Universidade de Aveiro
2021

ALEXANDRA MARQUES ALVES DE SÁ

MELHORIA DA GESTÃO DE DEFEITOS INTERNOS E DO FLUXO DE DADOS NA INDÚSTRIA AUTOMÓVEL

IMPROVEMENT OF INTERNAL DEFECT MANAGEMENT AND DATA FLOW IN THE AUTOMOBILE INDUSTRY

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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 Prof. Doutora Helena Maria Pereira Pinto Dourado e Alvelos, Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro.

“Strive not to be a success but rather to be of value.”

- Albert Einstein

o júri

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agradecimentos

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palavras-chave

indústria automóvel, veículos eléctricos, alta voltagem, ferramentas de qualidade, sistemas de dados de qualidade, produtos não-conforme

resumo

Nos últimos anos, com particular foco nas preocupações ambientais, temos vindo a assistir a um aumento na procura de veículos híbridos e elétricos. Para a construção destes veículos mais sustentáveis, são produzidas cablagens elétricas de alta voltagem, que atualmente implicam um contínuo desenvolvimento dos produtos. A produção de uma cablagem elétrica para um automóvel deve ser realizada com um rígido controle de qualidade, de forma a prevenir defeitos nos produtos.

Por conseguinte, o presente trabalho aborda a gestão de defeitos internos na indústria automóvel, mais especificamente num contexto de produção de cablagens elétricas de alta voltagem.

O seu objetivo foi o de procurar melhorar a gestão interna de defeitos e o fluxo de dados, através da implementação de uma nova e melhorada base de dados de qualidade, futuramente comum a diversas fábricas da Europa e do Norte de África, e de ferramentas da qualidade, no âmbito da Gestão da Qualidade Total.

Através da ferramenta PDCA, foi implementado um *Quick Response Quality Control* para, com recurso à monitorização e à realização de reuniões diárias multidisciplinares, se promover uma rotina de investigação aos defeitos identificados. Foi constatada uma melhoria na comunicação entre departamentos.

A metodologia aplicada na investigação da causa raiz do defeito de estanquidade nas cablagens de alta voltagem consistiu na utilização, em conjunto, de quatro ferramentas de qualidade: o Diagrama de Pareto, os 5W2H, o Diagrama de Ishikawa e os 5 Porquês. A causa raiz do defeito foi identificada como um problema de produção do conector A. Em abril de 2020, a produção usou apenas conectores bons, com um resultado de 0,18% defeitos, uma redução percentual significativa em relação aos 1,79% do registados no mês anterior.

Com a identificação de códigos de defeito incorretamente aplicados nas cablagens de alta voltagem, que provocavam incoerências no registo dos defeitos internos, foi atualizado o documento de códigos de defeitos, através da recolha de informação no chão de fábrica.

A base de dados para o rastreio de defeitos internos foi implementada numa área piloto da Yazaki Saltano de Ovar, através do ciclo PDCA. Foram analisadas a base de dados atual (QEDS), e a nova (QDS). Da aplicação das duas bases em paralelo durante um mês, e com o registo de 420 defeitos, verificou-se que a QDS forneceu mais resultados gráficos do que o registo da base de dados anterior, e proporcionou a possibilidade de uma análise diária, ao contrário da opção de análise única mensal da QEDS.

Os resultados do projeto apresentaram melhorias com as implementações introduzidas, nomeadamente uma comunicação mais eficaz dentro da equipa, um melhor ambiente de aprendizagem, melhorias na rotina de investigação de defeitos e no fluxo de dados.

keywords automobile industry, electrical vehicles, high voltage, quality tools, quality data systems, non-conformity products

abstract

In recent years, with the greater focus on environmental issues, there has been an increase in demand for hybrid and electric vehicles. For the construction of these more sustainable vehicles, high-voltage electrical cables are produced, which currently implies a continuous productive development. The production of electrical wiring for an automobile must be carried out with strict quality control in order to avoid product defects.

This work deals with the management of internal defects in the automotive industry, more specifically in the context of the production of high voltage electrical wiring.

Its objective was to seek to improve internal defect management and data flow through the implementation of a new and improved quality database, in the future, common to several factories in Europe and North Africa, and tools from the quality, within the scope of Total Quality Management.

Through the PDCA tool, a Quick Response Quality Control was implemented, using monitoring and daily multidisciplinary meetings in order to induce a routine of investigation of identified defects. Furthermore, improved communication between departments was verified and achieved.

The methodology applied in the investigation of the root cause of the air leak defect in high voltage wiring consisted of using, simultaneously, four quality tools: the Pareto Diagram, the 5W2H, the Ishikawa Diagram and the 5 Whys. The root cause of the defect was identified in a connector A production issue. In April, the production used only good connectors, with a result of 0.18% defects, registering therefore a significant percentage reduction from 1.79% in the previous month.

With the identification of incorrectly used defect codes in the high voltage cabling, which caused inconsistencies in the registration of internal defects, the defect code document was updated, through the collection of information on the factory floor.

The database for tracking internal defects was implemented in a pilot area of Yazaki Saltano de Ovar, through the PDCA cycle. The current database (QEDS) and the new one (QDS) were thoroughly analysed. From the application of the two databases in parallel for one month, with the registration of 420 defects, it was found that QDS provided more graphic results than the previous database, and also provided the possibility of a daily analysis, as opposed to the monthly single analytics option of the QEDS.

The project results showed significant improvements with the implementations introduced, namely a more effective communication within the team, a better learning environment, improvements in the defect investigation routine and in the data flow.

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List of Abbreviations and Acronyms

YEL - Yazaki Europe Limited
TQM – Total Quality Management
EDS – Electrical Distribution System
HV – High Voltage
TQM – Total Quality Management
AR – Action Research
RCA – Root Cause Analysis
BPM – Business Process Management
BPMN – Business Process Model and Notation
QDS - Quality Data Systems
YSE – Yazaki Saltano de Ovar
LQC – Line Quality Control
QC – Quality Control
YEG – Yazaki Europe Group

1. Introduction

The automotive industry is a worldwide competitive area due its rigorous regulation, the permanent technological development and the continuous introduction of new products in a way to adjust to market both of requirements and demands (Otto et al., 2020). Since it is characterized as a strong competitive sector with a complex main product, the financial investments need to be thoroughly applied, in a way to support the competitive market and, as described by Stylidis (2020), the "combination of mechanical parts, software pieces, various types of materials, advanced manufacturing processes, and high production volumes" involved. The greatest mode to increase the competitive side, and at the same time, guarantee the company financial stability, should focus on the organizational performance improvement (Vujović et al., 2017). Gouiaa-Mtibaa et al. (2016) emphasize that due to this competitive industry reality, companies should manage simultaneously different functional areas - such as maintenance, quality, production and marketing - and consequently, affirm that there is a need to develop new management approaches that promote interaction between them. Otto et al. (2020) underline that what is missing in the majority of the manufacturing automotive plants is a "practical guide to implement new technologies safely, effectively and efficiently". Zasadzień and Midor (2018) emphasize that, to meet the requirements imposed by the demanding and competitive market, the continuous improvement should be a systematic component of the strategy of every modern company.

In recent years, with the greater importance that has been given towards environmental issues and the consumption of more sustainable products, there has been an increase in demand for hybrid and electric vehicles (Al-Alawi & Bradley, 2013). This new product segment involves new designs, the use of different materials and more developed technology (Otto et al., 2020). Since it is a sensitive and powerful technology, all of these previous elements can cause safety risks and concerns, that can occur triggered by new quality defects, emphasizing the importance of an excellent and rigorous quality control in the production of new products (Ahire & Dreyfus, 2000; Otto et al., 2020).

In the production of automobiles, electrical wiring is essential, serving as an energy conductor for the vehicle to function properly. Its production must be carried out under strict quality control criteria, in order to avoid defective products and prevent serious accidents. For the construction of these vehicles which are related with e-mobility, high voltage wiring harnesses are produced (Otto et al., 2020). They are recent and more powerful wires, which are being continuously developed, involving adjustments in the production line that can include changes in the production method (T. Nguyen & Bell, 2015; Otto et al., 2020). Thus, continuous quality control is essential, focused on the analysis of root causes, and the implementation of actions for the prevention of defects.

1.1. Motivation and Work Contextualization

Yazaki Europe Limited (YEL) is in the process of implementing a database, more specifically a Quality Data System (QDS), common to all plants in Europe and North Africa, to assist the registration, analysis, and planning of possible actions for the prevention and reduction of internal defects. This project focuses on the internal defect management improvement and data flow, which includes the implementation of the referred database in a pilot area at Yazaki Saltano de Ovar. This pilot area will be the first high voltage production area to use the database. This practical project will be executed in a multinational scenario with the application of several concepts and quality tools to the automotive industry, within the scope of Total Quality Management (TQM), in the perspective of continuous improvement. TQM tools are considered an asset for the industry, contributing to an improvement in the quality management of the organization and being an advantage over the competition brands (Chung et al., 2008).

As previously mentioned, the pilot project for this database will be implemented at Yazaki Saltano de Ovar, more specifically in a customer production sector of the area EDS, which stands for Electrical Distribution System. The chosen production sector, which will be mentioned during this project as Customer X, is relatively recent, it is focused on the production of high voltage (HV) wiring and is composed of three the sub-areas: cutting (P1), crimping and accessories (P2) and assembly (P3). The Customer X area was chosen because it complemented the most recent projects in EDS, with the furthermost cleaning and process detailed requisites. At Customer X, many recurrent defects used to occur, without a routine investigation to properly identify root causes. Associated with that factor, it was not specified the P1 and P2 impact in the detected defects at P3 area. So, the focus of this project will be carried out around the assembly area (P3).

The practical project for the Customer X was also triggered because there was no team member completely focused on the internal defect analysis and investigation area. With the continuous technological development of this high voltage production area, the production lines are constantly changing, causing instability in the process and several new and unknown internal defects, which, if not detected in time, can reach the customer translated converted into a nonconforming product.

1.2. Objectives

Customer X is a recent high voltage production area. In the creation of this area, concepts, documents, and defect codes for low voltage products were applied, which were not properly adjusted to the needs of these new electrical wirings. Thus, one of the objectives of this project is the correct adaptation and updating of these tools, with focus on the update of the Yazaki Defect Coding Catalogue, to make them suitable for high voltage wiring analysis.

The improvement of the routine investigation and team communication is also an important objective. As this is a new production area, it is a new project for all the team members involved, in addition to an improvement in the research routine, the scope for learning and knowledge exchange should also be worked on.

Another key point is the implementation of the new database, the Quality Data System, with the aim of improving the management of internal defects, through an upgrade in the system's functionalities, compared to the current database. In addition, with this new database, homogeneity of management and operation among all Yazaki factories at European and North Africa levels is intended, allowing for easier and better analysis of results through the uniformity of collected data. It is intended to improve the flow of information, as well as to prevent and reduce internal defects and their recurrence.

Within this project, that focuses on the improvement of internal defect management and data flow, there were set four main objectives:

- The update of documents to be better suited for high voltage (HV) production.
- An improvement in the team communication process.
- The implementation of the Quality Data System for registration and treatment of internal defects.
- An improvement in the defect investigation and response, with a reduction in internal defects.

2. Methodology

The project was conducted during an eight-month internship, from 6th of October 2020 till the end of May 2021. To carry out this process, the Action Research (AR) methodology was applied, with the purpose of investigating the initial situation and, subsequently, proposing and implementing improvements in the specific context (Koshy et al., 2014).

The AR was developed from the case study methodology and its application was initiated in the social sciences field, with Kurt Lewin main contribution (Bhat et al., 2021; Erro-Garcés & Alfaro-Tanco, 2020). For College et al., the AR is applied so that the researcher who is part of the study develops a case study in combination with primary data in order to determine the responses to the research questions with more insights (as cited in Bhat et al., 2021). Basically, as research is about generating knowledge, Koshy et al. (2014) explain that AR method "creates knowledge based on enquiries conducted within specific and often practical contexts". Meyer refers that the main advantage of the AR is the fact that it is a methodology that focus on providing solutions to practical problems and provides the practitioners empowerment, by making them participate in the research and also the subsequent development or implementation activities (as cited in Koshy et al., 2014).

Koshy et al. (2014) and Erro-Garcés and Alfaro-Tanco (2020) provide important features of the AR approach, which are essential to be considered in this project. These features are presented in Table 1.

Table 1- Features of Action Research approach

Features of the Action Research approach	
Koshy et al. (2014)	Erro-Garcés and Alfaro-Tanco (2020)
It is used for practice improvement. It involves action, evaluation, and critical reflection – through the combination of action and research.	Dual objective: research and practitioners' contributions, both defined in a joint way to avoid hierarchy level among them. So, they consider that it is important to differ between practitioner's contribution and managerial contributions.
It is participative and collaborative; it is undertaken by individuals with a common purpose.	Researcher–practitioner interaction: This has a double implication: the researcher acts as an agent of change; the practitioner has an active participation in all the stages of the process. This implies active and participatory collaboration among both agents.
It is situation-based and context specific.	Gathering data: According to Coughlan and Coghlan (2002), "action research can include all types of data gathering methods" (p. 238). This is linked with the fact that having a holistic view of the problem to be analyzed implies to get information from multiple sources
It develops reflection based on interpretations made by the participants.	Cyclical nature: AR projects are characterized by including continuous feedbacks in all the stages, which provoke spiral cycles (Ballantyne, 2004); AR methodology can be analyzed as a cycle where new AR studies can be further developed.
Knowledge is created through action and at the point of application.	
It can involve problem solving if the solution to the problem conducts to the improvement of practice.	
Its findings will emerge as action develops, but these are not conclusive or absolute.	

According to Coughlan and Coughlan (2002), this methodology is employed with a cycle, presented in Figure 1, composed by one pre-stage – context and purpose -, six main stages – data gathering, data feedback, data analysis, action plan, implementation and evaluation -, and one meta stage - monitorization.

The AR cycle is focused on a problem, which is expressed in a research question(s). The research question to be studied in this specific project is expressed in the next question.

RQ: "How to improve the management of internal defect and improve the data flow of the Customer X high voltage production area?"

To generate solutions for this research question, the next steps were pursued.

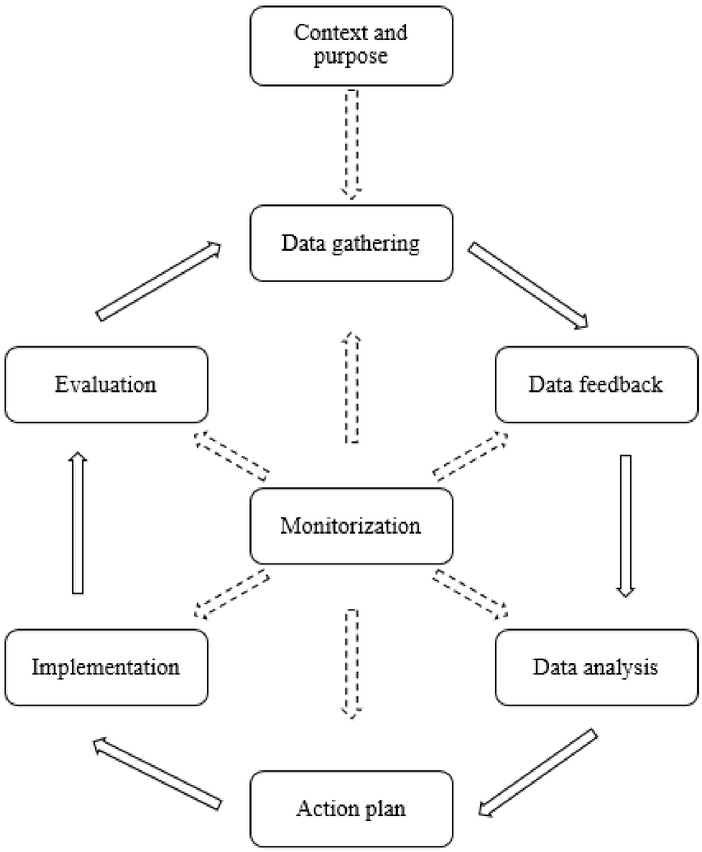


Figure 1- Action Research Methodology (adapted from Coughlan and Coghlan, 2002)

In the first place, understanding the context and purpose of the project and organization, with integration in the company and observation in factory floor. It was crucial to start this project with training together with the quality control team to understand the quality daily work routine, the entire production line, products, and work environment of the operators.

After integrating the organization and understanding the context, an analysis of the initial situation was conducted, with the application of a BPM lifecycle. First, the data collection was performed through a triangulation of data sources: document and report analysis, observation on the factory floor, and informal interviews with employees involved in the process. Triangulation is mainly applied to provide more trust in data analysis and to increase the validity of inference in qualitative and quantitative research (Kern, 2018; Ubeda et al., 2017).

The next step had to do with the organization of the information which had been collected, so that it was possible to analyze it critically, through the creation of an AS-IS Model with the BPMN 2.0 tool. A critical analysis was made of the AS-IS Model together with an Ishikawa diagram.

After analyzing the collected data and identifying the critical points, the improvement proposals are presented, and improvements implemented. For the implementation of the improvements, namely the QRQC Whiteboard and Quality Data System (QDS), the PDCA cycle was applied, for the pursuit of the continuous improvement of the processes. An internal defect investigation was also presented, where quality tools and concepts, used in the automotive industry were applied, within the scope of Total Quality Management (TQM).

Next, the evaluation consists of the discussion of the improvement implementation results and conclusions are elaborated. Following the evaluation, which was conducted, it was possible to identify critical points for improvement.

During the AR cycle a monitoring of each of the six main stages was performed. Usually, an Action Research cycle always originates a new Action Research cycle, providing continuous knowledge and improvement (Coughlan & Coghlan, 2002).

The presentation and analysis of the practical project was supported by a literature review of the applied concepts, which was carried out throughout the period of the internship.

2.1. Report structure

This report is divided into five main chapters, each of which will have sub-chapters:

Chapter one – The first chapter presents a brief introduction and contextualization of the practical project to be developed, covering the automotive industry, particularly the global introduction of hybrid and electric vehicles, along with the quality concerns and safety risks they involve. After the introduction, are presented the motivation and work contextualization are presented and the objectives to be attained and, finally, the structure of the report.

Chapter two – This chapter describes the methodology that was used for the development of the project in a theoretical perspective, as well as the way it was applied in this particular work.

