each product.

- How to analyse and represent the information to monitor each product and process?

There are statistical principles and techniques that support the analysis of the data. The representation of information on a dynamic dashboard allows the user to freely explore and draw his/her conclusions. Keeping the visualization simple and showing only the most relevant information is a key point to develop successful information dashboards.

- How to collect the data from the production and how to distribute information to the relevant stakeholders?

All the initiatives of digitalization should follow a common strategy. Only the needed data for the stakeholders should be collected and stored, respecting its aim of being used for analyses and to support decisions. The data should also be available for when the decisions need to be made if it is on the job floor or on a department meeting. The development of a dashboard that can be accessed in different platforms and in different contexts, with near-real-time data will certainly impact the way stakeholders use data in their decisions.

7.3. LIMITATIONS AND FUTURE WORK

There were limitations and setbacks during the project. One of the main barriers felt throughout the project was the lack of a global strategical view from the management level on how to tackle the problem. This issue led to some ambiguity on deciding which approach would be better to execute the quality data mart. Nevertheless, the aim was to test and make successive interactions in order to establish a standard on how to develop the quality data marts.

Another main struggle was related to accessing data. The difficulties faced with working and using data were not expected at the beginning of the project.

As next steps, the recommendation would be to finish implementing the quality data mart of case two, where the Grafana software should be used. Afterwards, MS Power BI and Grafana software should be compared and analysed. A decision regarding the software and the direction should be reached before starting another case. Regarding the proposed process, it should be analysed and validated and the necessary adjustments should be made.

The future work regarding the quality data marts is to integrate predictive analytics and to evaluate the use of the quality data marts on the decision-making process. Considering the Industry 4.0 developments, it is expected that the role of the quality engineer would focus “on real-time, data-based investigations of problems’ causalities and ensuring quality is produced by stable [processes]” (Watson, 2019).

The main contributions of this work focus on leveraging from the recent IT developments to build systems that support the work of the quality engineer, with the implementation of one quality data mart and setting the foundation for the development of quality data marts with a defined process. The creation of dashboards with near-real-time data enables the stakeholders to use it in their decision-making process. Therefore, the results of this project allow stakeholders to make better and faster decisions and contribute to the development of a data-driven mindset in the company.

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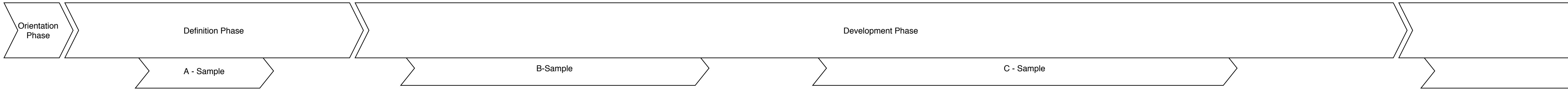
APPENDIXES