Chapter three – In chapter three, a review of the concepts that will support the development of the practical project and the evaluation of its results is presented. First, an analysis of the concept Quality Management was performed, with emphasis in Total Quality Management and in the quality tools applied in the practical work. Then, the theme of quality control in the automobile industry, with a particular focus in the high voltage production. Next, the Business Process Management tool, and Information Systems, namely quality data systems and the Unified Modeling Language are explored.

Chapter four – Concerning chapter four, the development of the practical project is presented and discussed. First, the company in which the project took place, Yazaki, is introduced. Afterwards, the analyse of the initial situation of the project is presented, and improvement actions are proposed, analysed and implemented. For each one, a subchapter with the methodology applied, results discussion and lessons learned is included.

Chapter five – Finally, the core conclusions of the project and guidelines for future work are presented.

3. Theoretical Background

3.1. Quality Management

3.1.1. Quality Management: concepts and evolution

The term ‘quality’ does not have a concrete and unique definition (Gudanowska, 2010, Urban, 2007, as cited in Olszewska, 2017). Gryna (2001) summarize quality as “external and internal costumer satisfaction”. According to Pinto and Soares (2018), quality can be defined as the “degree of satisfaction of requirements given by a set of intrinsic characteristics of an object”, including the requirements and expectations of customers. However, Shewfelt (1999) affirms that “it is generally agreed that consumer satisfaction is related to product quality”, but also expresses that quality can be characterize as “an absence of defects or a degree of excellence”. Ultimately, he highlights that “what quality is then depends on the perspective of the viewer” (Shewfelt, 1999).

Shewfelt (1999) emphasizes the definition of quality under different orientations, namely a product orientation and a consumer orientation. Product orientation underlines quality as “a set of attributes inherent in a product that can be readily quantified during handling and distribution”. Consumer orientation defines quality in terms of “consumer satisfaction, a concept less tangible and less quantifiable” than the previous one.

Olszewska (2017) considers quality management as a "dynamically developing research discipline and scientific consideration" and as a “very broad concept”. According to Hamid (2019), the quality management evolution has incorporated changes in the principles, systems, tools and techniques over time. In his literature review he concluded that over time, as "the focus has changed, the principles have also changed and as the principles have changed, the systems, tools and techniques have also changed in quality management field". This statement highlights a relationship and dependence on the systems, tools and techniques in the principles, and the principles in the focus.

Hamid (2019) affirms that quality management has been studied since the beginning of the 20th century. The interest sparked when Fredrick W. Taylor emphasized the importance of quality inspection (Hamid et al., 2019). Quality is an area that went by a several amount of concept progress, as Chung et al. considered being the four main evolution phases: inspection, quality control, quality assurance and finally TQM (as cited in Othman et al., 2020). However, in consistence with Hamid et al. (2019) considering research about quality management over time, there where five main dimension evolutions: Quality Inspection (1900s ~ 1920s); Quality Control (1920s ~ 1950s); Quality Assurance (1950s ~1980s); Total Quality Control (1960s ~ 1990s); and Total Quality Management (1980s ~ present). The first two dimensions with product focus, the third with process focus, the fourth with system focus, and the present one with focus on the people in organization, specific in network and smart environment (Hamid et al., 2019). Figure 2 presents some question examples related with each focus.

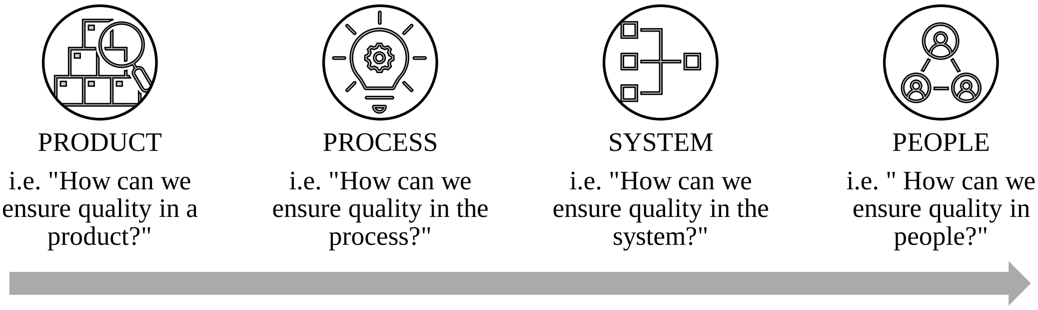


Figure 2- Evolution of QM focus (adapted from Hamid et al., 2019)

Nevertheless, as an evolution in the quality section, Chung et al. referred that Total Quality Management has its origins in the beginning of 1920, a decade when product quality control was employed together with statistical theory (as cited in Othman et al., 2020).

After World War II, two aspects had a major influence in the quality concept: the Japanese revolution and the importance of quality in the public opinion (Gryna, 2001). The TQM concept was established in Japan, guided by acquaintances J. M. Juran, W. Edwards Deming, A. V. Feigenbaum, Philip Crosby and Kaoru Ishikawa, and are summarized in Table 2.

Table 2- Quality concept highlight (adapted from Gryna, 2001)

Research person	Quality concept highlight
J. M. Juran	Defended a balanced attitude applying "quality management, statistical and technological concepts"
W. Edwards Deming	Summarized fourteen main quality points focused on organizational management, conveying, similar to Juran, a wide view of quality
A. V. Feigenbaum	Addresses the idea of total quality control, in relation to all the functions of an organization
Philip Crosby	Considers zero defects as the only standard of performance and defines quality strictly as "compliance with requirements"
Kaoru Ishikawa	Presented to the Japanese community the application of simple quality tools for analysis and problem solving

A research on the publications from the year 1995 till 2015 presented in the Scopus Database, showed that the issue of Quality Management was a trend in 2009, and in the year 2015 was still current in many fields, such as Medicine, Engineering, and Business, Management and Accounting (Olszewska, 2017).

Corresponding to what was described in Teixeira (1999) work by referring to main guidelines, TQM solutions can be developed in any type of corporation and they should cultivate frameworks suitable for their manager’s vision of quality management. In the context of the construction sector, according to Lasserre et al. and Torbica et al., what they perceived was the lack of motivation by the contractors in upgrading the quality in their projects and the organization in general (Othman et al., 2020).

In Fundin et al. (2020) article, is presented an interesting perspective of future evolution of QM, namely for the year 2030. The future QM themes consist of: (a) systems perspectives applied, (b) stability in change, (c) models for smart self-organising, (d) integrating sustainable development, and (e) higher purpose as QM booster. The study also identified six positive QM values and aspects that need to be preserved and nurtured: (1) value as a guiding and unifying WHY for the entire organisation; (2) leading with a systems perspective and in collaboration; (3) belief in human potential, aiming to strengthen the system around people, for people; (4) providing systematics and methodologies for inquiring and understanding underlying causes and variation; (5) research that is close to practice, relevant, and interactive; and (6) knowledge on HOW to develop organisational capacity for learning, change, and adaptation.

3.1.2. Total Quality Management

With increased competition in the markets and greater demand from customers, companies are required to provide products with higher quality. Thus, it has become essential to adopt quality management techniques, such as the application of TQM (Ferdousi et al., 2018).

Like Chung et al. explain, TQM is a philosophy with the aim to achieve the quality requirements and expectations of the customer, and that delivers a variety of long-term benefits (as cited in Othman et al., 2020). TQM is characterized as a collective and interconnected system of quality practices, associated with organizational performance, and it is demonstrated to be effective in a diversity of industries, particularly in the manufacturing sector (Othman et al., 2020; Valmohammadi & Roshanzamir, 2015). It focuses on the application of methods and human resources to enhance the processes of an organization, allowing, among other factors, the improvement of the quality of products and services, the cost reduction, the customer satisfaction, the improvement of flexibility and the adaptation of the company to the Marketplace (Ferdousi et al., 2018; Yu et al., 2020).

With the changes published in the new standard ISO 9000: 2015, the quality principles have been changed, having been reduced from eight to seven (Vexillum, 2021). The seven principles of TQM are described as fundamental rules or beliefs in the management of an organization, focused on continuous improvement, and for the customer as well, considering the needs of all the involved parties (Diamandescu, 2016; Pinto & Soares, 2018). The seven principles of TQM are presented in Table 3.

Table 3 - Principles of TQM (adapted from Vexillum, 2021)

Principle	Description
Costumer focus	Organizations depend on their customers and therefore should understand their current and future needs, satisfy their requirements and strive to exceed their expectations
Leadership	Leaders establish unity in the organization's purpose and direction. They must create and maintain an internal environment that allows the full involvement of people to achieve the organization's goals.
People’s Commitment	People, at all levels, are the essence of an organization and their full involvement enables their capabilities to be used for the benefit of the organization.
Process approach	Desired results are most efficiently achieved when resources and related activities are managed as a process.
Continuous improvement	Improving the overall performance of an organization should be a permanent objective of that organization.
Evidence-based decision making	Effective decisions are based on data and information analysis.
Relationship management	An organization and its stakeholders are interdependent, and mutually beneficial relationships enhance their ability to create value. Currently, companies must know how to manage not only suppliers, but all interested parties, such as employees, surrounding communities, regulatory bodies and competitors.

According to a study with thirty two participants made by Othman et al. (2020), in a construction company in Malaysia, the results indicated that the factor associated to employees was the one that most critically affected the TQM implementation.

The application of TQM, with the purpose of developing a culture based on quality principles, leads to the continuous improvement of both methods and processes. Thus, the investment in TQM practices will help to reduce and prevent the nonconforming products and, consequently, the associated costs, increasing the motivation of the employees and also improving the organizational environment and the company’s image from the client point of view (Pinto & Soares, 2018).

Prajoso and Sohal (2006) defend that the concept of TQM can be approached based on two different business orientations: customer orientation and process orientation. In customer orientation, organizations are focused on obtaining a market advantage over competitors, in order to attract more customers with differentiated products and competitive prices. On the other hand, under the guidance of processes, companies aim to find improvements in the efficiency of processes, with the objective of eliminating defects and waste.

In the Total Quality Management (TQM) approach there are a set of tools that, implemented in an organization, help in the prevention and reduction of internal defects and in general avert poor quality products (Kahya et al., 2020; Othman et al., 2020).

3.1.3. Continuous Improvement: the PDCA cycle

The PDCA cycle, also known as Deming Cycle or Shewhart Cycle, follows four steps – Plan, Do, Check and Act - in relation to the planning, implementation, control and continuous improvement of the processes (La Verde et al., 2019; Realyvásquez-Vargas et al., 2018).

According to Realyvásquez Vargas et al. (2018), several authors affirm that the PDCA cycle is not just a simple tool. They defend that it is a philosophy of continuous processes improvement introduced in the organizational culture of companies. The PDCA cycle is represented in Figure 3, with a description of each of the phases, according to Gorenflo et al. (2009) and La Verde et al. (2019) explanations.

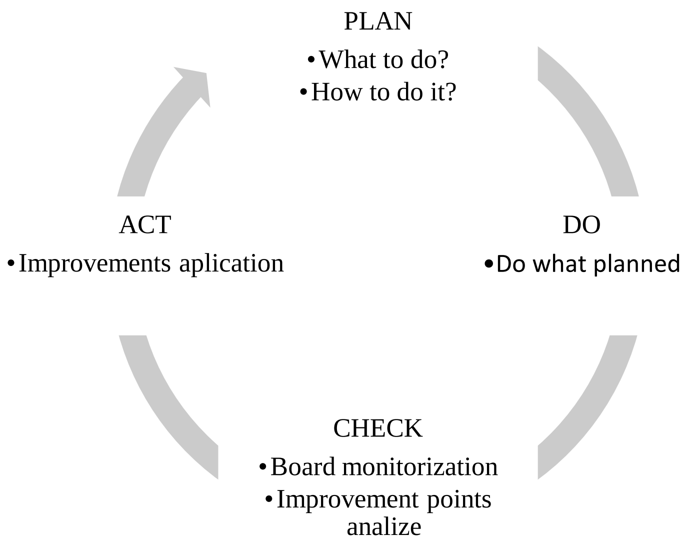


Figure 3- PDCA cycle (adapted from La Verde et al., 2019)

Plan – Consists in establishing the objectives and processes necessary to deliver results according to needs and expectations. In this first phase, improvements and opportunities are identified, with a subsequent identification of the priorities. Likewise, according to an analysis of the initial situation and problem identification, possible solutions are proposed to solve it.

Do – The second stage is when the planned actions are put into practice according to the established procedures and timelines. Additionally, unexpected events, learned lessons and acquired knowledge should be considered.

Check – Consists in an analysis through a monitorization and evaluation of the processes results, and characteristics of the actions implemented, in such a way to verify that there is consistency between what is achieved and what has been planned. A before and after comparison is performed verifying whether there were improvements and if the established goals were achieved.

Act - It is the phase where there is a periodic checking that the system is consistent with what is planned and appropriate actions for the continuous improvement of operational, organizational and management processes are taken. In case objectives had been reached, this phase involves the development of methods aimed to standardize the improvements. In case that data is insufficient or circumstances had changed, or even the project is abandoned and a new one has begun from the first stage, the verification is repeated to obtain new data and re-test the improvement. (Gorenflo et al., 2009; La Verde et al., 2019)

In terms of practical applications, Matsuo (2013) concluded that quality management based on the PDCA cycle is an effective tool for enabling workplace learning, in a way that it allows to better generate and share valuable new knowledge and discard outdated knowledge in the workplace. La Verde et al. (2019) described a successful PDCA application for a laboratory management, that demonstrate positive results in terms of material savings, job optimization, quality of results and organization of internal processes. Realyvásquez-Vargas et al. (2018) concluded that the PDCA cycle enables the detection of improvement opportunities and also their development and implementation in lean manufacturing projects.

In their paper, Nsafon et al. (2020) proposed a hybrid model based on integrating AHP-VIKOR with the PDCA cycle, for a renewable energy installation plan in rural communities in Africa. AHP-VIKOR can be divided in two concepts: AHP is a theory of measurement through pairwise comparisons and depend on the judgments of experts to obtain priority scales, and VIKOR focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria (Zhu et al., 2015). They describe that "the uniqueness of this model is the management support characteristic of the PDCA cycle that provides coherence between the planning process and the actual project, as well as criticisms and responses for the proposed system". The results show that the selected hybrid energy system does guarantee a reliable system configuration and economic benefits (Nsafon et al., 2020). Nguyen et al. (2020) also approach in their research the application of PDCA combined with other support tools, in this case for the quality improvement of sustainable packaging, emphasizing the benefits of the PDCA methodology in quality improvement.

In the current pandemic reality, Chen et al. (2020) presented a study with the application of the PDCA cycle in a COVID-19 intensive care unit (ICU). The PDCA cycle was positively applied to standardize the nursing management in the ICU, by developing and applying effective nursing management approaches.

3.1.4. Quality tools for internal defect management

For a company to be a leader, it is essential to maintain a sustainable competitive advantage, which is achieved by prioritizing high quality products (Ahire & Dreyfus, 2000). According to Bayazit and Karpak (2007), zero defect is one of the priorities and focus for quality control of companies from different industries.

In the automobile industry, quality control aims to reduce internal defects, namely to reduce levels of rework and scrap (Ben Ruben et al., 2017). In addition to causing security problems, non-compliant products involve a high monetary cost for the organization and can also involve clients' claims (Abrahams et al., 2015).

Quality management tools allows to detect incompatibilities and to prevent them, by detecting the source or even looking for the causes that originated problems in these sources. These methods, when cleverly applied, allow to increase the level of quality of the products offered (Czerwinska et al., 2020).

Nagyová et al. (2019) presented a application of a Root Cause Analysis (RCA) with quality tools in the automobile industry for claim solving, and after a literature review defined RCA as "a step- by-step method that leads to the discovery of faults or root cause".

Quality tools and RCA are not just applied in the industry area. Brook et al. (2015) showed that quality tools can be applied in a medical context for RCA of serious adverse events, designed with two aims: "the identification of factors that underlie variation in performance or that predispose an event toward undesired outcomes and the development of effective strategies to decrease the likelihood of similar adverse events occurring in the future". The quality tools emphasized in the study were: the 5Why method, Ishikawa diagram, causal tree mapping, affinity diagrams and Pareto diagrams (Brook et al., 2015). In another scenario, Ahmed and Rezouki (2020) applied in their research a combination of Ishikawa, Pareto diagram, and Why techniques to perform a root cause analysis to specify the main factors that lead to bad selection for the highway projects in Iraq, analysing the corruption factors involved. These were the same three tools applied by Al-Zwainy et al (2018) in their research to identify and diagnose the causes of construction project failure by utilizing different project management process groups. According to Pacana and Siwiec (2021) study, in a case in the complex aerospace area, together with non-destructive tests, it was possible to apply simple and complementary quality management techniques - 5W2H method, Ishikawa diagram and 5 Why method - to successfully identify the root causes of a steel product problem and implement corrective actions.

When performing a root cause analysis, in addition to determining the final root causes, it is also important to propose solutions for the current problem and to prevent future ones (Santen et al., 2019).

Next, some quality tools that will be addressed and applied in the context of the practical project are briefly described.

3.1.4.1. Data Collection Forms

A check sheet, as a data collection form, is one of the seven basic quality tools (Uddin, 2021). Check sheets or forms are applied to record data in a simple and accessible way (Dale, 2003; Leavengood & Reeb, 2002). It can be applied to collect and determine any unfavourable events that may occur within the process, such as non-conformities positions and items, machine or associated equipment breakdowns, and non-value-adding activities (Dale, 2003).

It is a document which is prepared previous to the data collection and recording, and for its construction, the six steps proposed by Dale (2003) and presented in Figure 4, can be followed.

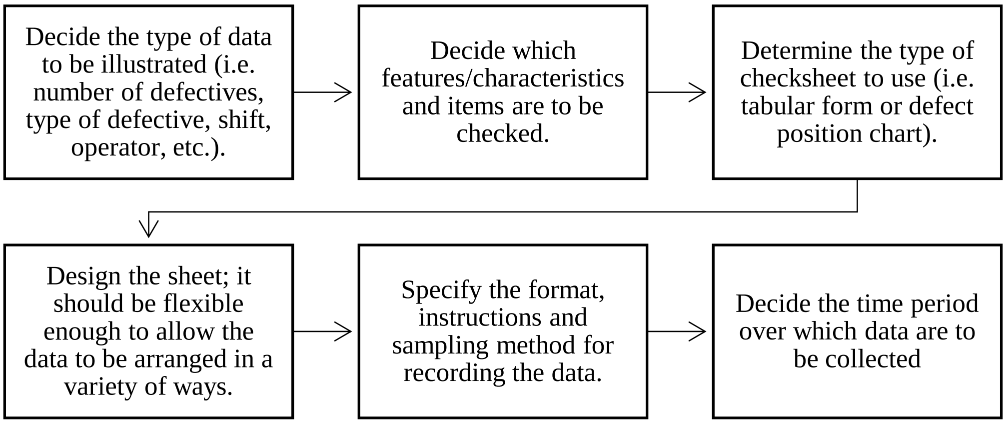


Figure 4- Check Sheet creation steps (adapted from Dale, 2003)

Uddin (2021) shows the aplication of a check sheet to collect information about defects and variation in grading, in the the hardwood flooring industry. Leavengood and Reeb (2002) affirm that the check sheet is a helpful tool for collecting data for the Pareto diagram, and also presents a practical example of this combination.

3.1.4.2. Pareto Diagram

The Pareto diagram is a form of bar graph that sorts the results from the more frequent one to the less frequent one. This graph has two vertical axes: the one in the left shows the ocurrence of each event and the one from the right represents the cumulative sum of the occurrence of the events that could be solved, usually in percentage (Dale, 2003). The goal is to prioritize events, highlighting the reality that most problems come from a few causes. The Pareto analysis can indicate which problems to solve and in what order, along with providing a comparison over different time periods (Dale, 2003).

The Pareto chart was created when Wilfredo Pareto, an Italian scientist, that understood that 80% of the wealth was received by 20% of people in Italy (Leavengood & Reeb, 2002). M. Juran converted a 80/20 Pareto rule to develop the 80/20 Principle, also known as the Pareto Principle (Realyvásquez-Vargas et al., 2018).

The Pareto diagram main advantages are that: it decomposes a problem into categories or factors; it identifies the key categories that contribute the most to a specific problem; it allows prioritizing the vital problems over the rest, and it shows where to focus efforts (Realyvásquez-Vargas et al., 2018).

For the Pareto diagram construction, the ten steps designed by Dale (2003), presented in Figure 5, can be followed.

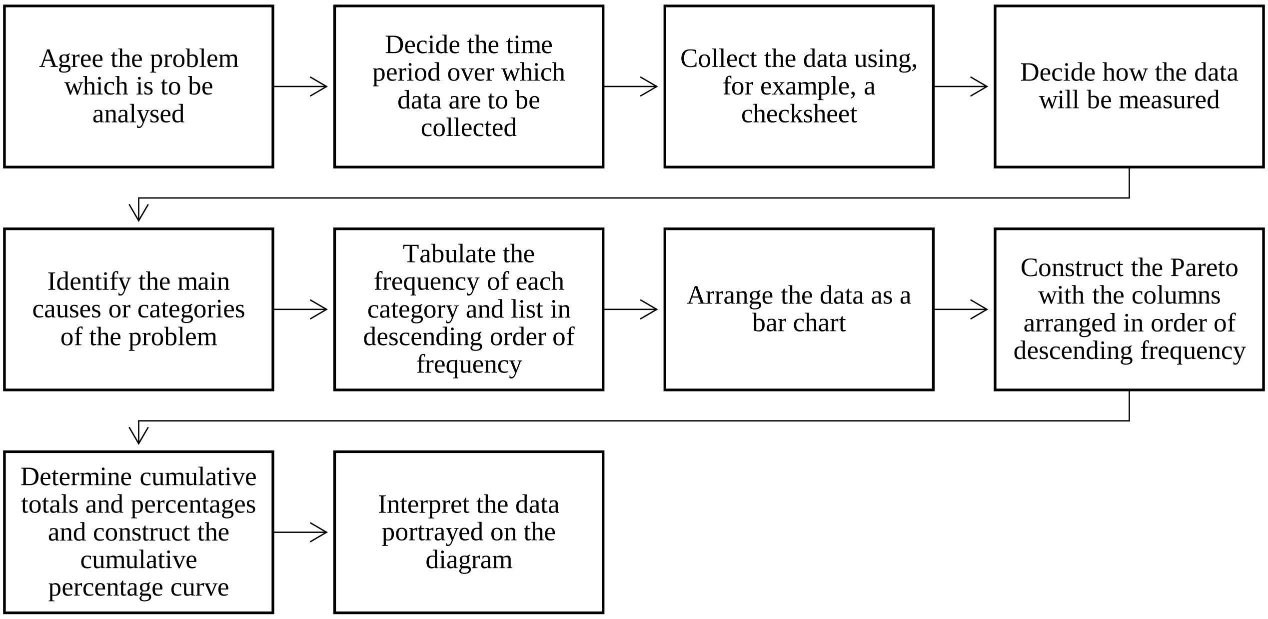


Figure 5- Pareto Diagram creation steps (adapted from Dale, 2003)

Roriz et al. (2017) present an industrial case study where a Pareto diagram, was applied to analyze the initial situation, and to identify, from the various non-conformities, the one that was detected more frequently. This Pareto diagram is presented in

Figure 6, where can be observed as an example of the Pareto structure that correspond to what was previously described by Dale (2003).

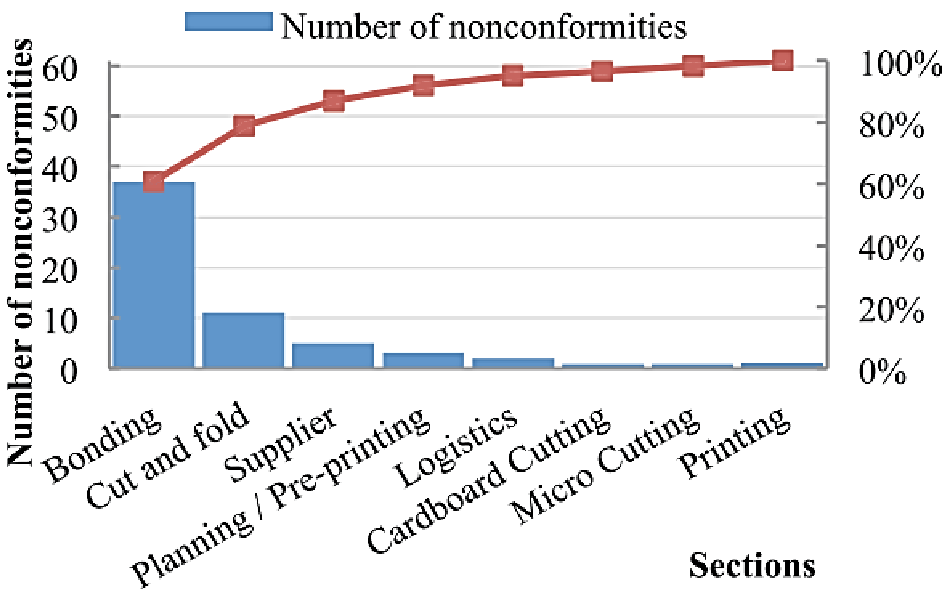


Figure 6- Pareto Diagram example (Roriz et al., 2017)

Realyvásquez-Vargas et al. (2018) in their study supported the idea that the combination of PDCA cycle, Pareto diagram and flowchart help to globally increase the competitiveness of manufacturing companies.

3.1.4.3. 5W2H Method

The 5W2H method can be used to make a characterization of the problem, highlighting the most important information, merely by executing seven questions: five W's – what, why, where, who, when –, and two H's – how and how much (Czerwinska et al., 2020; Pacana & Siwiec, 2021). In this way, a clear and short definition of the problem can be obtained (Czerwinska et al., 2020). The 5W2H method is also applied to help in the development of efficient action plans, with the aim to make better decisions and to better understand what needs to be done, in a problem solving or process implementation (Nagyová et al., 2019).

Czerwinska et al. (2020) mention the importance of the traditional 5W2H method being implemented in an analysis cycle, in which its output is the input of another quality management tool, the Ishikawa diagram.

3.1.4.4. Ishikawa Diagram

The Ishikawa diagram also known as cause and effect diagram, is utilized in a way to distinguish the possible causes and identify root causes (Pacana & Siwiec, 2021). This diagram have the format of a fish, the problem to be analysed is identified in the section named fish head, and the potential causes and sub-causes are exposed in the fish bone structure (Luca & Pasare, 2019). An example of the Ishikawa diagram structure is presented in Figure 7, and it was applied in Botezatu et al. (2019) industrial processes investigation to focuses the aspects able to affect the roughness of the surfaces obtained by milling on cast iron workpieces.

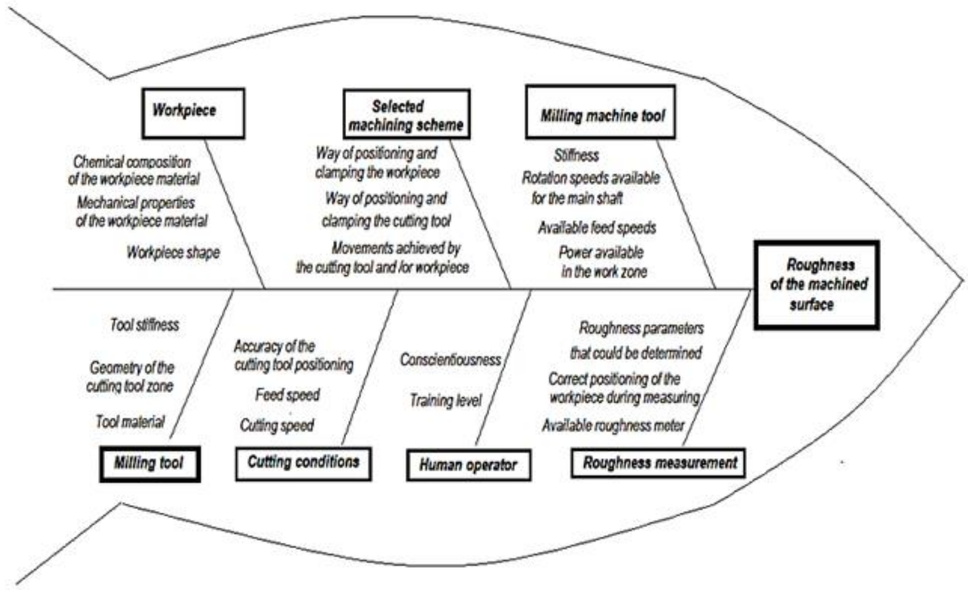


Figure 7- Ishikawa Diagram example (adapted from Botezatu et al., 2019)

In the manufacturing processes, the quality characteristic of the product can be affected by the resources often known as 5M1E: Man, Machine, Materials, Method, Measurement, and Environment. This are the resources normally applied in the first level of the Ishikawa Diagram, where the possible causes of indications are identified (G. J. Duan & Yan, 2020; Pacana & Siwiec, 2021). For Duan (2020), this six resources are involved in all manufacturing process and are described as inputs in the manufacturing activities, resulting in data as output.

Chokkalingam et al. (2017) affirm that the major advantage of applying the Ishikawa diagram is that it is a visual tool, in which all the information collected is in a graphic structure. As a visual tool, the Ishikawa chart encourage and appeal team members to contribute for the problem analysis (Brook et al., 2015).

In Chokkalingam et al. (2017) defect investigation, it was used a Ishikawa diagram different from the traditional one. It was applied a quantitative Ishikawa diagram, in which a weight was attributed to each cause and its percentage of influence in each defect, and all this data was presented in the diagram.

3.1.4.5. 5 Whys Method

The 5 Whys method is an iterative interrogative technique applied to explore cause and effect relationships associated to a specific problem, quickly implemented in the Toyota corporation (Nagyová et al., 2019; Zasadzień & Midor, 2018). It is considered a type of brainstorming methodology, where the main objective is to identify the root cause of the problem, and consists in asking five times the question "Why?" (Ahmed & Rezouki, 2020; Pacana & Siwiec, 2021). Each answer to a 'why' question forms the basis for the next 'why' question (Nagyová et al., 2019). In theory, the purpose of this method is that after asking 'why" five times one of the 'why' is likely to reach the root cause (Al-Zwainy et al., 2018).

For Al-Zwainy et al (2018) an advantage of the 5 Whys tool is the fact that it is simple to use and it is easy to complete without statistical analysis. Card (2017) defends that 5 Whys is a common tool for RCA because of a combination of pedigree, simplicity and pedagogy. Card (2017), in a way considers the simplicity of the tool as an advantage, but also states that the main problem of applying the 5 Whys is the fact of completely simplifying the process of exploring the problem. Thus, the author states that this tool forces users to pursue only a single analytical path for all the problems, insisting on a single root cause as a target for solutions and assumes that the fifth 'why' is inherently the most effective and efficient spot to intervene. He concludes that the tool "can illustrate both the need for depth - as a positive example - and the need for breadth - as a negative example -, when analyzing complex problems" (Card, 2017).

Al-Zwainy et al (2018) say that the 5-why analysis technique can be used individually or as a part of the Ishikawa diagram. In the Ahmed and Rezouki (2020) study, for example, they applied the 5 why to "filter" the Pareto diagram results. In their paper, Zasadzień and Midor (2018) applied the 5 why tool, together with other quality engineering tools, to improve the maintenance processes in a small company providing services for the agricultural and construction industries.

3.1.4.6. Quick Response Quality Control

The Quick Response Quality Control (QRQC) tool has Japanese roots, since it was developed at Nissan and is grounded in the Japanese attitude known as *San-Gen-Shugi*, in combination with a daily management activity to support problems, and its analysis and resolution in a period of time well-known by every participant (Brito et al., 2017; Nedeliaková et al., 2018). The name San (Three) Gen (Reality) and Shugi (Principle) is related with the three realities presented in Table 4, adapted from Sibaja research (as cited in Villalba et al., 2019).

Table 4- The three realities of San Gen Shugi (adapted from Villalba et al., 2019)

Realities	Questions
Genba?	Where is the work done? The real place?
Genbutsu?	The actual condition of the thing? The product, the defect?
Genjitsu?	Actual situation? The facts, not theory?

The QRQC tool is characterized as a simple and logical solution to a given production or business operation problem within the twenty-four-hour timeframe. It is a technique that focuses on quality control to guarantee that all problems are identified and isolated, and a subsequent solution is found and implemented quickly and effectively (Brito et al., 2017).

Brito et al. (2017) present QRQC as a philosophy capable to find the requirements related to the necessary speed in answering to the customers' needs, in such a way to become a crucial differentiator for the preservation of a sustainable business in a competitive market, regarding problem solving techniques on the manufacturing shop floor. In some cases, a quick response is vital to preserve the customer and processes, in order to prevent an unwanted situation (Nedeliaková et al., 2018). QRQC is considered a team approach with two important points that should be emphasized: the first one is "speed is a differentiating element in any quality system" and the second one is "speed is not synonymous of superficiality or careless approach" (Brito et al., 2017; Nedeliaková et al., 2018). In their study in a railway context, Nedeliaková et al. (2018) present an QRQC application based in four main activities and seven phases, as can be seen in Figure 8. The four main activities are the same ones applied by Villalba et al. (2019), in their study in the automobile area.

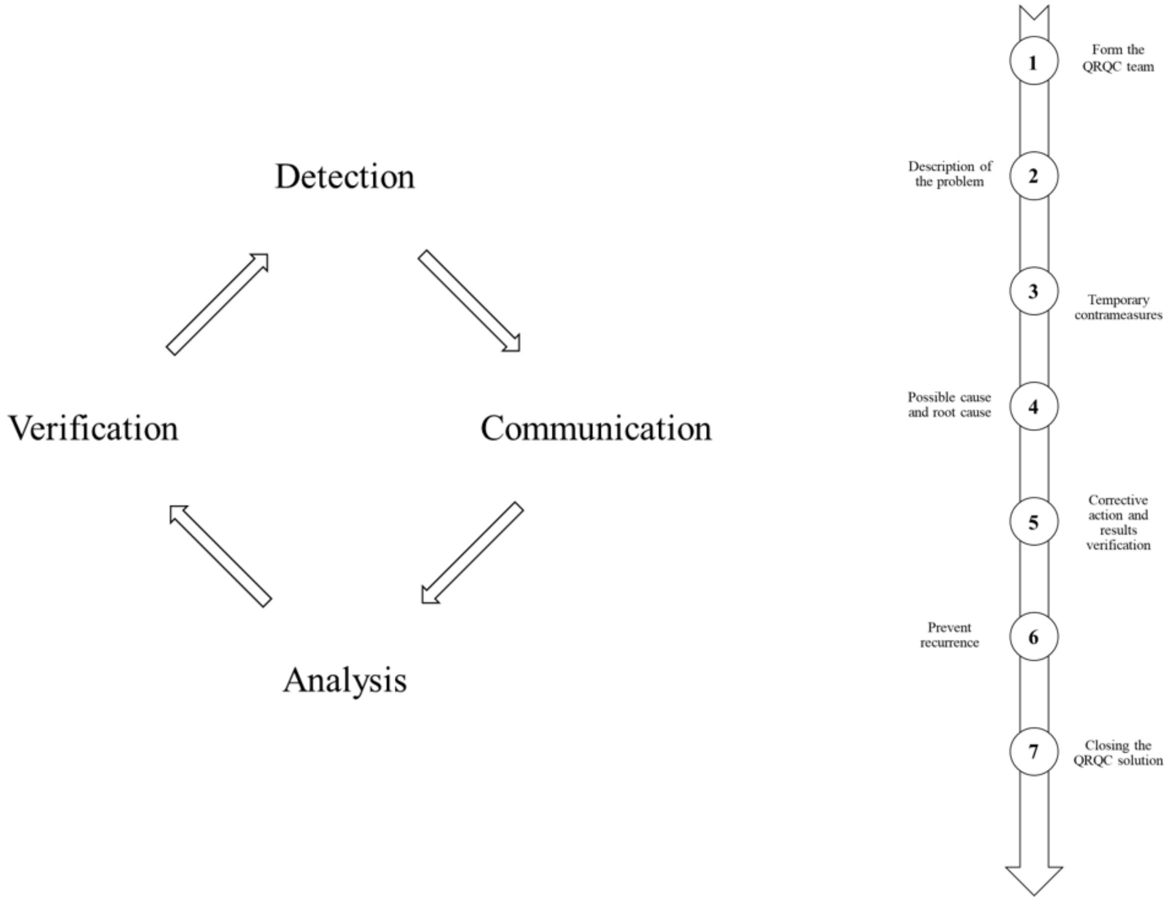


Figure 8- QRQC main activities and steps (adapted from Nedeliaková, 2018)

According to Wojtaszak, this tool is used in many different areas along the supply chain, as for example, it can be applied for customer complaints, internal scrap rates, Overall Equipment Effectiveness (OEE), accident rate, among other applications (as cited in Brito et al., 2017).