APPENDIX 1: QUALITY DATA MART PROCESS

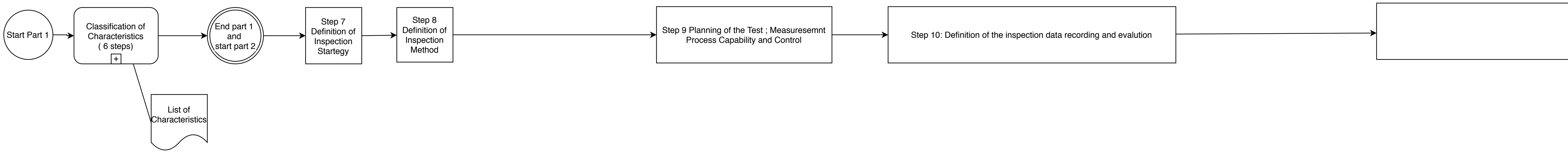
APPENDIX 2: GATEWAY EXECUTIVE SUMMARY

APPENDIX 3: EHS1+ EXECUTIVE SUMMARY

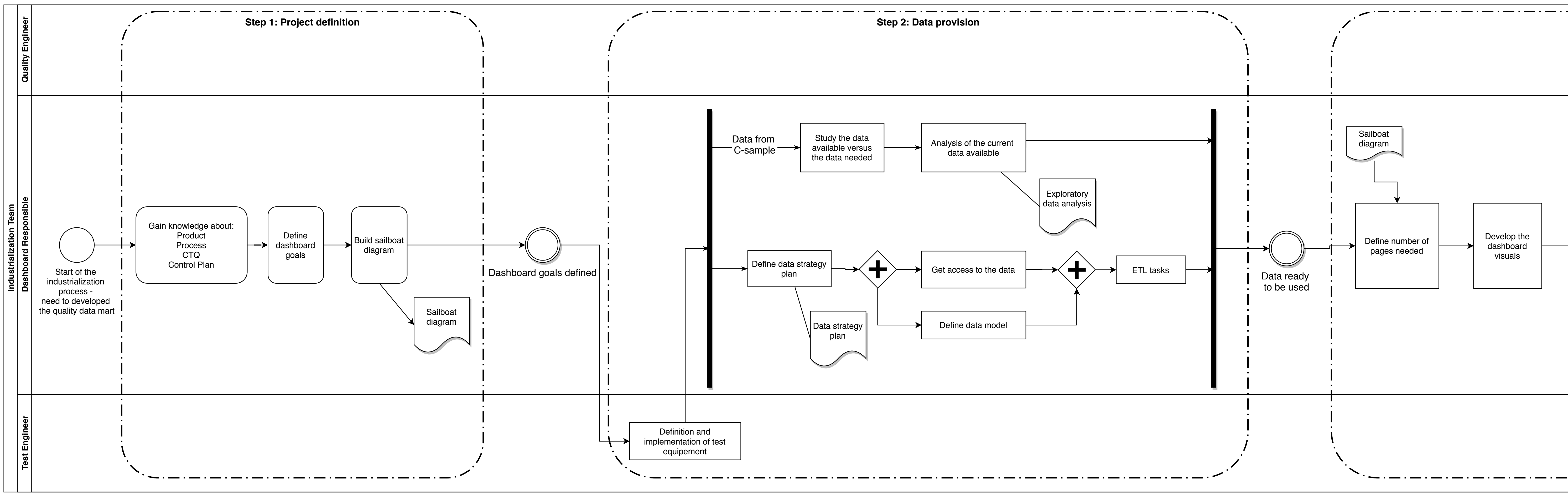
INDUSTRIALIZATION PROCESS

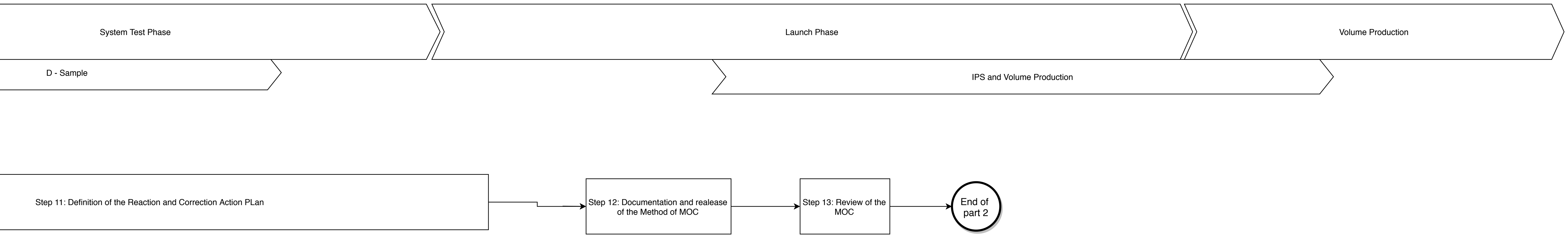


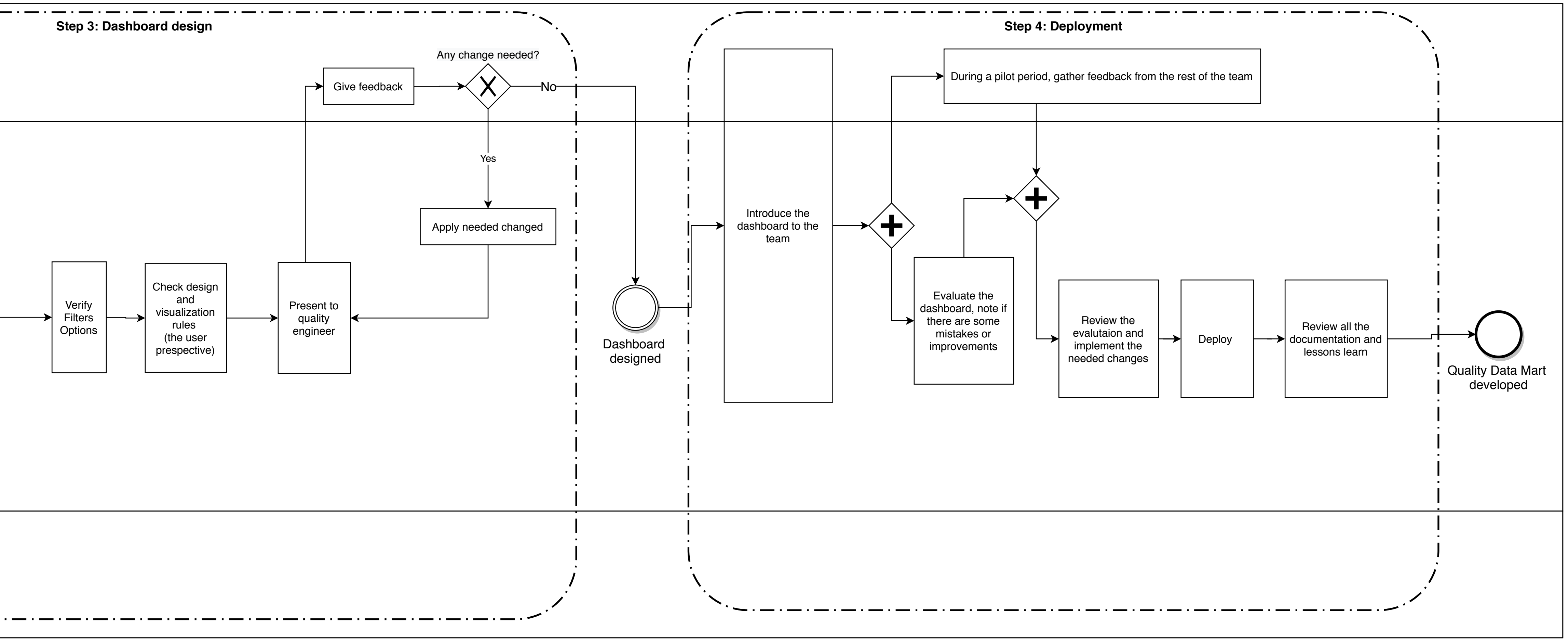
MANAGEMENT OF CHARACTERISTICS



QUALITY DATA MART PROCEDURE




System Test Phase
Launch Phase
Volume Production
D - Sample
IPS and Volume Production
Step 11: Definition of the Reaction and Correction Action PLan
Step 12: Documentation and realease of the Method of MOC
Step 13: Review of the MOC
End of part 2


Step 3: Dashboard design
Any change needed?
Give feedback
No
Yes
Apply needed changed
Verify Filters Options
Check design and visualization rules (the user prespective)
Present to quality engineer
Dashboard designed
Step 4: Deployment
Introduce the dashboard to the team
During a pilot period, gather feedback from the rest of the team
Evaluate the dashboard, note if there are some mistakes or improvements
Review the evalutaion and implement the needed changes
Deploy
Review all the documentation and lessons learn
Quality Data Mart developed

GATEWAY
QUALITY DASHBOARD

BOSCH

Gateway Quality Dashboard
Executive Summary

Project Motivation

- Overview of Gateway Critical to Quality (CTQ) characteristics behavior to trigger preventive analysis during mass production stage.
- Support improvements to the production process by working out the rejection rate and respective failure modes.
- Improve the handling and response to the customer complaints by working with structured visuals of the main product data.
- Allow the marking and the correlation between production events, possible quality deviations and respective causes.
- Support as a proof of quality data mart concept.

Targets and Deliverables

- **CW19xx: Create Gateway Quality Dashboard:** use the cockpit core model previously defined to create visuals for the Gateway CTQ characteristics and main product data.
- **CW19xx: Present the dashboard and share respective link to the stakeholders:** BU FIRE team, OvrP Management team, Test Engineering team, VS team.
- **CW19xx: Start using and take advantages from the dashboard data:** implement way of working with the dashboard in the VS FIRE and VS Organization dynamics.

Project Team

Core Team

- Rita Mendes (OvrP/QMM)
- (OvrP/MFE1)
- (OvrP/MOE3-CSI)

Steering Board

- s (OvrP/QMM)
- (BT-FIR/QMM)

Stakeholders

- VS-CSI
- BT-FIR/ENG
- BT-FIR/QMM

Owner

- (OvrP/MOE3-CSI)

BOSCH

Gateway Quality Dashboard
Tasks and Time Schedule

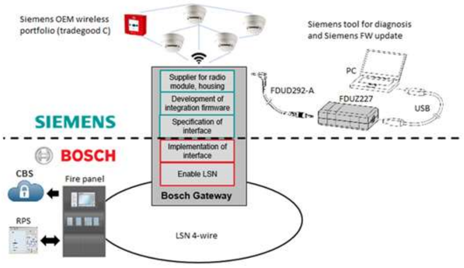
Week	Main Task	State	Slide
CW19xx	Define dashboard motivation and stakeholders involved	Done	2-3
CW19xx	Evaluate CTQ characteristics with BU project team and main product and process data	Done	4 -6
CW19xx	Define data strategy Define variables available and needed	Done	7 -8
CW19xx	Define the data structure and model of the data	Done	
CW19xx	Define statistics to be used, analysis visuals and structure them into the dashboard	WIP	9-15
CW19xx	Create the dashboard in Power BI, publish the Power BI report and get access link	WIP	
CW19xx	Share project and respective results with all stakeholders. Document lessons learned		

Gateway Quality Dashboard
The Product

The project "Wireless Integration" shall replace the obsolete LSN (LSN = Local Security Network Classic) wireless trade good portfolio. Replacing this portfolio with a new wireless system will allow Bosch ST to offer addressable, wireless detectors and manual call points to its customers. This wireless portfolio is essential for Bosch ST to gain projects, which require some wireless components.

Wireless systems are still considered as niche products, which are required for applications:

- where cabling is not possible due to the wall's material
- which are 'heritage protected'
- where cabling is not wanted due to aesthetic reasons (e.g. glass ceilings)
- where a fast extension / creation of a fire alarm system is necessary.

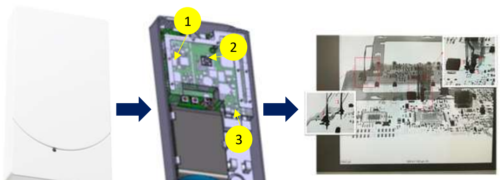


Components:
- Hardware
  - Radio module
  - Antena
  - Housing (case)
  - Bosch PCB
- Software

Gateway Quality Dashboard
Critical to Quality characteristics

Function

- ✓ Radio Gateway forms a radio cell together with the radio devices that are connected via radio to monitor signals from them.
- ✓ Radio Gateway communicates with the control panel via the detector line to transfer monitored signals.
- ✓ Power to Radio Gateway is supplied via the detector line and via a battery pack ensuring a permanent power supply for the radio gateway.



X-ray of antenna and audio jack soldering joints.

1 - RF Module
2 – MCL-USB adapter
3 - Antenna

Critical to Quality characteristics

- ✓ RF Module is seen as a critical component. It is supplied by Siemens to Ovar plant where it goes through the soldering robot process over the pcba.
- ✓ System "RF Module and Antenna" are responsible to receive and transmit RF signals form external devices, in this case, from the smoke detectors and to the Fire Panel Controller. Therefore, RF Signal Strength is a CTQ characteristic, 100% measured in Gateway production process (Final Test) simulating the reception of the signal (FDUZ to DUT) and the transmission of the signal (DUT to FDUZ).

  Nevertheless, soldering joints between the Antenna pins and the RF Module must fulfill IPC-1-610 requirements. Therefore, regarding to Antenna pins, wetting and vertical filling rate of hole are CTQ characteristics.
- ✓ Soldering requirements are also applied to the MCL-USB adapter used to connect FD-net/C-NET devices to a personal computer, transmit signals to SWING radio devices via radio and as an interface converter for USB on MC link. Therefore, MCL-USB adapter pins, wetting and vertical filling rate of hole are CTQ characteristics.
- ✓ Gateway allows the device status detection on itself by 4 LED: LED nº 1 – localization; LED nº 2 – Maintenance mode active; LED nº 3 – General fault or Low battery voltage; LED nº 4 – Wireless network not completely functional. Therefore LED color and intensity shall be controlled.