Rocha et al. (2017) present a quality management improvement implementation in the automotive sector. For this objective, the QRQC methodology was applied, involving the combination of four sequential quality tools: 5W2H, Ishikawa 5 Why Diagram and Pareto Diagram. In the context of the automotive industry, Villalba et al. (2019) describe a study with the aim to propose the application of visual management techniques and the implementation of a QRQC methodology for problem solving in distribution logistic activities and demonstrated, through a case study, the benefits in terms of customer satisfaction and reduction of internal costs.

The practical case results shown by Brito et al. (2017) concluded that "the QRQC constitutes an innovation in the field of quality management, as it combines management and attitude in order to solve, in a simple and logical way, the great part of the production problems". Nedeliaková et al.(2018) applied the QRQC tool in a rail transport process and concluded that it enables certifying products in rail transport to assure quality and accomplish delivery times.

3.2. Quality Control in the automobile industry

Next is present a review of the theme quality control in the automobile industry, with a particular focus in the high voltage production.

3.2.1. High Voltage wiring harness: hybrid and electrical vehicles

A wiring harness is a set of circuits - conducting wires - and components whose main function is to coordinate and control the entire electrical distribution system of the vehicle, as for example the headlights, the ignition, and the windshield (Yazaki Europe, 2021a).

Depending on the type of vehicle - combustion, hybrid or electric – there are two types of wiring that are produced: low voltage and high voltage (HV). The low voltage wirings are applied in so-called standard vehicles, as Otto et al. (2020) describe, which operate almost entirely through internal combustion engines. However, in the case of HV, their production is recent. It started in the last decade, as a response to the technological development of the automotive industry, commanded by consumer convenience and government requirements (Torrisi et al., 2005). The HV wirings are produced to be integrated in electrical and hybrid vehicles, that have started emerging successfully in the market over the past few years, in parallel with the increase in environmental and sustainability concerns. These concerns are also integrated in the government requirements which were previously referred. The difference between the two e-mobile vehicles - hybrid and electrical - is that a hybrid vehicle is "a vehicle with a conventional engine and an electrical motor", and electrical vehicles "have only an electrical motor, or multiple electrical motors, to propel them" (Otto et al., 2020). Thus, in a hybrid vehicle, the low-voltage and high-voltage wiring harnesses coexist (Q. Duan et al., 2021).

In hybrid and electrical vehicles, a power voltage of 520V is generally applied, which strongly differs from the 28V of the traditional system. The high value, which represents a quantity of more 492V than the ‘standard vehicle’, can conduct to an increased and risky number of quality problems, such as corrosion, electromagnetic noise, arc discharge and leakage (Q. Duan et al., 2021).

3.2.2. Quality concerns and safety risks

As previously mentioned, for a company to maintain its leadership in the market, a sustainable competitive advantage is needed, achieved with the prioritization of high quality products (Ahire & Dreyfus, 2000). For this purpose, strict quality control is required, involving effective management of internal defects. This management makes it possible to prevent defects by reducing the amount of rework and scrap (Ben Ruben et al., 2017). Defects are considered one of the wastes in manufacturing systems that most affect in a negative manner the delivery times, cost and quality of products, inducing critical situations between the company and the customers (Realyvásquez-Vargas et al., 2018). It is a severe matter when a nonconforming product arrives at the customer because, in addition to degrading the image of quality associated with the brand, it can cause safety problems, thus provoking serious dangers. This is of particular concern in some sectors, like the automobile industry (Lixandru, 2016). Leavengood and Reeb (2002, p. 2) explain the terms ‘nonconforming product’ and “nonconformity” in the follow way:

> “A nonconforming product is one that fails to meet one or more specifications, and a nonconformity is a specific type of failure. A nonconforming product may be termed defective if it contains one or more defects that render it unfit or unsafe for use. Confusion of these terms has resulted in misunderstandings in product liability lawsuits. As a result, many companies have adjusted their internal terminology and now use the terms ‘nonconforming’ and ‘nonconformity’ in favor of ‘defective’ and ‘defect’.”

Regarding safety in the wiring harness production, Q. Duan (2021) emphasizes two points to be considered, which are related to components integrated in the design of high voltage connection systems, namely a) high voltage interlock loop (HVIL) and b) environmental seal of connector, with both components examples in Figure 9.

Figure 9- a) High voltage interlock loop (HVIL) and b) Environmental seal of connector

3.2.3. Quality control to guarantee product quality

Duan and Yan (2020) describe the quality of a product as a set of requirements strongly linked to the product characteristics. According to Hu et al., in automobile production, an increase in product variation has a negative relationship with product quality, among other factors (as cited in Otto et al., 2020). According to Yingying et al. and Zhang et al.**,** the entire product manufacturing process can impact the product quality (as cited in G. J. Duan & Yan, 2020). Duan and Yan (2020) sustain that when a quality problem in the production process occurs, it was most probably caused by one or a combination of the 5M1E quality resources. For example, Gouiaa-Mtibaa et al. (2016) affirm that preventive maintenance policies can impact considerably in increasing equipment reliability as well as product quality. As Duan and Yan (2020) affirm, "The main purpose of product design is to provide product functions to meet user demand. The purpose of quality features is to ensure the realization of product functions". Established on the role of the quality features in the product manufacturing process, they can be divided into three categories: (1) Functional quality features - refers to a product function that ensures the user’s needs are met; (2) Direct quality features - meets the requirements of the functional quality characteristic; (3) Indirect quality features - derived during the design process to ensure direct quality characteristics, which are usually directly related to the product structure (G. J. Duan & Yan, 2020).

Linked to product design, Dr. Juran defended that quality cannot be inspected into the product, instead it should be designed into a product, at the earlier phases of product development (as cited in Gijo, 2021). However, Kujawińska and Vogt (2015) defend that controlling belong to the four main functions of management, together with planning, organizing, and leading. Among the various categories of controlling in the production companies, quality control is one that has a significant importance, and in the production processes is defined as "the evaluation of one or more features of the product, and comparing the result with the expectations" (Kujawińska & Vogt, 2015). In the automobile industry, quality control aims to reduce internal defects, namely to diminish levels of rework and scrap (Ben Ruben et al., 2017). In addition to causing security problems, non-compliant products involve a high monetary cost for the organization, and leads to the increasing costs of poor quality (Abrahams et al., 2015; Gryna, 2001). As presented by Gryna (2001), the costs of poor quality are defined as the "annual monetary loss of products and processes that are not achieving their quality objectives". The three variables that most affect the cost of poor quality are cost of nonconformities, cost of inefficient processes and cost of lost opportunities of sales revenue.

A sustainable competitive advantage in a market, as necessary in the automobile industry, is achieved by prioritizing high quality products (Ahire & Dreyfus, 2000). In a literature review on this topic, Luca and Pasare (2019) concluded that the product quality is a focus on the management of companies that intend to profit from the sale of products in competitive markets. Bayazit and Karpak (2007) affirm that zero defect is one of the priorities and focus for quality control of companies from different industries.

Duan and Yan (2020) strongly underline that the future of quality control passes by intelligent production systems using Internet of Things (IoT). They created a real-time quality control system (RTQCS), that relates historical data information with measured data flow information, with the aim of quality prediction (G. J. Duan & Yan, 2020).

3.3. Business Process Management

Business Process Management (BPM) is considered a tool with influence in several areas of computer research (Geiger et al., 2018). This tool has evolved from other management concepts, such as information technology innovation, quality management, Business Process Reengineering (BPR), process modeling and workflow management systems (Hassan, 2017).

BPM is used to model organizational processes in modeling languages, followed by the implementation of process models in executable software (Geiger et al., 2018). It is applied with the main objective of aligning business processes with the strategic objectives of the organization and with the needs of customers, changing the approach from functional orientation to process orientation (Arevalo et al., 2016; Nadarajah & Kadir, 2014). It is intended to ensure that critical processes that directly affect customers are efficient and effective. The main aspects of BPM are the structured, analytical, multifunctional process, focused on the customer and continuous improvement (Nadarajah & Kadir, 2014). The application of BPM allows the user to focus on the design, execution, monitoring and improvement of business processes. Currently, companies adhere to systems that support the execution of processes, to simplify and automate intra-organizational processes (Mendling et al., 2018).

For a correct application of BPM, the BPM Life Cycle is presented bellow in Figure 10, which essentially consists of six steps: process identification, discovery of the process, process analysis, process redesign, implementation of the process, and process monitoring (Dumas et al., 2018). This methodology is employed to help identify critical point and propose possible improvements (Dumas et al., 2018).

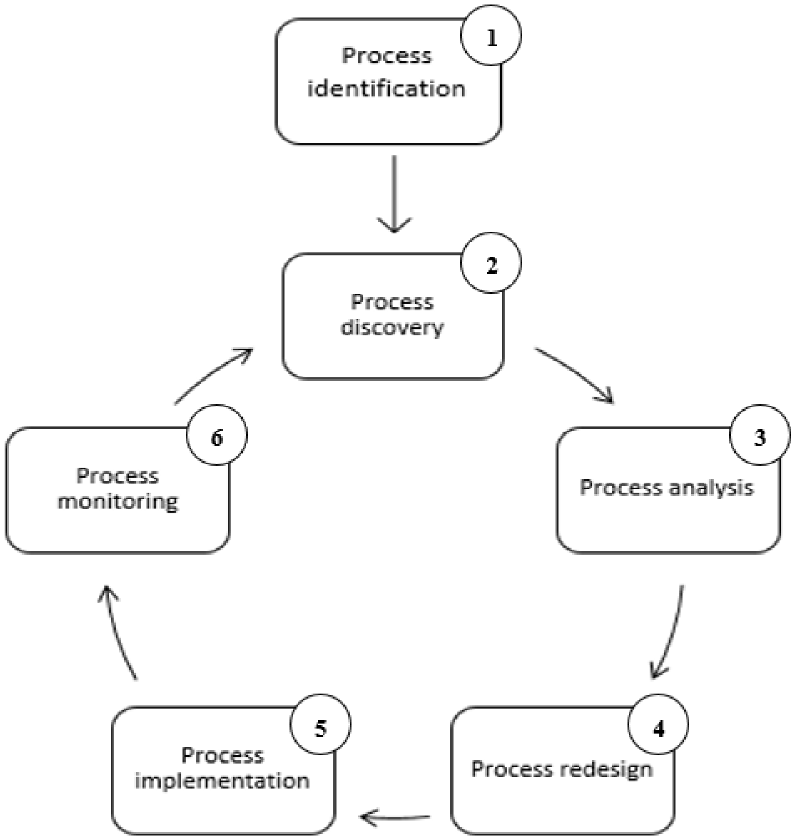


Figure 10- BPM lifecycle (adapted from Dumas et al., 2008)

3.3.1. Business Process Model and Notation

Business Process Model and Notation (BPMN) is a currently widely accepted language for process modeling, both in industry and in research. The model created by the Object Management Group (OMG), has the aim to describe functional behaviors of a business process (Boonmepipit & Suwannasart, 2019). BPMN is a standardized notation for communication between stakeholders in a business process and, according to Boonmepipit and Suwannasart (2019), the BPMN symbols are classified in four basic categories: a flow objective, data, a connecting object, a swimlane, and an artefact, exemplified in Figure 11. In Figure 12 is presented an example of a payment process modelled by BPMN, with application of symbols from the four previous categories.

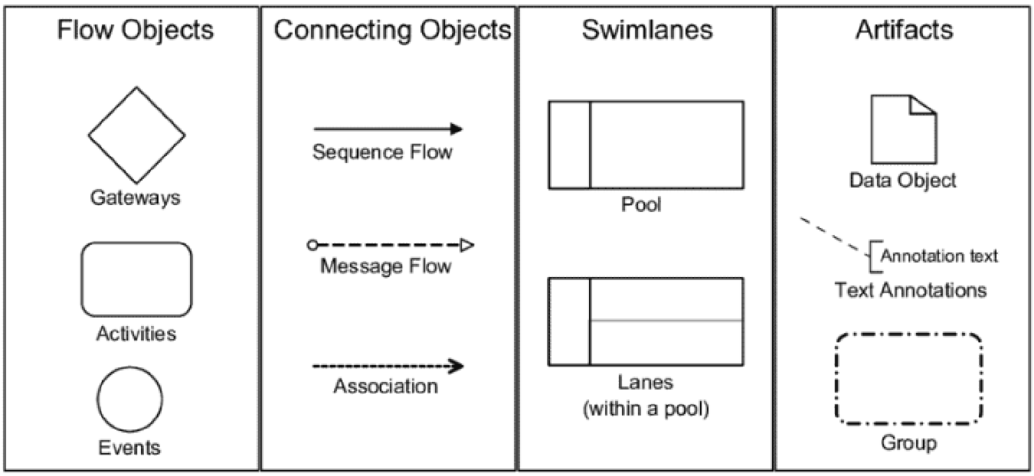


Figure 11- BPMN symbols (Simple Programmer, 2021)

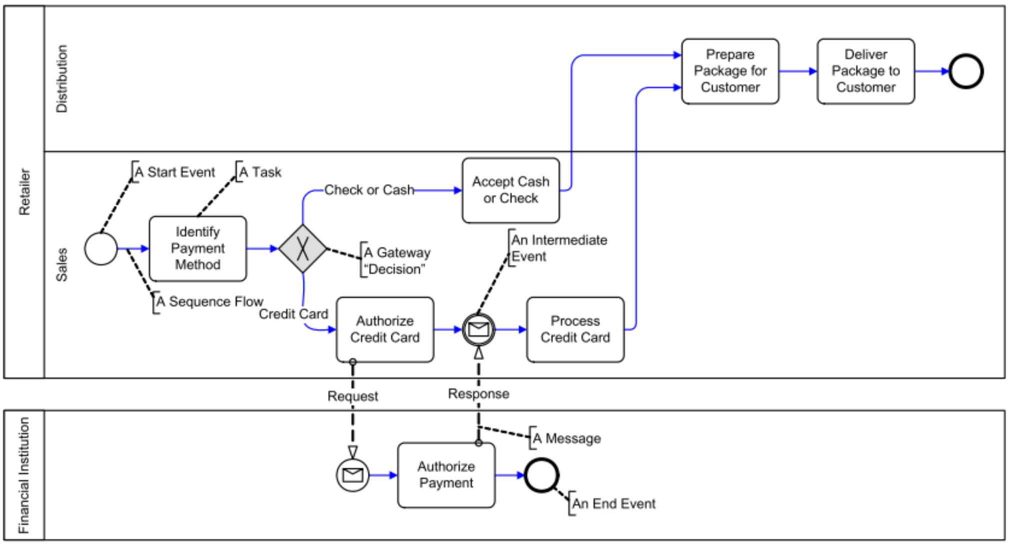


Figure 12- BPMN process example (Recker, 2010)

BPMN can provide the connection between the business process design and the process implementation (García-Domínguez et al., 2012). Another advantage of BPM is that allows to model different aspects and perspectives, namely, control-flow, organizational, case and time (Arevalo et al., 2016). However, Arevalo et al. (2016) emphasize a negative aspect of BPMN being the fact that it does not consider the time dimension in its models, and, to improve this tool, they applied a model-driven approach to propose a BPMN metamodel extension to address time-perspective. Boonmepipit and Suwannasart (2019) also highlight the fact that BPMN cannot handle the decision-making in business processes, but refer the Decision Model and Notation (DMN), created by OMG, as an alternative to complement BPMN and to manage the decision-making of business processes. In their study, Respício and Domingos (2015) approach the reliability of the overall BPMN processes and underline the fact that BPMN needs to include Quality of Service (QoS), because of the relevant aspects of QoS in business processes.

The latest version of BPMN 2.0, published in January 2011, emerged as a support for the execution of BPMN process models, adding a standardized serialization format to the standard. The implicit objectives of this update are to bridge the gap between process modeling and software execution (Geiger et al., 2018).

In their article, García-Dominguez et al. (2012) present a comparison of BPMN 2.0 with other notations, such as IDEF3 and Value Stream Mapping (VSM), through a case study based on a textual description of a manufacturing process. IDEF3 is a tool created to capture descriptions of sequences of activities, that applies two kinds of models: process schematics and object schematics (Mayer et al., 1995). With the comparison they concluded that: BPMN 2.0 can be characterized as a 'superset' of IDEF3 process schematics, even though BPMN cannot model the existing objects and their transitions like IDEF3 object schematics can, and that VSM is a more considerable simpler notation that can complement BPMN. Based on the case study results, they recommend the BPMN 2.0 application in two situations: "describing the information-intensive activities which support the manufacturing process", and "describing repetitive manufacturing processes with few variations" (García-Domínguez et al., 2012).

3.3.2. Bilateral effects between Business Process Management and Total Quality Management

As previously mentioned, one of the seven principles of TQM is the Process Approach, defined as the application of a process system, including the identification, management, and interaction between them. This approach allows the organization to reduce costs by simplifying and optimizing processes (Diamandescu, 2016; Pinto & Soares, 2018). This concept meets the main objective of BPM addressed by Mendling et al. (2018), which aims to simplify and automate intra-organizational processes.

With the application of BPM, a correct process structure is proposed to ensure correct organizational management, together with the implementation of quality tools. It is important to integrate process management with continuous improvement in order to ensure a more streamlined communication between processes to solve existing problems and increase the added value to those through continuous improvement (Bardales et al., 2020).

BPM is an important tool in several quality areas. The example presented in Saab et al. (2018) article is related to the control of predictive quality performance and the continuous search for quality anomalies in quality performance over time. In this case, it the author emphasize that is essential to understand what is the focus, and which analytical methods are required for implementing control and improving quality using BPM, as well as which analytical methods to detect and predict anomalies (Saab et al., 2018).