Gateway Quality Dashboard
Process, Inspection Plan

Process

SMT
↓
THT (soldering Robot)
↓
Coating
↓
Milling
↓
FAS:
- Functional Test
- Soldering
- Final Test
↓
X-ray
↓
CAT

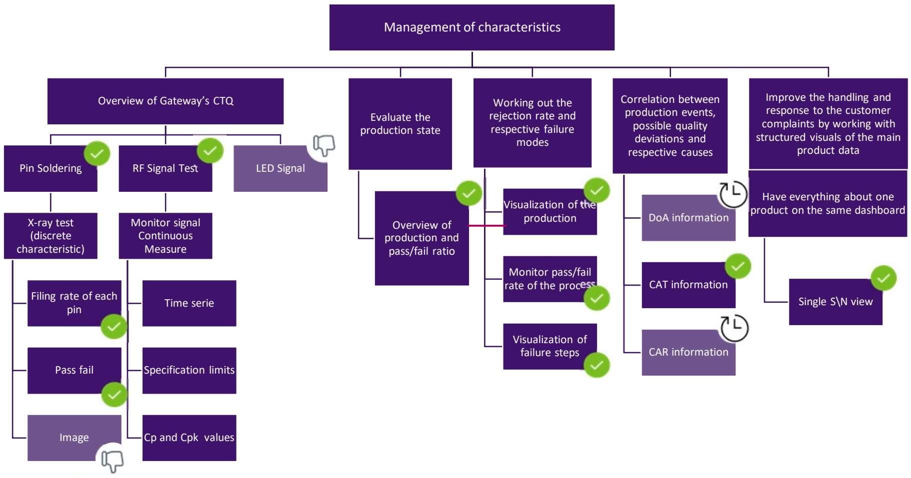
Inspection

Quality Plan: Final Assembly , Product Audit

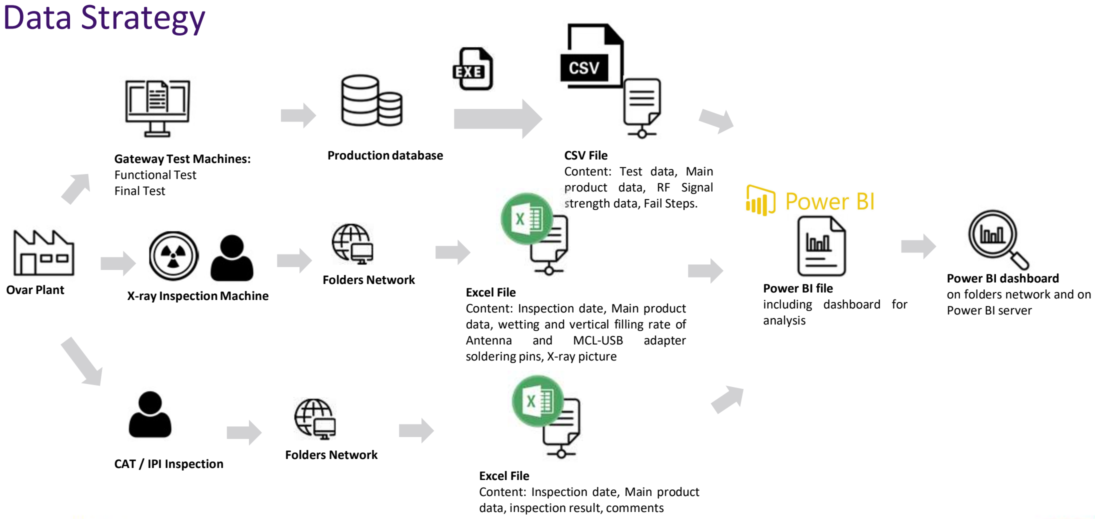
FAS	**STA-1 Gateway** **FcT (Programming and Test)**	All Products	STL3-Q6500-0463-OvrP PQI Functional Test Gateway STL3_Q6507-0073-OvrP OvrP Maintenance Plan Functional Test Gateway
	STA-2 Gateway **Manual Soldering**	All Products	PQI SWL3-6802-063-OvrP Manual Soldering Gateway
	STA-3 Gateway **Encasing**	All Products	PQI SWL3-6802-063-OvrP Encasing
	STA-4 Gateway **Final Test**	All Products	STL3-Q6500-0464-OvrP Final Test Gateway STL3-Q6500-0474 OvrP Maintenance Plan Final Test Gateway
	STA-5 Gateway **Packaging**	All Products	PQI SWL3-6802-062-OvrP Packaging Gateway
	FAS Process Control	According to Control Plan	CP_2019.005 Gateway Control Plan
		Non conforming products	SVL3-Q2006-OvrP Control of Non-Conforming Products
PRODUCT AUDITS	**A-Test: X-Ray**	100%	Checking according to IPC A-610 guidelines. X-RAY INSPECTION - Gateway.xlsb
	Q-Test: Customer Acceptance Test	1-5% of daily production batch	STPD-00029-000 Periodic Testing Procedure STPD-25545-000 Product Audit SWL3-Q2000-192-OvrP CAT Instruction **Production Test Specification Gateway** Z-Test_FWI-270.xlsx
	Q-Test: Complete Product Audit	1 unit /quarter	STL3-Q2000-022-OvrP_CPA Template **Production Test Specification Gateway** Z-Test_FWI-270.xlsx
	Z-Test: Reliability	100 ppm /Year	**Production Test Specification Gateway** Z-Test_FWI-270.xlsx