The TQM paradigm focuses on all processes in the organization and is primarily based on a systematic approach to BPM. The PDCA cycle can be considered as a general BPM structure within the TQM. That is, under the TQM model, BPM focuses on the integration of TQM principles, methods and tools in processes (Stravinskiene & Serafinas, 2020).

Ahire and Dreyfus (2000) claim that design management and process management are two important elements in the implementation of TQM, although they are drastically different in relation to their improvement, visibility and technical objectives. In order to analyze the impact of design management and process management on operational quality, the authors carried out a study that involved the participation of companies from different industries. They concluded that, with improvements in design and process management, there is a clear positive impact on internal quality data - such as scrap and rework reduction - and external quality data - such as the number of complaints, warranty, litigation, and market share. The results of this study also indicate that organizational learning allows companies with a mature implementation of TQM to apply more rigorous design and process management efforts, and that their synergy of efforts provides superior quality results. In the case of high-voltage cables, Duan et al. (2021) claim that their design is the key technology to guarantee the trustworthiness and safety of the drive system. However, they present a design problem of the hybrid cars: the electromagnetic interference (EMI), which involves the constant optimization with electronic module and wiring harness design (Q. Duan et al., 2021).

3.4. Information Systems

3.4.1. Information Systems concept

Whitten and Bentley (2007) define 'system' as "a group of interrelated components that function together to achieve a desired result". In relation to the term 'Information System' (IS), they define it as "an arrangement of people, data, processes, and information technology that interact to collect, process, store, and provide as output the information needed to support an organization" (Whitten & Bentley, 2007). Keen described IS as "the effective design, delivery, and use of information technologies in organizations" (as cited in Tate et al., 2014).

IS are applied for data registration, storage, and process. A IS converts data into useful and easy information to use, in a way that data is the input, and information is the output of the process (Devanbu et al., 1991). IS distribute information that can be applied to support decision making in an organization (Bernroider & Stix, 2006). When there is intervention of the human mind, the information can be transformed into knowledge, through the information interpretation (Kendall & Kendall, 2013; Whitten & Bentley, 2007). As Ortiz and Park emphasize, the lack of information can trigger problems in people, processes, and organization, and does not add value to the customer. In addition to this idea, Bilalis et al. also explain that even if the information is available, corporations have the daily challenge of analyzing and communicating effectively, as they affirm that information need to be "visible, clear and simple" (as cited in Cepeda & Lopes, 2019).

Whitten and Bentley (2007) emphasize four perspectives to view an information system: the players, the business drivers, the technology drivers and the process. The same authors also present ten basic principles for system development: [1] get the users involved; [2] use a problem-solving approach; [3] establish phases and activities; [4] document throughout development; [5] establish standards; [6] manage the process and projects; [7] justify information systems as capital investment; [8] don't be afraid to cancel or revise scope; [9] divide and conquer; [10] design systems for growth and change.

According to Dennis et al. (2009), the System Development Life Cycle (SDLC) is constituted by the four main phases for a system developed: planning, analysis, design and implementation. However, Kendall and Kendall (2013) describe a system development with seven phases, as presented in Figure 13. According to Bashir et al. (2016), software maintenance is the most important phase of a software development life cycle as maintenance consumes almost forty to eighty percent of the total software development cost.

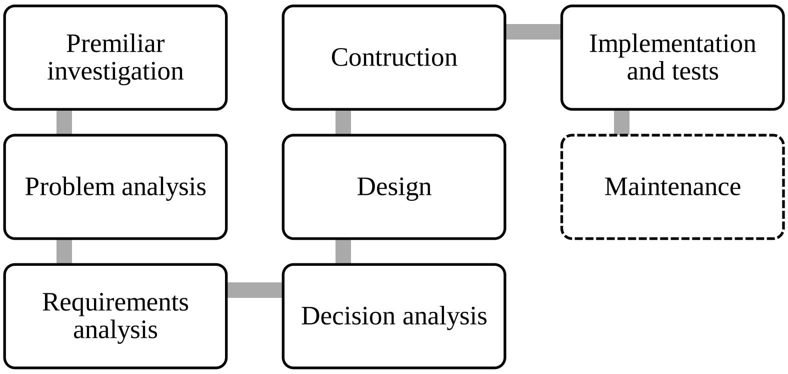


Figure 13 – Information System development steps (adapted from Kendall and Kendall, 2013)

Tate et al. (2014) emphasize the importance of measuring the IS success, because of the costs and risks of these large technology investments in comparison with their potential beneficial return.

In their article, Raman and McClelland (2019) explore and present a broad agenda on future research about information systems, with a joint goal approach of compassion and financial gain through information and communication technologies. They defend that compassion-driven approaches are the sustainable way for information and communication technologies to contribute to economic value.

3.4.2. Quality Data Systems

In their paper, Kano and Nakagawa (2007) highlight a problem common to many different industries: "how to build a reliable model from limited data, how to analyze the model and relate it to first principles, how to optimize the operating condition, and how to realize a system monitoring and control online and maintain it”. According to the study approached by Ferdousi et al., (2018), information technologies are considered an organizational factor, which in addition to allowing the transmission of information in a faster and more timely manner, also help in the use of tools and systems that support the organization's on a daily basis, in terms of management of process and data managing and quality reporting.

Quality Data Systems (QDS) serve as data storage tools. This data history allows the treatment and analysis of data. With this treatment, it is possible to identify critical points, analyze the causes and propose solutions (Hariono et al., 2018).

Kano and Nakagawa (2007) identify the use of operation data to improve product quality and yield, applying a data-base approach, Data-based can assist in the process control and monitoring in various industries. They also affirm that to attain product quality improvement, it is necessary to develop a system having at least these three functions: “to predict product quality from operating conditions; to deduce better operating conditions that can improve the product quality, and to detect faults or malfunctions for preventing undesirable operation (Kano & Nakagawa, 2007).

As Adamus et al. state, quality management systems do not possess the identical structure or design (Gumpert & Reese, 2019).

3.4.3. Information Systems Modelling: UML

Unified Modeling Language (UML) is a type of language standardized by the Object Management Group (OMG), which stands out for its simplicity and versatility, facilitating its use (Ciccozzi et al., 2019). UML has earned recognition in the last few years due to its multi-view support (Bashir et al., 2016). It is mostly used to specify, build, visualize and document object-oriented information systems, offering various diagrams to model software systems. (Bashir et al., 2016; Dobing & Parsons, 2006). The principles on which it is based are simplicity and consistency in the use of different elements. The basic structure of the UML are basic elements on the basis of which the diagrams are defined; relationships that relate the elements; and diagrams that group the elements (Dennis et al., 2009). In this way, UML offers a set of intuitive graphical and textual description techniques that are supposed to be easily understandable for both system developers and expert users working in the application domain (Breu et al., 1997).

Davies et al. (2006) present a paper with results of a survey conducted nationally in Australia on the status of conceptual modeling, gathering 312 responses. The study found that UML was between the six more frequently used modeling techniques, along with ER diagramming, data flow diagramming, systems flowcharting, workflow modeling, and structured charts.

In the next section, the Class Diagram and the Relational Model are further explored, as they are going to be applied in the practical part of this project.

3.4.3.1. Class Diagram

A class is a description of a set of objects and contains attributes and operations. Inside a class, these objects have similar properties, or relations in common (Breu et al., 1997). Thus, the class diagram represents the classes that comprise the system, excluding dynamic information, that is showing what the classes are and how they are related, but it does not show how they interact (Siau & Lee, 2004).

A Class Diagram presents a group of classes, interfaces, collaborations, and relationships. Relationships also have multiplicity, which details how an instance of an object can be associated with other instances (Dennis et al., 2009). In Figure 14 is presented a class diagram example of an order system. For example, are identified and can be observed:

- The class Customer with the attributes name and address;
- The types of relationships: association; aggregation and generalization;
- Multiplicity (i.e., one customer can make zero or several orders; one order only can be made by one customer);
- Line item as a Role in an aggregation relationship;
- Payment as an Abstract class.

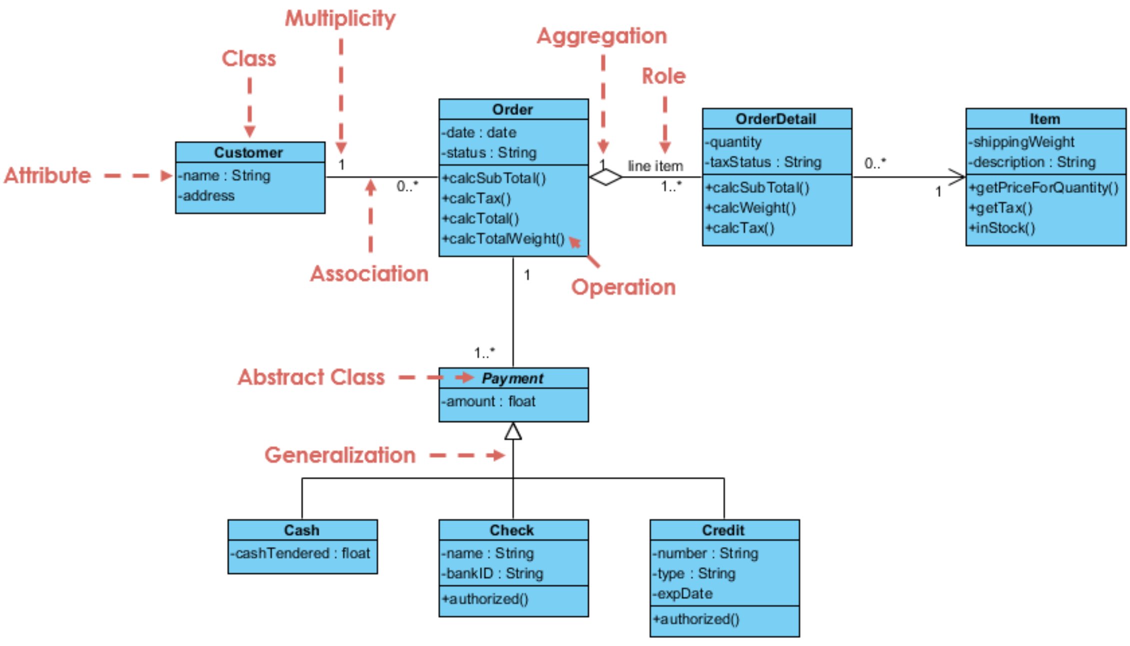


Figure 14- Class Diagram exemple (Visual Paradigm, 2021)

It is considered a static model, because the structure that it describes is always valid, independently of the lifecycle phase of the system (Dennis et al., 2009).

3.4.3.2. Relational Model

After the class diagram is performed a transition to a Relational Model follows. For the transition to occur without problems, the class diagram must be prepared with the perspective of modeling the structure of a Database (DB); The Relational Database (BDR) contains a structure of tables, composed of columns (attributes) and rows (Tuples), with related tables, when necessary (Dennis et al., 2009).

4. Practical project

4.1. Yazaki

Yazaki is strongly considered the world's largest producer of electrical harnesses. A harness is a set of circuits - conducting wires - and components whose main responsibility is to coordinate and control the entire distribution of the car's electrical system, as for example the headlights, the ignition and the windshield (Yazaki Europe, 2021a).

Yazaki's history began in 1929, when Sadami Yazaki started selling electrical wires for automobiles. In 1941, with the founding of Yazaki Electrical Wire Industrial Co. Ltd. and a promising development in the automotive industry at the time, eight years later the company founder made an important strategic decision to focus on the production of automotive electrical harnesses, which sets the course for success of this company until today (Yazaki Europe, 2021a).

Currently, this Japanese group is present in 45 countries, in a total of 142 locations. Deeply rooted in Japanese cultural traditions and values, its main focus is customer satisfaction (Yazaki Europe, 2021a). Yazaki group plants can be described as *monozukuri* companies. *Monozukuri* is a Japanese word that literally means ”production”, “manufacturing” or “making of things”, consisting of the words *mono* which means “products”, and *zukuri* which means “process of making or creation” (Saito, 2006). The wider meaning includes a combination of technological expertise, know-how and spirit of Japan's manufacturing practices (Nakano, 2017).

Yazaki has a global commitment to provide high value and services to all customers, reflected in the excellent quality of its products. With a focus on technological developments and monitoring market needs, Yazaki offers a wide range of products in the global automotive and energy systems sectors. Recently, it began its expansion into a third sector, mainly focused on the areas of nursing care and business related to the environment issues. In the integrated business system currently at Yazaki worldwide, there can be found areas such as research and development, production, sales and local management (Yazaki Europe, 2021a).

At Yazaki, the synergy of information between factories through the combination of resources is intrinsic to the company's culture, providing an exchange and implementation of ideas and practices from one region to another, that result in innovation, excellent results and global success (Yazaki Europe, 2021a).

4.1.1. Yakazi Saltano de Ovar

Currently, Yazaki is recognized for its pivotal role in valuing and developing the automotive industry, for the quality of its products. In Portugal, this organization has a plant operating, Yazaki Saltano de Ovar (YSE), which also represents an industry with a strong impact on the national economy. Figure 15 shows an aerial view of the YSE plant.


Figure 15- Yazaki Saltano de Ovar (YSE)

In 1986, Portugal was the pioneer European country for the implementation of a Yazaki production plant. Today, YSE is a Japanese automotive multinational, which includes an R&D center - Porto Technical Center (PTC) - which develops the technical designs of the components, and the Manufacturing Unit divided in five different production areas: Electrical Distribution Systems (EDS), Datacon, Molds, Wire and Power Distribution Units (PDU).

4.1.1.1. Electrical Distribution Systems

The Electrical Distribution System (EDS) is the area where the vehicles' electrical distribution systems are produced. In this production area, wiring is normally produced for four parts of the car: engine, doors, main part and body.

Depending on the type of vehicle - combustion, hybrid or electric – there are two types of wiring that are produced: low voltage and high voltage (HV). The low voltages wirings are applied in standard vehicles, which operate almost entirely through internal combustion engines. The HV production started in the last decade, as a response to the technological development of the automotive industry. The wirings HV are produced to be integrated in electrical and hybrid vehicles, that have started to emerge successfully in the market over the past few years, in parallel with the increase in environmental and sustainability concerns.

Within the low voltage and high voltage production, the EDS lines are divided by customers, and each costumer has projects.

The practical project described in this work is inserted in the EDS area, in a high voltage wiring (HV) production sector designated as Customer X. In the Customer X production area products from two projects are produced: PROJ1 and PROJ2.

4.1.2. Quality Culture

Organizational culture is identified as critical for TQM implementation and the company performance, and managers should be conscious of the culture values emphasized in their organization because of the direct impact on the TQM practices and performance (Valmohammadi & Roshanzamir, 2015). This idea is likewise deeply rooted in Yazaki's daily work.

Quality is a Yazaki core value. As stated by the current Head of Central Quality, in Yazaki the established working method is to "work in a safe environment, with quality focus and always with high motivation, to enhance customer trust." (as cited in Yazaki Europe, 2021b). In this automotive industry company, high quality products and services, application of innovative tools and processes, consistency, and customer satisfaction are prioritized. The quality system which is applied is transversal to all factories, and the dedication to high quality is required due to the focus on the customer (Yazaki Europe, 2021b).

At Yazaki, these results are an example of a collective responsibility for quality. All employees contribute to the applied quality system. The belief that the best way to achieve excellence in quality is rooted is through problem prevention, and not through its late detection and correction (Yazaki Europe, 2021b).

The Policy that is followed in the company culture is expressed in Figure 16.

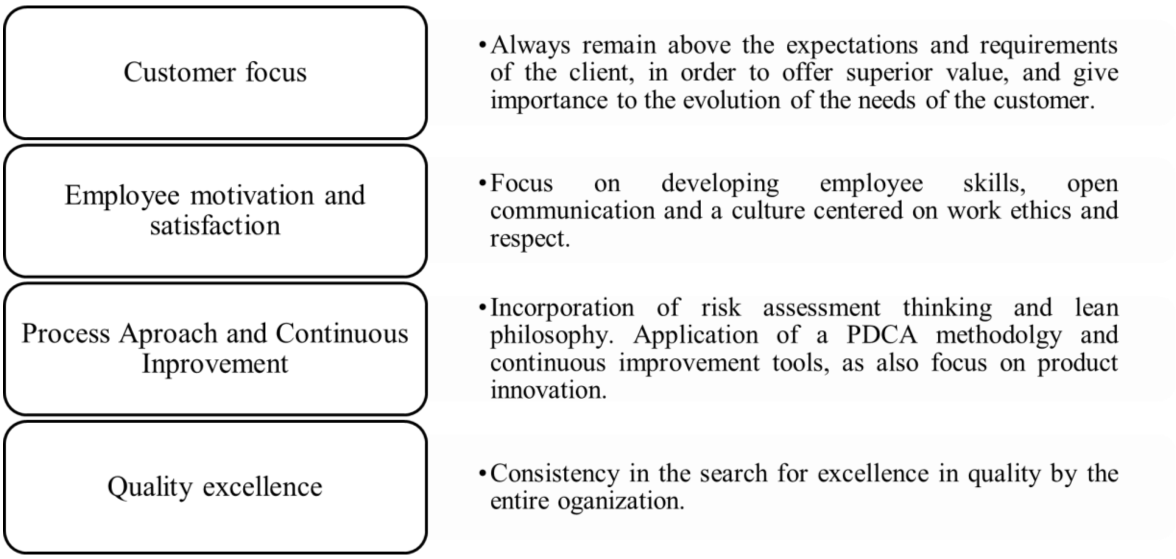


Figure 16- Yazaki Quality Policy (Yazaki Europe, 2021b)

To evaluate the quality excellence of the company, main Quality KPI's are used and are applied to all factories. In Table 5, the main Quality KPI's applied at Yazaki for the defect analysis are listed. In addition, a brief description or how they are calculated is presented.

Table 5- Yazaki Quality KPI's

CO Claims: Customer official	Number of claims raised by the customer officially.	
RE Claims: Resident Engineer Claims	Number of claims raised by the Resident Engineers at customer side.	
CO+RE/100KMH: (MH = Man Hours)	$\frac{\text{Number of CO + RE Claims}}{MH} * 10^6$	
PPM: (Part Per Million)	P1 and P2: PPM = $\frac{\text{Number of P1 and P2 defects}}{\text{\# Cut circuits}} * 10^6$	Customer: PPM = $\frac{\text{\# of CO Defects pieces}}{\text{\# of shipped W/H to customer}} * 10^6$
DPM 10^3: (Defects Per Million)	P3: DPM$* 10^3 = \frac{\text{Number of P3 defects}}{\text{\# W/H produced}} * 10^3$	
FTT: (First Time Through [%])	P3: $FTT = \frac{\text{Number of W/H passed with 0 defects in the E} - \text{checker}}{\text{\# W/H produced}} * 100$	
RR: (Rework Rate[%])	P3: $RR = \frac{\text{Number of W/H reworked out of production process}}{\text{\# W/H produced}} * 100$	

4.2. Initial situation

4.2.1. Process analysis using BPM

In an improvement project, the first step is acknowledging and understanding the process. To support the understanding of this process, a model was created based on the BPM method. This initial process model was mapped by using the BPMN 2.0 tool on the Signavio platform.

For the construction of the model, the BPM lifecycle was applied. This methodology is employed to help identify critical point and propose possible improvements.

To understand the initial situation process identified in YSE in October 2020, only the first three steps of the BPM cycle were applied:

1. **Process identification:** First, the process architecture was carried out to understand which processes are important and need improvement. For this case, a process was addressed where the need for improvement had already been indicated by the company. The internal defect management process of the HV wiring assembly line was chosen because it is a recent and an under-development area.

2. **Discovery of the process:** In this step, from the collection of information, the mapping of the current process was constructed, identified as AS-IS Model.

In this practical project data triangulation combining text, survey, and interview data, as referred in Kern (2018) was used. The three data sources explored were observation, informal interviews, and analysis of documents, and they are described in Table 6.

Table 6- Information collection

Data Source	Description
Observation	The process was observed on the factory floor for 1 month. Employees were additionally observed when they were completing all documentation involved in the process, and at the end of the month the entire process was also monitored in the database and information export.
Informal interviews	Informal interviews were conducted with 6 elements: the assembly and cutting LQCs, the line manager, the rectifier, and the Quality Team Leader. These interviews were conducted with these elements that are located daily on the factory floor and are directly involved in the process, in order to obtain a model that most closely represents the real situation in the area.
Documents	In addition to the analysis carried out on all documents that are completed during the process, the Non-Conforming Product Control Standard was also analyzed.

After the information collection, it was possible to describe the process. First, it was identified the division of the area, the team involved, the products produced and the types of defects that can occur. Then, the process was described. Following, these steps are presented.

Area division

In the production of a HV wiring, we have three main production line areas: P1 (Cut), P2 (Crimping and Accessories) and P3 (Assembly). In this specific case, the wiring is produced in a clean and close sector composed by two rooms, one integrated by the Cut, Crimping and Accessories (P1 and P2) lines, and the other constituted by the Assembly lines (P3).

Team involved

In the process of managing internal defects in the assembly lines, where the study will focus, the team involved consists of the assembly line operator that identifies the defect, the rework operator, the assembly line leader, the Assembly Quality Control Team (Assembly LQC) and the Quality Team Leader.

Products

Currently, there are two main projects in this area, PROJ1 and PROJ2. In total, there are eleven Part Numbers, each part number being produced in a dedicated line. From these eleven part numbers, five belong to PROJ1 and six to PROJ2.

Process

This section will describe the internal defect management process of the High Voltage (HV) wiring assembly lines for electric and hybrid cars. It will focus on the explanation of the management process when a defect is detected in the assembly line and the register involved.

When an operator detects a defect, he places a Non-Conform Label, as presented in Figure 17, duly filled on the product, and places it on the red box in the workstation. If the defect was detected while the product is along the production line, the operator just mentally registers (remembers) or writes it down on a scrap workstation paper. However, if the defect is detected on a final inspection workstation, there are two possibilities: if it was detected in the electrical inspection, the operator registers the defect in the electrical inspection sheet (example presented in Appendix A); if it was detected in the 2nd visual inspection or the firewall station, the operator registers the defect in the visual inspection sheet (example presented in Appendix B).

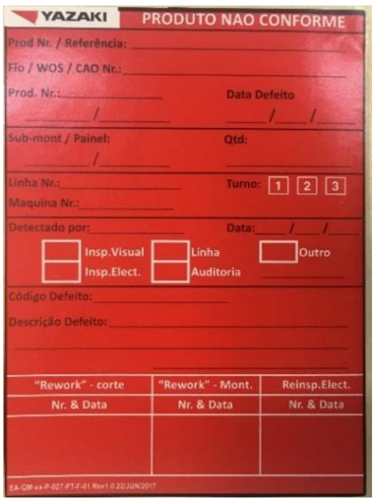


Figure 17- Non-Conform label

As these products are transported in trolleys, the rectifier operator will go to the respective car in parallel and check if there are more products with the same defect. The rectifier operator removes the product from the box and then analyzes the wiring, fills the HV Wire and Harness Rectification document (example presented in Appendix C) and performs the rework or the scrap process. If the rework is performed, he needs to fill the Non-Conform Label with the identification that the rework has been done, as presented in Figure 18, and then places the product back on the production line. If the product can not be rectified, the rectifier sends it to Scrap and change the registration in the computer system.

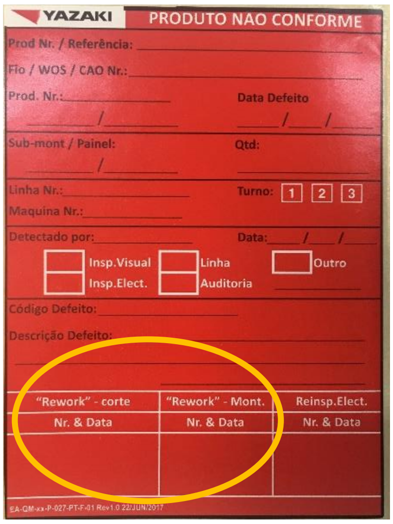


Figure 18- Non Conform label with rework identification

At the end of the shift, each visual inspection operator registers all line defects in a scrap line paper and gives it to the line leader that organize all line scraped papers (example presented in Appendix D). After the end of the shift, because of lack of time, the line leader registers all defects in the Aleatory Internal Defect sheet, which is designated in this process as Daily Log sheet (Appendix E). In the next morning, before the beginning of the shift, the line leader fills the excel document with the production information (Appendix F).

At the end of each month, the line leader delivers these sheets to the Assembly LQC. In the second and third days of the next month, the Assembly LQC enters these data into the QEDS, which is the current quality database used. Subsequently, the Quality Team Leader confirms the data and extracts the monthly reports, where quality graphs are presented. The reports are printed and posted on the assembly line to be shown to all employees.

With all this process information, the AS-IS Model was developed to represent the initial situation, presented in Figure 19.

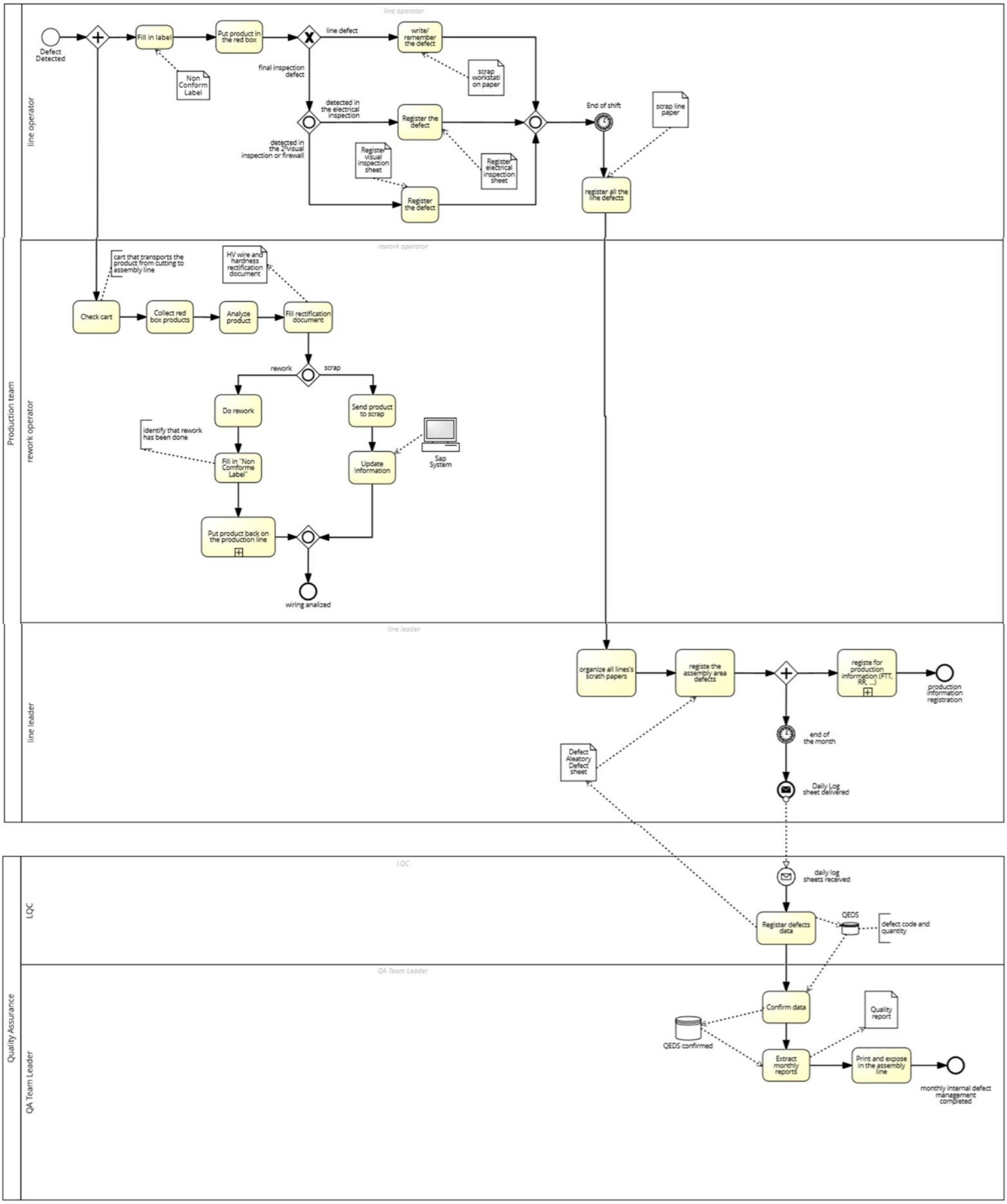


Figure 19- AS-IS Model

3. **Process analysis:** After the completion of the mapping of the AS-IS Model, an analysis of the model was carried out.

After observing, understanding the process and all aspects involved in the management of internal defects at Customer X it was possible to analyze the current situation and identify points for further improvement.

To explore the problems identified in the BPMN model, an Ishikawa diagram was created, that provides organized information visualization and deeper understanding of the critical point. The Ishikawa Diagram is presented in Figure 20.

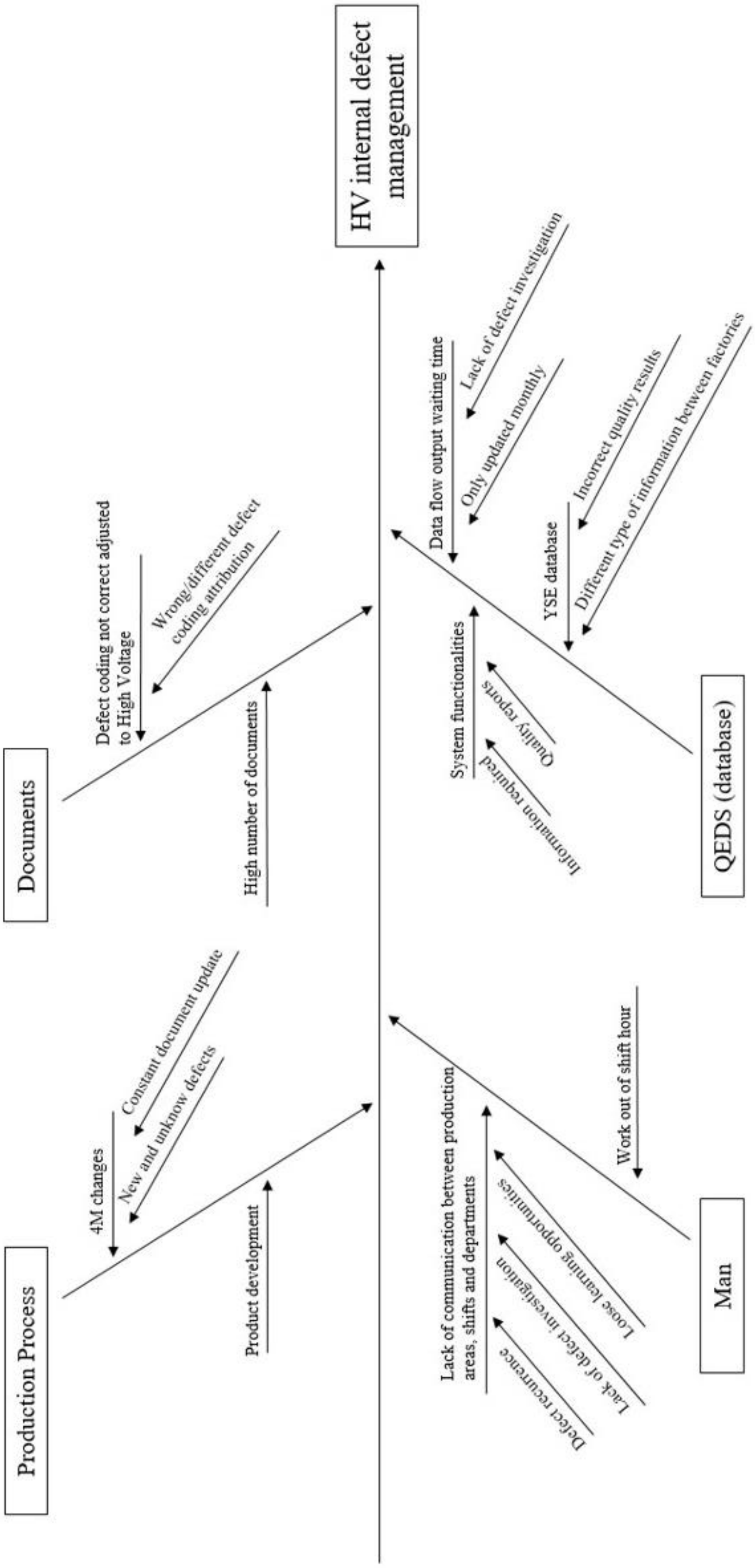


Figure 20- Ishikawa Diagram for initial situation analysis

As can be observed in Figure 20, the identified problems were divided in four categories, explained in detail in the next points:

Production process

As previously mentioned, HV wiring harnesses are new products in the automotive industry. Due to the constant changes included in 4M - Man, Method, Machine and Material - it is also necessary to constantly update the documents applied on the production line and to manage defects. Some examples are Quality Alerts and Process Standards - documents with examples of accepted product (OK) and defective product (NOK).

Documents

High Voltage products can involve different and unknown defects, in comparison with the normal production of the last decades, the Low Voltage wirings. In this way, it was possible to detect that the coding defects presented in the Defect Coding Catalog (For Wire Harness), are not correctly adjusted to High Voltage production. This situation can cause a wrong attribution of defect coding, or even a different attribution of the same defect from two different collaborators.

Another aspect is that, as observed in the AS-IS Model, a high number of documents for the defect registration is needed. Basically, people from different departments are registering the same defect data, but for different information outputs, because in the end of the month this information is also registered in the QEDS. This situation provokes rework and time loose, as presented in Table 7, where we can observe that a high amount of time of the eight daily work hours is applied in these registrations. The time presented expresses an estimate, identified using informal interviews with the parties involved.

Table 7- Register time applied

Responsible	Document	Time/Shift
Electrical inspection operator	Electrical inspection sheet	10min
Visual inspection operator	Visual inspection sheet	10min
Visual inspection operator; Line leader	Scrap line paper (register + organization)	3-5min
Line leader	Daily Log sheet	15min
Line leader	Production information excel document	10min
Rework operator	HV wire and harness rectification document	10min
Assembly LQC	QEDS (database)	60min

Man

There are some communication failures, from one shift to the next, encompassed also by communication failures and mutual assistance between the quality, production, and engineering departments, or even from one area to the other. This situation provokes a lack of routine in defect monitoring. This lack of investigation is also involved in the high recurrence of some defects, for which the root cause has not yet been identified. Lack of communication can also lead to lost learning opportunities because the interaction and exchange of knowledge between departments is not promoted.

QEDS Database

The actual database used in EDS for management of the internal defects, the QEDS Database, was created in a way to simplify the registration and creation process of graphics for the EDS Quality Department at YSE. But in a more detailed analysis, it can be seen that the database is not sufficient for the functions that need to be undertaken for a correct defect analysis and prevent defects to be performed.

In this Database, for the administrators, it is possible to create, edit and remove: Clients; Processes; Models; Shifts; Defects and Inspections. For the LQC's it is allowed to introduce the data related to the defects in each inspection and inspected circuits. For the rest of the team, it is possible to see the Reports related to the defects that result from the inspections.

The Data base is divided by Mass Production and Prototypes. Inside of Mass Production – the Customer X case – it is divided by P1, P2 and P3 area. In each inspection, in P1 and P2 area, the compulsory fields to register are Area, Client, Process, Shift and Data. In P3 area, the required fields are the same, but with the addition of Model.

The data registered can be submitted by the LQC in the end of the month, and only the administrator can edit or delete any information registered. When the data is submitted, it is possible to extract the monthly reports in three types of formats: word, PDF and Excel.

Training on the use of the Database was carried out with the Quality team. Then, the phase of use and familiarization with the database took place, together with the analysis of the respective user manual. After these steps, critical points were identified.

In the current process, a poor tracking of internal defects was identified with the current Quality Data System (QDS), due essentially to two factors. Firstly, the fact that it is only possible to update the QDS once a month. Second, the poor QDS functionalities in terms of the type of information introduced and subsequently extract monthly reports with quality graphics. This aspect highlights the lack of further investigation into the causes of defects that have occurred, leading to recurrence of defects. HV is a recent and developing area, where there are defects that are being identified for the first time, so that the correct analysis and identification of root causes must be considered as one of the focuses in quality control. In this context, there must be a more frequent analysis than a monthly one.