Gateway Quality Dashboard
Use Case Diagram

Legend:
- Done
- WIP
- Cut out



Gateway Quality Dashboard
Data Strategy



Gateway Quality Dashboard
Main product data

Critical to Quality characteristics

Main product data

Test or Inspection data

Variables

Functional Test
- ✓ Type Number/CTN
- ✓ S/N
- ✓ RF Module ID
- ✓ Traceability ID
- ✓ Production date
- ✓ Production time
- ✓ LED color and intensity
- ✓ ~~Test Result~~
- ✓ Failed Steps

Final Test
- ✓ Type Number/CTN
- ✓ S/N
- ✓ RF Module ID
- ✓ Traceability ID
- ✓ Production date
- ✓ Production time
- ✓ RF Signal Strength (system to device; device to system)
- ✓ Test Result
- ✓ Failed Steps

X-Ray
- ✓ S/N
- ✓ Inspection date
- ✓ Inspection time
- ✓ X-ray result (Soldering Pins 1–5)
- ✓ X-ray pictures for failed units (not always)
- ✓ Test Result

Specification and Control Limits
- ✓ USL
- ✓ LSL
- ✓ UCL
- ✓ LCL

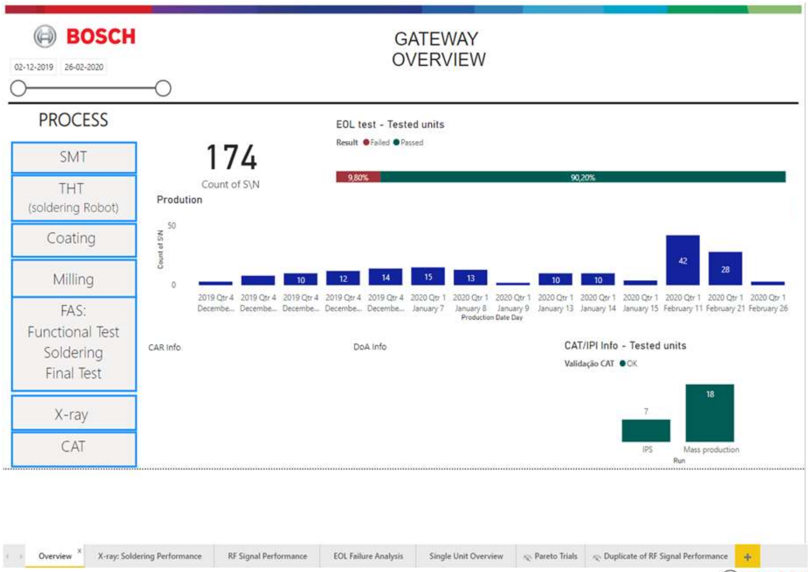
Extra Data
- ➢ CAT
- ➢ DoA
- ➢ CAR
- ➢ FOR
- ➢ Planned and target production (for the year, month or day)

BOSCH

Page 1

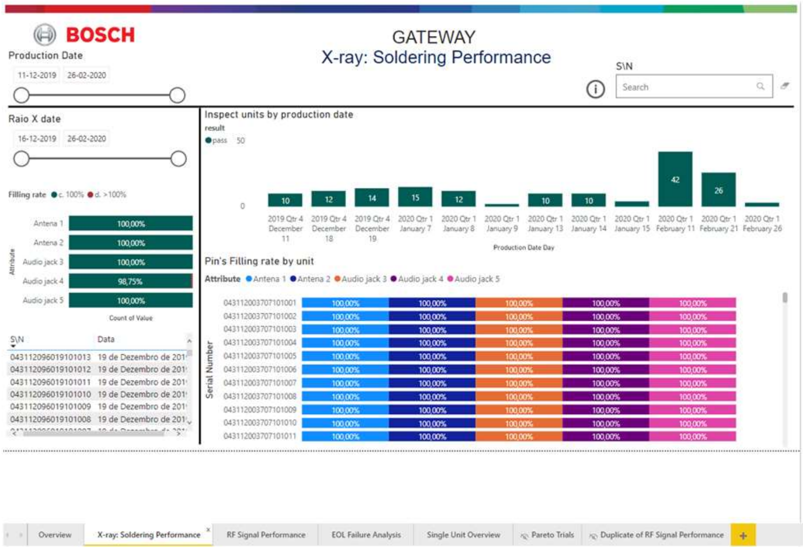
AIM: quick overview of the state of the process

Production Process
Number of units produced (Count of distinct S/N in Final Test)
Selection of Date
Production per date
Pass/Fail Rate of Final test - % of S\N that pass/fail
CAR, DOA and CAT information



BOSCH

Page 2



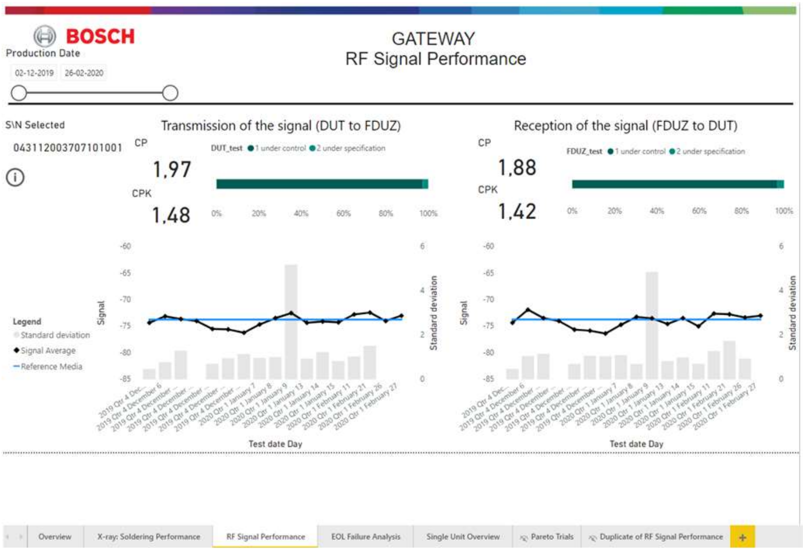
AIM: evaluate the soldering performance base on the X-ray inspection