Another issue is that this quality database is not used in any other Yazaki unit. There is no homogeneity in the type of database used for all the companies. This fact can create difficulties in accessing information by the Central Quality Team as they need to analyze the data from all the factories in order to compare quality results.

4.3. Proposal improvements and implementation

In this section the main improvement actions proposed and implemented are described, namely (i) a whiteboard creation, (ii) the investigation of defects and the identification of the most important to solve, which consists in air leak detected in tests performed to the cables, (iii) the development of new high voltage cables defect coding and (iv) the promotion of a new database modelling and implementation.

4.3.1. Whiteboard as a Quick Response Quality Control

In the initial situation, it was found that the defects were not registered correctly, with all the necessary information, and not even all the defects that occurred were registered. A reason for this to happen is that the two projects are being examined are recent, and new and unknown defects can occur.

Thus, in the assembly area, a Whiteboard was implemented to record the internal defects that happen in this area. This Whiteboard was implemented as a Quick Response Quality Control (QRQC) tool to help the team to analyse a defect situation and quickly respond to control and prevent the problem. Based on the data obtained in this board, it will be possible to view and understand the defect data reality that the area presents, in a more reliably way.

The Whiteboard implementation was initiated in the middle of November 2020 and was performed under a PDCA cycle, a methodology which is already familiar in the company culture. The applied cycle is described in Figure 21.

The first step consists in planning the implementation. A board was reused from another production area and transformed for this purpose. The board and column title were designed, printed, and plasticized, to be inserted in the board with double side tap. Information was collected with the quality team to understand the aim of the information to register in the board. In this way, the seven columns detailed in Table 8 were defined.

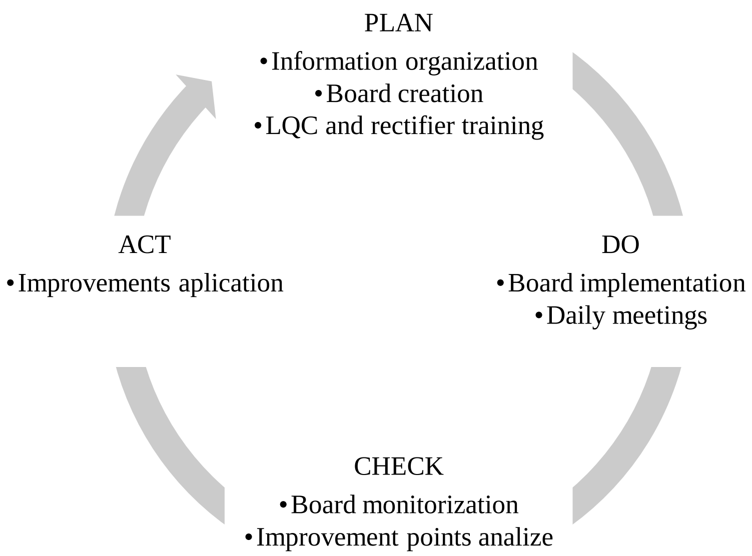


Figure 21- PDCA cycle for Whiteboard implementation

Table 8- Witheboard columns description

Column Name	Description
Part Number	Part Number of the product in which the defect occurred
Date / Shift	Date and shift in which the defect was found
Defect	Description of the defect
Line / station	Line and station where the defect was detected
Quantity	Quantity of products with the defect detected
Cause	Cause of the defect, the immediate cause. It was asked to describe it in more detail in order to get to the root cause
Actions	Depending on the causes identified, propose actions to be applied
Destination	After analyzing the wiring, the product has the destination of scrap or rework.

After this preparation, in the last week of November 2020, the Whiteboard was ready to be shown in the production line, in order to impact the team, including the operators, so that they could recognize the seriousness of the quantity of defects that occur. An example picture of the Whiteboard is presented in Figure 22.

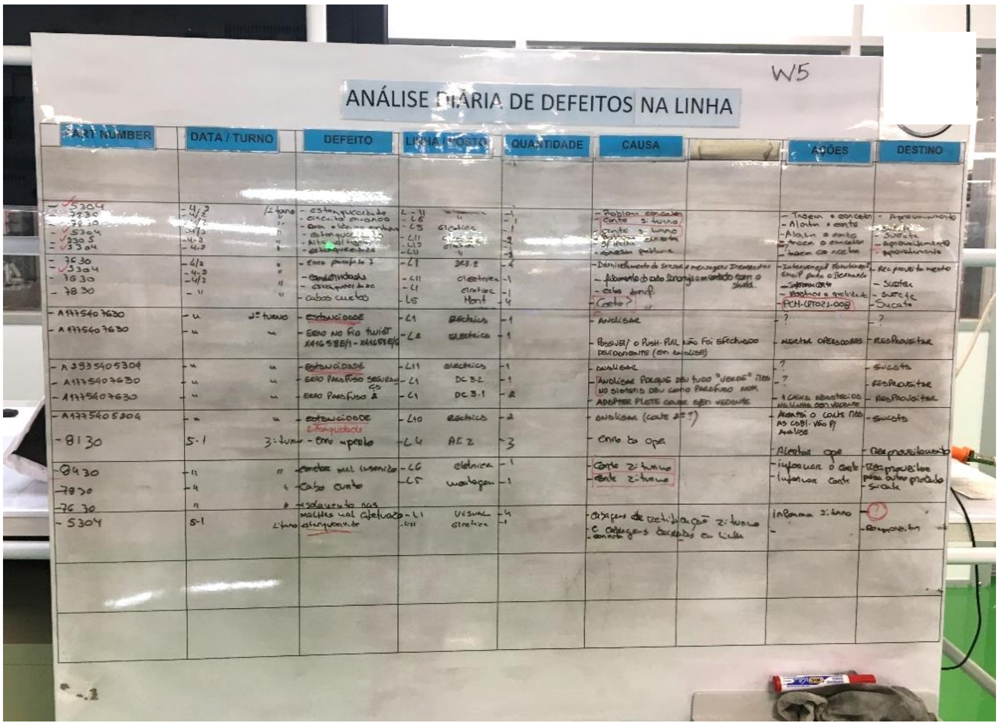


Figure 22- Whiteboard in the production area

In the Whiteboard, all internal defects identified in the three work shifts are recorded. This registration is intended to be performed manually by the rectifier or the LQC of each shift. So, the necessary training was performed between these collaborators: the whiteboard was explained, and some example registrations were accompanied. The defect registration started in beginning of December 2020.

After this implementation, daily meetings were implemented to monitor the defects. Every day at 9 am, a fifteen minutes meeting is held in front of the Whiteboard to analyze the defects that occurred in the three shifts of the previous 24 hours period. The members participating in this meeting are presented in Table 9.

Table 9- Daily internal defect meeting participants

Department	Participants
Quality	The cut, crimping and accessory LQC, and the assembly LQC
Production	Cut, crimping and accessory line leader Assembly line leader Rework operator
Production Engineering	The area process engineer

Although the management of internal defects is a responsibility of the quality team, it is necessary to emphasize the importance of this meeting to generate a multidisciplinary and cooperative environment. The presence of the line leaders is crucial because they are the ones who coordinate the line operators on a daily basis and who are continually present on the shop floor, being able to contribute with their point of view about what it is not correct and should be change, and to transmit the opinions of the operators. The presence of the production engineering team is also decisive, as given that Customer X's lines are constantly evolving, with changes, for example, in machines and layouts, several defects can be caused by these changes. In these meetings, on the part of the production engineering, interesting suggestions can also come up to take action on internal defects because, by having the right information and being updated about the identified defects, they acquire more understanding and experience for future modifications.

After the daily meeting, the cut, crimping and accessory line leader and LQC conduct a meeting with their area operators, to show the defects, with existing examples using the physical wiring or defect photos, and alert for future prevention. In this way, every production area collaborator is updated and informed.

After four months of employing this teamwork work methodology in this area, in March 2021, it was possible to conclude that this implementation was well accepted and helped to create a routine and a more communicative approach to deal with the defects. Besides the daily meeting between these three departments, line operators also demonstrated interest and concern to what is daily discussed in the board.

In addition to the positive feedback, some improvement points were identified, and the Whiteboard was changed for a new board layout. with the objective of improving the whiteboard appearance and better organizing the information. The board is now bigger and has additional columns. The new columns are described in Table 10.

Table 10- Whiteboard additional columns description

Column Name	Description
Source	The area where the defect was provoked
Responsible	The person responsible to do the action
State	The state of the defect analyses, divided in four phases: 1. Identification of the defect cause 2. Proposal of corrective actions 3. Implementation of corrective actions 4. Production OK

The whiteboard template can be observed in Appendix G and the new board exposition in the production line is presented Figure 23.

Figure 23- Improved Whiteboard in the production area

To help the three shifts understand the board information and for future trainings, a filling standard was created, that can be seen in Appendix H.

The whiteboard implementation and outputs had very positive results and feedback. The experience was so positive that the quality team decided to implement, at the beginning of May 2021, the whiteboard in a new production area, for another client, as shown Figure 24.

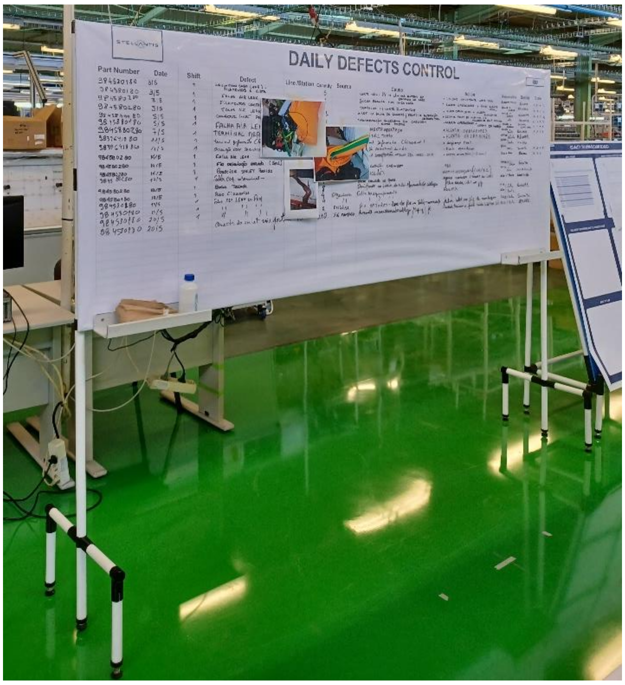


Figure 24- Whiteboard implemented in another production area

Lessons Learned

The Whiteboard implementation in the production area provided a clarified update of the area reality. Being a big and visual tool, the board caught the attention of indirect collaborators but also of the production operators. The operator curiosity in his/her own work quality increased, which had impact in a more careful and dedicated approach to work.

Currently, the quality area is living the TQM dimension, with focus on people in the organizations. With this focus, the implementation of the Whiteboard in the production area revealed to be a successful strategic way to improve the communication between departments in the organization and, at the same time helped with the internal defect reduction.

The decision to implement the Whiteboard in another production area, shows the great reception of the company in relation to the first implementation. In this perspective, it is expectable that in new processes, the whiteboard can be implemented to analyze the daily and unknown defects, keeping everyone informed and updated.

The limitation observed in this implementation is the size of the Whiteboard. On days when there are many defects, their information has to be erased more frequently, making it difficult for subsequent shifts to respond to defects related to the erased information. In terms of height, on days when there is a big quantity of defects, the information must be erased more frequently, impairing the response of other shifts to that defect.

4.3.2. Defect investigation

4.3.2.1. Adopted Methodology

The methodology employed in this part of the work was established based on the application of quality tools for the investigation of an impacting high voltage defect in the analysed production area. Four quality tools were combined, following the order presented in Figure 25: in the first stage, the Pareto diagram, then the 5W2H method followed by the Ishikawa diagram and, finally the 5Why method.

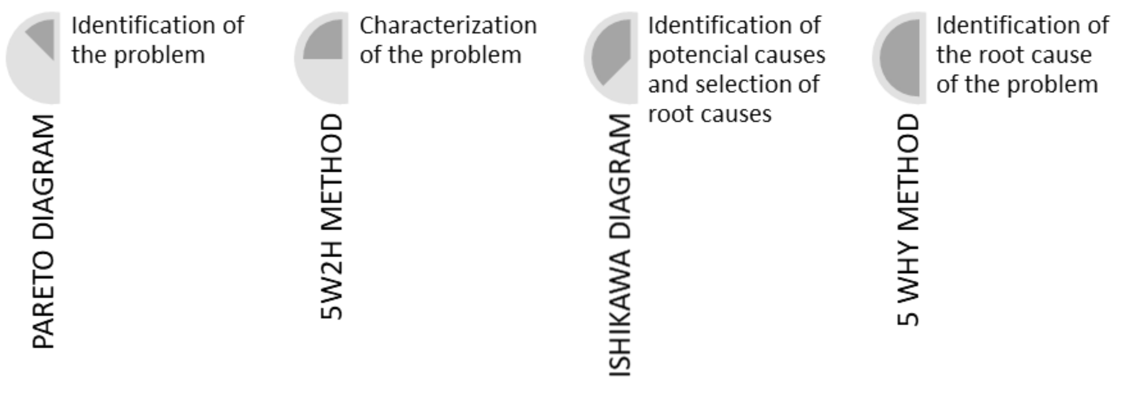


Figure 25- Sequential relation between the quality tools

The Pareto diagram was used to evaluate the impact of each detected defects, to identify the major(s) internal defects in the area and to visualize the defect evolution over time.

After the identification of the problem, in a way to introduce a characterization of the focus problem, the 5W2H method was applied, with the purpose of answering the following seven questions: “What?”, “Where?”, “When?”, “Who?”, “Why?”; “How?” and “How much?”.

In the third stage, the Ishikawa diagram was used in order to isolate potential causes and to undergo the selection of root causes. As referred in the third chapter, the quality characteristics of the product can be affected by the 5M1E; therefore, the six resources considered for this study were: measurement, material, man, method, machine, and environment.

In addition to the Ishikawa diagram, the 5 Why tool was applied to clearer analyse some of the potential causes distinguished. As the 5 Why method was employed, it helped to explore with more detail each possible direction, consequently discarding various potential causes identified previously.

4.3.2.2. Results and discussion

The defect evolution was monitored in a four-month period, from December 2020 till March 2021, through the QRQC whiteboard data. The first and fourth month Pareto diagrams are presented in Figure 26 and Figure 27, respectively.

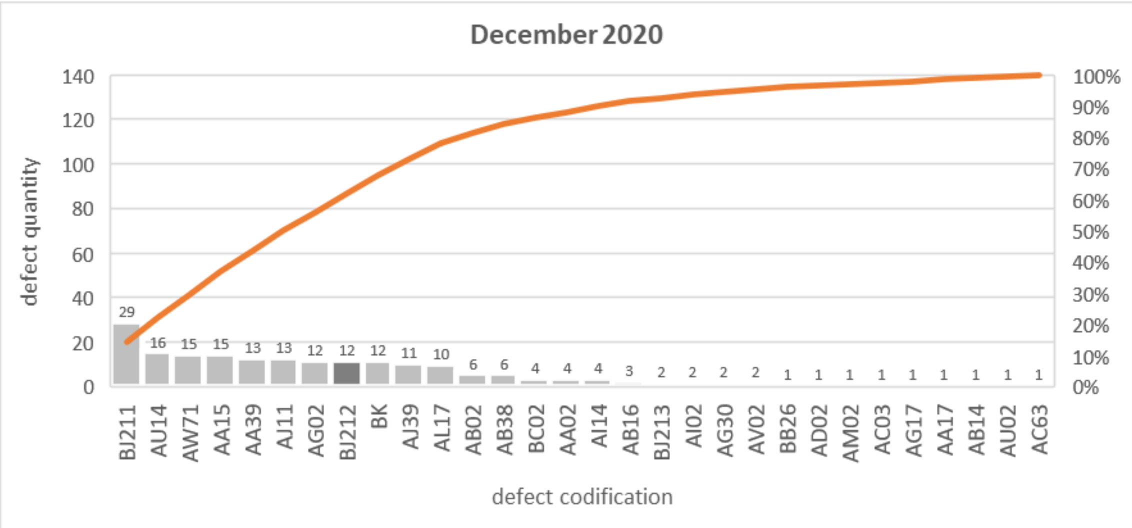


Figure 26- Pareto Diagram, December 2020

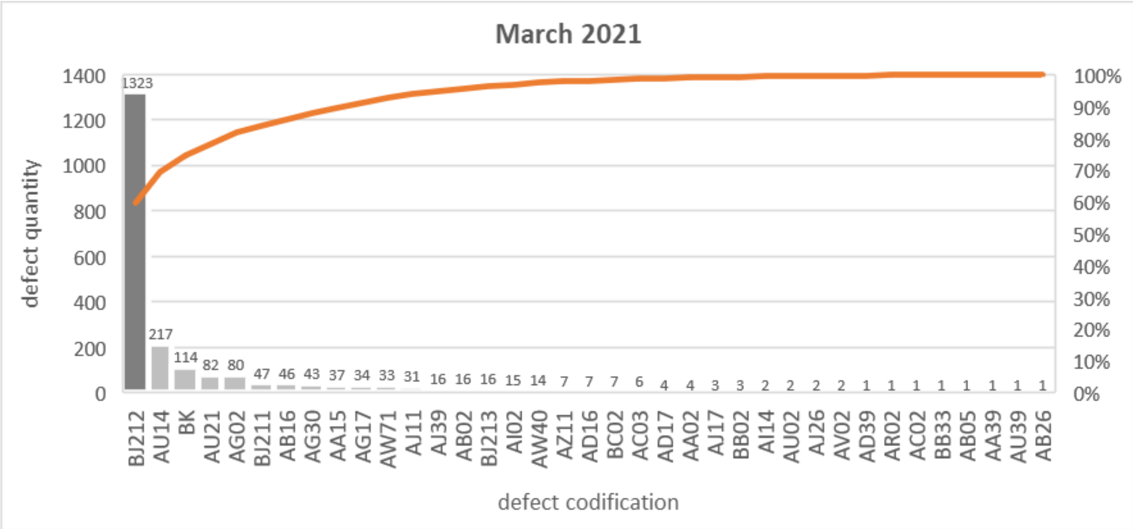


Figure 27- Pareto Diagram, March 2021

In December, there was a total of 202 defects and in March the number increased into a total of 2221. Comparing the Pareto Diagrams from December 2020 to March 2021, one quantity defect highlights, it is possible to observe an increase in the number of air leak test failures, identified as BJ212. The air leak test is performed to verify that the cable is fully insulated. During this test, the wire harness is placed in the electrical inspection machine, air passes through the wire harness, and if it falls below the stipulated value, it means that the wiring has a leak, which may in the future cause safety problems when connected to the vehicle. In December, there were 12 air leak test failures that represents 5,94% of the total of 202 defects. In March 2021, the air leak test defect is the biggest defect in the assembly area, representing 1323 defects of a total of 2221 defects identified in the assembly area, thus representing 59,57%.