CONTENT:
Pass/Fail Rate by date
Filling rate per soldering pin
Filling rate of each S\N
~~Link to pictures~~

Search per S/N

BOSCH

Page 3



AIM: monitor the RF signal, know the process capability

Evaluation of point under control, under specification and out of control
Cp and Cpk values for determined time period
Distribution w/ specification limits (Control Chart)

Standard desviation of the points of determined time period (the grey bar of the graphic)
- quickly helps identify the day that mint have had some out of control point (see 2020 January 9)

- Averages of the points in determined time period (high average can be sign of out of normal situation)

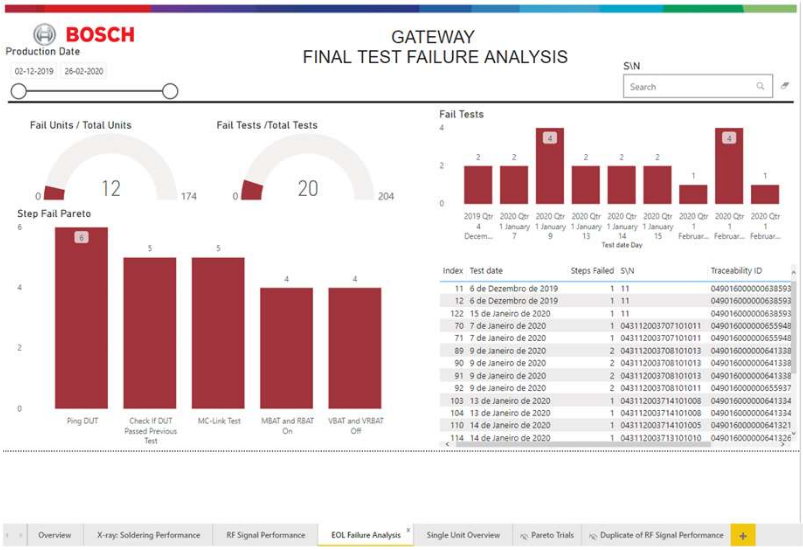
After identifying the critical point it's possible to explore the single points of that period

BOSCH

Page 4

AIM: Analyze failures from final test

CONTENT:
Pass/Fail Rate
Failed Steps
Search per S/N and step

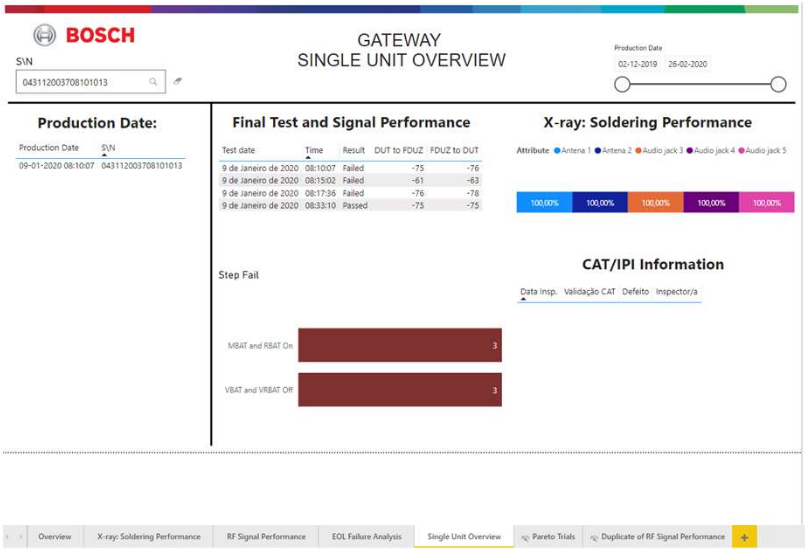


BOSCH

Page 5

AIM: Have information regarding a S\N on the same view

CONTENT:
Selection of a S\N
Pass/Fail of Final Test
Possible Failed Steps
RF signal
Filling rate per soldering pin
~~Link to picture~~
Information about CAT /IPI (if applied)



BOSCH


BOSCH

EHS1+ REXROTH
QUALITY DASHBOARD

BOSCH

EHS1+ Quality Dashboard
Executive Summary

Motivation for Project

- Overview of Rexroth Critical to Quality (CTQ) characteristics behavior to trigger preventive analysis during mass production stage.
- Support improvements to the production process by working out the rejection rate and respective failure modes.
- Improve the handling and response to the customer complaints by working with structured visuals of the main product data.
- Allow the marking and the correlation between production events, possible quality deviations and respective causes.
- Support as a proof of quality data mart concept

Targets and Deliverables

- **CW2005 – Mapping Rexroth CTQ**
- **CW20xx – Create Rexroth Quality Dashboard**
- **CW20xx: Present the dashboard and share respective link to the stakeholders:** BU team, OvrP Management team, Test Engineering team, VS team.
- **CW20xx: Start using and take advantages from the dashboard data:** implement way of working with the dashboard.

Tasks and Time Schedule

Week	Main Task	State	Slide
CW19xx	Define dashboard motivation and stakeholder involved	Done	2
CW2005	Evaluate Critical to Quality characteristics with BU project team and main product and process data	Done	3-6
CW2009	Define Data Strategy Define Variables Available and needed	WIP	7-8
CW2010	Define the data strutuure and model of the data		
CW2012	Define statistics to be used, analysis visuals and structure them into the dashboard		
CW2015	Create the dashboard in Power BI, publish the Power BI report and get access link		
CW2020	Share project and respective results with all stakeholders.		

Project Team

Core Team

- Rita Mendes (OvrP/QMM3))
- [redacted] (OvrP/QMM3)

Steering Board

- [redacted] (OvrP/QMM3)
- (BU/QMM)

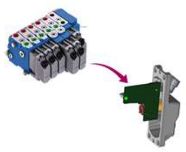
OvrP/QMM3 | 2019-05-31

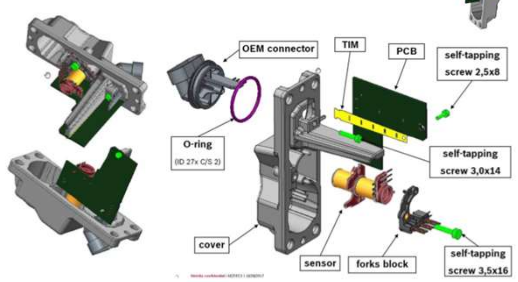
BOSCH

EHS1+ Quality Dashboard
Critical to Quality characteristics

Function

- ✓ Functional principle: Closed loop control of valve spool position
- ✓ Standards: ISO 25119 (functional safety)
- ✓ Hydraulic valve slices
- ✓ Electro-hydraulic actuation modules EHS1





Critical to Quality characteristics

- ✓ **Soldering requirements:** Solder joints must comply with IPC-A-610 class 3 requirements (100% hole filling with menisci on both sides, free of defects)
- ✓ **TIM** (thermal interface material) **dispensing** - this material is responsible for the heat dissipation from PCB to the cover, and crucial for the functionality of the product. Its required to dispense homogeneously the defined TIM quantity on Cover's "finger".
- ✓ **OEM Connector and O-ring** – these two components need to be assembly correctly in order to isolate the valve from liquids and oils
- ✓ **Screwing**: the process of screwing is fundamental for the product to guarantee its robustness (since the product its expose to vibration during its normal use).
- ✓ **Purchased Material**: Some of the characteristics that are critical for the functionality of the product are monitor and ensure by the supplier.

EHS1+ Quality Dashboard
Process, Control Plan

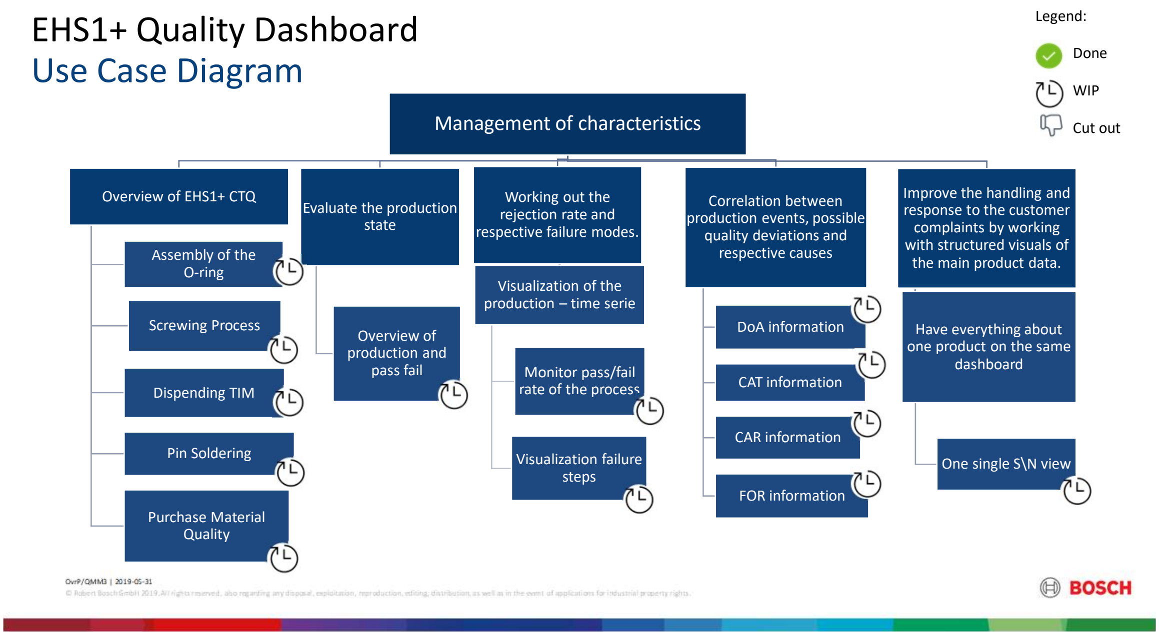
Process

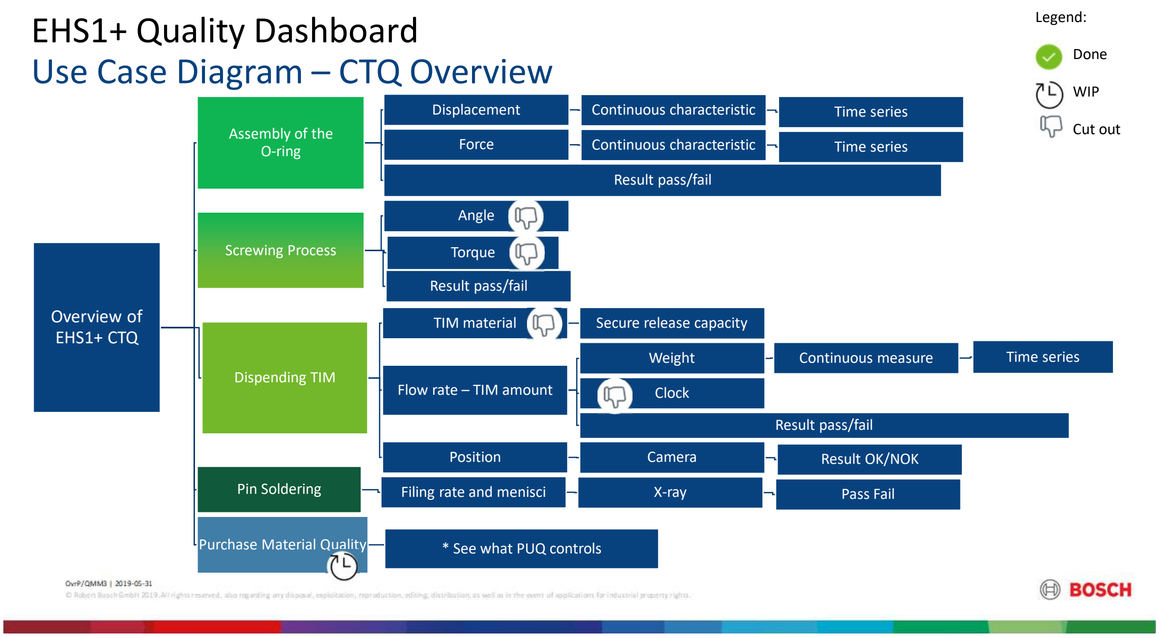
Suppliers → Marking of PCBs (Laser Marking) → Double Side SMT → AOI → PCB Separation V-cut → Functional test → Pre-Assembly OEM Connector +O-ring → Press OEM Connector into Cover → Pre-Assembly Sensor and Forks block

→ Screwing ECU → Dispensing TIM → PCB Assembly → Screwing → Soldering 3 Components, 10 pins → End of Line Test → Packaging → X-ray Inspection → CAT Inspection

Control Plan

Suppliers	PCB	PCB cut	Pre- assembly	Dispensing TIM	Soldering	WS4	Extra
PUQ Evaluations	AOI	FcT	Automatic inspection Weight and Force on the connector Screw driver control	Digital Scale Automatic inspection – camera Internal control – clock Screw driver control	X-ray inspection	EOL test	CAT Inspection


EHS1+ Quality Dashboard
Use Case Diagram
Legend:
Done
WIP
Cut out
Management of characteristics
Overview of EHS1+ CTQ
Assembly of the O-ring
Screwing Process
Dispending TIM
Pin Soldering
Purchase Material Quality
Evaluate the production state
Overview of production and pass fail
Working out the rejection rate and respective failure modes.
Visualization of the production – time serie
Monitor pass/fail rate of the process
Visualization failure steps
Correlation between production events, possible quality deviations and respective causes
DoA information
CAT information
CAR information
FOR information
Improve the handling and response to the customer complaints by working with structured visuals of the main product data.
Have everything about one product on the same dashboard
One single S\N view
OvP/QMM3 | 2019-05-31
BOSCH


EHS1+ Quality Dashboard
Use Case Diagram – CTQ Overview
Legend:
Done
WIP
Cut out
Overview of EHS1+ CTQ
Assembly of the O-ring
Displacement
Continuous characteristic
Time series
Force
Continuous characteristic
Time series
Result pass/fail
Screwing Process
Angle
Torque
Result pass/fail
Dispending TIM
TIM material
Secure release capacity
Flow rate – TIM amount
Weight
Continuous measure
Time series
Clock
Result pass/fail
Position
Camera
Result OK/NOK
Pin Soldering
Filing rate and menisci
X-ray
Pass Fail
Purchase Material Quality
* See what PUQ controls
OvP/QMM3 | 2019-05-31
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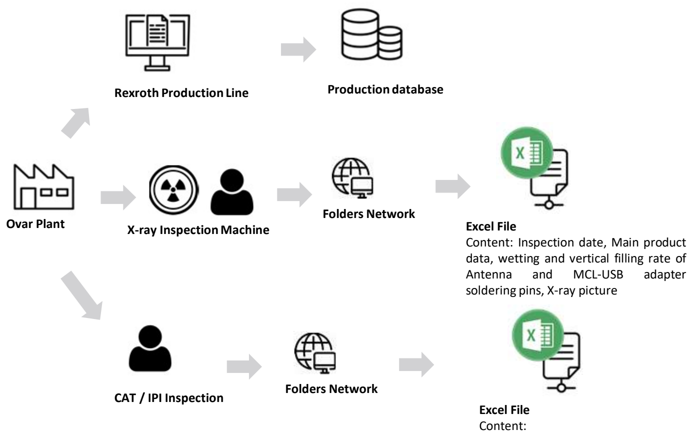
EHS1+ Quality Dashboard
Data List

Process	Parameter	Where?	Raw data
Assembly of the O-ring	Displacement	EHS1PLUS-TighteningPress-1	Crimping_FinalPosition = 7.20
	Force		???
	Pass/Fail		
Screwing Process x4	Pass/Fail	EHS1PLUS-TighteningPress-1	LeftScrewDriver_Error = none – OK
		EHS1PLUS-DispensingTightening-1 (??)	
Dispending TIM	Flow rate	EHS1PLUS-DispensingTightening-1 (??)	???
	Position OK/NOK from camera	????	Pass Fail
Pin Soldering	Pass Fail	EHS1PLUS-Soldering-1	Soldering Result
	X-ray result	Excel X-ray	Filling rate x10 = 0-100%
Purchase Material Quality	TBD	PUQ information	TBD
FcT	Result Pass Fail	EHS1PLUS-FUNC-1	
	Step Fail		Components that fail (?)
EoL	Result Pass Fail	EHS1PLUS-Final-1	
	Step Fail		Solenoid …

EHS1+ Quality Dashboard
Data Strategy



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