In Figure 28 a bar diagram is presented, where the air leak defect quantity evolution can be visualized, during the four months that were analyzed. In December, a total of 12 defects air leak test failures were identified, in January there were 109, in February 129, and in March to a total of 1323 defects. Along with the defect data, in the bar diagram is also possible to visualize the monthly quantity produced: 38177 harnesses in December, 17049 in January, 56611 in February and, 78988 harnesses in March. The percentages in Figure 28 represent the monthly ratio of the air leak test defects in relation to the production quantity. This production value is important because in this area the production is not constant, it is a pull system that depends on the client orders.

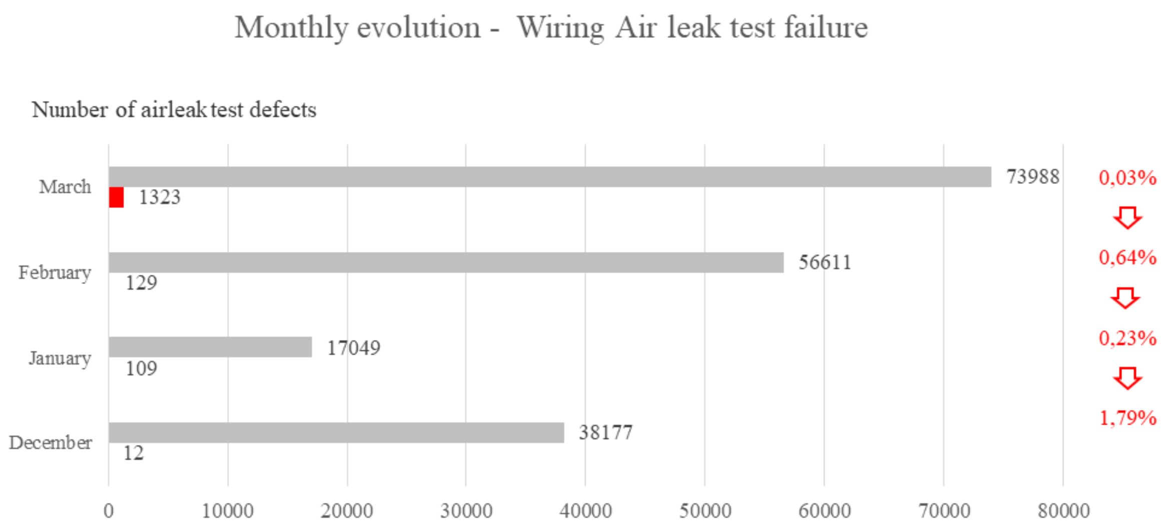


Figure 28- Monthly evolution

In the majority of the wiring with the air leak test defect it was not possible to identify the root cause(s) with the information of the area and investigation resources, and the non-conform wiring with this defect was inexplicably increasing month by month, inducing a significant and concerning number of scrap material. So, with this scenario, a further investigation was conducted to identify the root cause(s) of the air leak defect.

The air leak test is made in an electrical inspection machine in the end of the production line as a final inspection. From the air leak test failures identified in some causes were visually detected by the reworked operator, such as damaged wire, damaged seal, seal in incorrect position, presence of a foreign substance, and filaments damaging the wire. While these causes were only identified in a minor number of non-conform wirings, the major percentage of non-conform wirings did not have an identified cause, as is represented in Figure 29.

With the identification of the cause investigation problem, the 5W2H method was applied to give a contextualization of the situation as presented in Figure 30.

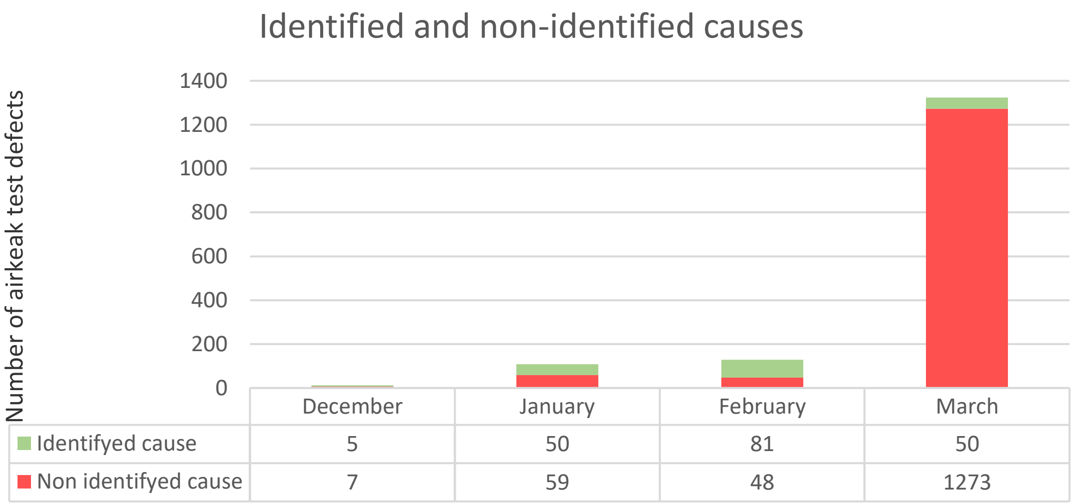


Figure 29- Monthly evolution: non-identified and identified causes

WHAT	Wiring air leak test failure
WHERE	Detected in the electrical inspection machine, in 8 different lines and wiring types
WHEN	During 4 months, in the 3 daily shifts
WHO	By the operator of the electrical inspection workstation
WHY	**Root cause not identified**
HOW	With the airleak test values not according to specification
HOW MUCH	In a total of 1387 non-conform wirings, during a 4 month period

Figure 30- Wiring air leak test failure: 5W2H Method

Although this production area is focused on a single customer, twelve different products are produced, each one in a different line. The air leak defect with the non-identified causes was detected in eight different products, culminating in eight different production lines and electrical inspection machines. Therefore, it was necessary to find a common factor.

As it can be concluded using the information in Figure 30, in this stage it was not possible to answer the "why" question, which will be the focus of this investigation. To continue this study, the Ishikawa diagram was applied, being presented in Figure 31. The potential causes which were recognized were considered and investigated with the aim of identifying the root cause of the problem.

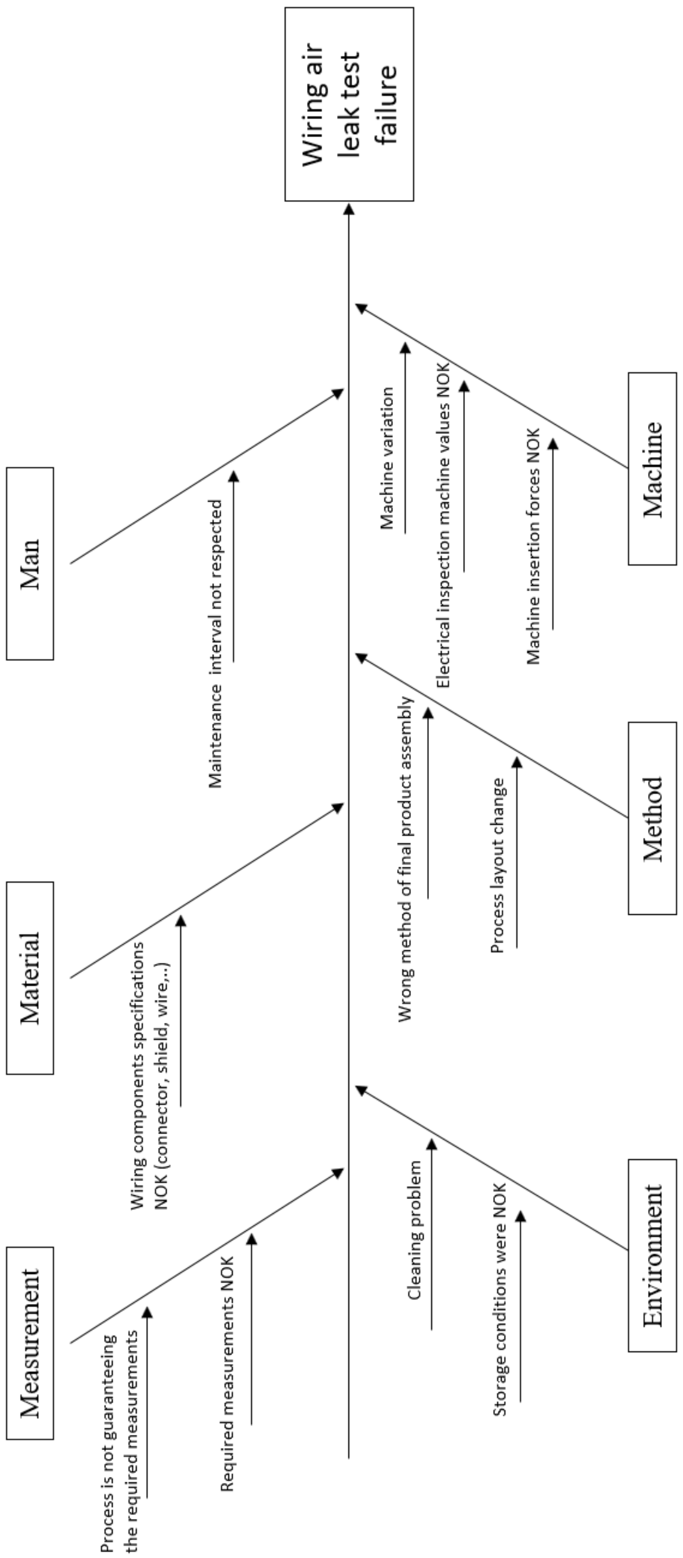


Figure 31- Wiring air leak test failure: Ishikawa Diagram

As presented in Figure 32, additionally with the Ishikawa Diagram, the 5 Why tool was applied to better identify some of the distinguished causes. Each column presents a step of the "Why?" question, following the arrows flow.

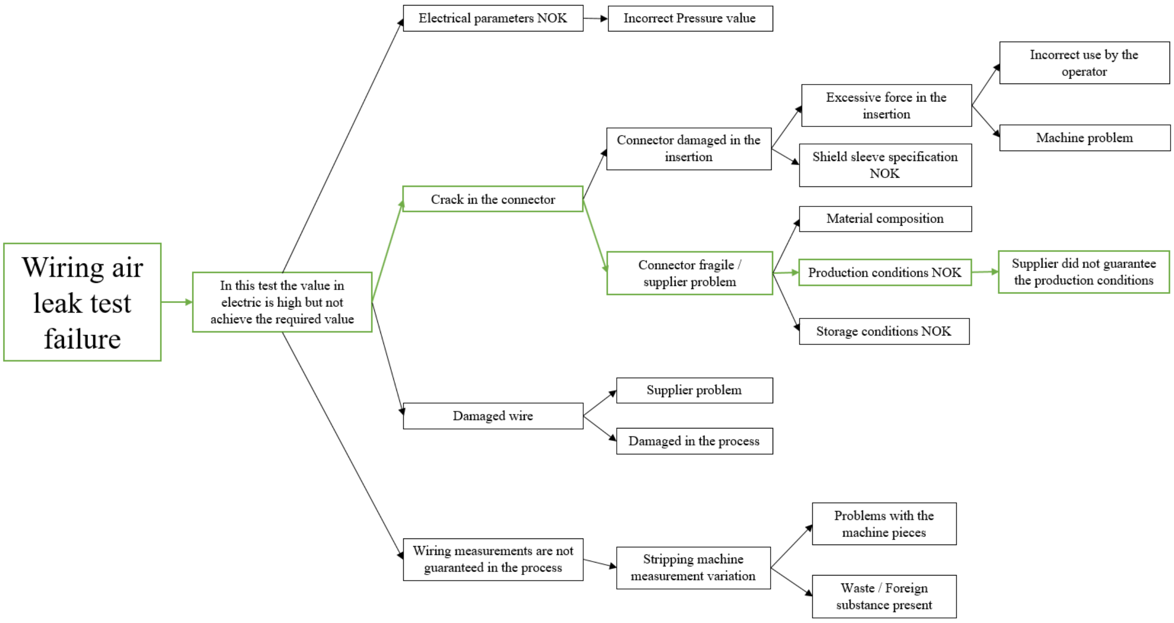


Figure 32- Wiring air leak test failure: 5 Why Method

A water test was performed, where the wiring was immersed in water, and at the same time there was pressure inside with air. During the test, it was possible to observe a leak of air emerging from connector A, but it was not possible to visually identify the specific location of the leak in the connector. It could be verified that connector A was a common component in the 8 different products already identified. With a first visual inspection, it was not possible to detect anything non conform on the connector A. As they are high voltage cables, they are bigger and thicker than the low voltage cables, making it difficult to analyze them internally. The only way to analyze the inside of these connectors is a destructive test, which involves sawing the connector. The process of sawing the connector can only be carried out by the area of rework operator. According to the established process, the connector must be sawed vertically. Several samples were sawn this way, and nothing was ever identified.

After this situation, five defective wiring units were sent to laboratory, where a crack in connector A was found. Then, an analysis to understand if anything in the production process could affect and provoke the crack in the connector A, was performed in the shop floor, together with the engineering team. Then, it was excluded any possible cause, and it was considered that there could be a problem with the connector material that could fragilize it. This was communicated to the supplier for analysis.

A supplier root cause was identified. The connector was not produced with enough humidity, fragilizing the connector harness. This root cause and its path crossing the five why is identified with the green colour in Figure 32.

Besides the plant investigation, the connector supplier also applied the Ishikawa Diagram in their investigation report, in such a way to show the client the investigation of the problem, and what potential causes were to be considered. With this application, it is possible to compare how the two companies applied this tool and to indicate that the Ishikawa diagram is used in various production companies to assist the defect investigation. Luca and Pasare (2019) point out that there are not many studies in the literature on the application of the Ishikawa diagram for the injection mold industry. In their paper, they explain how they applied the Ishikawa diagram for the defect causes classification obtained by the injection of plastic material production, which is also the technique for the connector A production.

The supplier Ishikawa Diagram is represented in Figure 33.

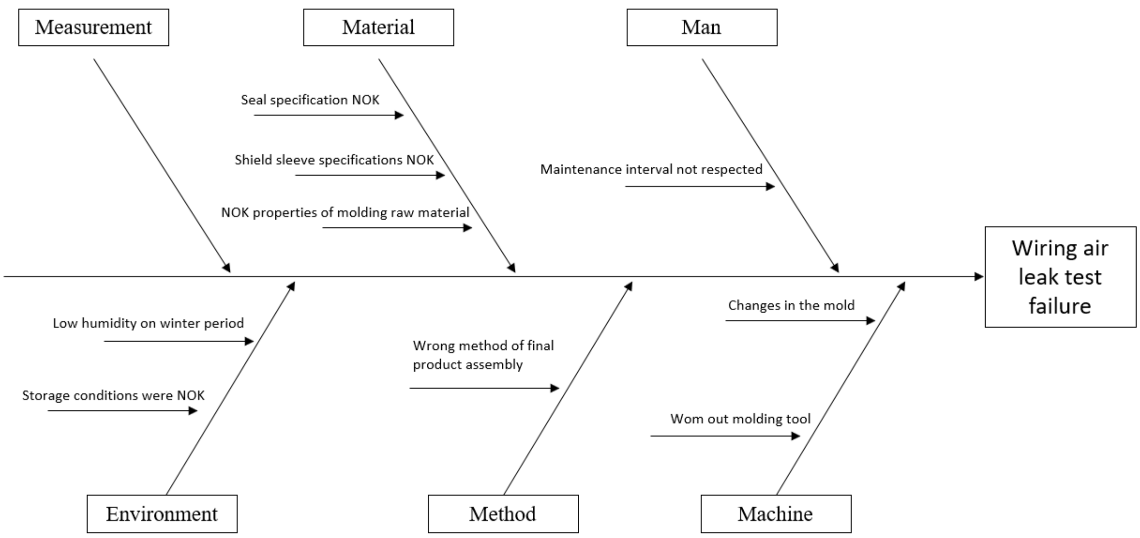


Figure 33- Supplier Ishikawa Diagram

The supplier admitted the connector problem and sent good connectors in the beginning of April, and the rest of the unused connectors were sent back to the supplier. In April, production only used the new connectors. In a total of 38995 wiring produced, 71 air leak test failures were identified, representing 0,18%, which is a substantial percentage reduction comparing to the previous month. From those air leak test failure, only 3 wirings presented the fissure on connector A.

The major consequence of this specific defect is that all these non-conform wirings are going to scrap. Currently, there is not a special tool that does not cause damage in the wire, in the process of removing the non-conform connector and replacing it with a new one, so it is not possible to substitute connector A.

4.3.2.3. Lessons Learned

This was a detailed investigation in a complex process. The quality tools which were applied were useful to analyse every possible root cause, and to organize the information in an intuitive visual approach.

The quality tools helped us in a more detailed investigation of the defect, in the direction of the identification of the root cause. The purpose of the study was achieved, the root cause was identified, and the percentage of defect and scrap material was reduced.

It is worth noting the lack of existing tools to analyze defects in high voltage wiring, in a multinational company known worldwide. The ideal scenario would be the possibility to analyze this type of defects with non-destructive tests, not repeatedly destroying both the component and its defect.

4.3.3. New HV Defect Codes

As previously mentioned, some documents used in the production of low voltage wiring have been applied to the production of high voltage wiring, without the necessary adjustment to this new technology. One of the documents pertaining to this situation is the Defect Coding Catalogue (For Wire Harnessed), applied by Yazaki, that can be observed in Appendix I. Each defect has a category, a defect type, and an associated code.

When a defect occurs, to register it is needed to assign a code. Currently, some high voltage defects are not included in any of the defects that are on Yazaki's list. From the observation done up to the moment, this situation can occur due to two reasons. First, in the case that there is no defect listed that can describe it. Some components of these HV projects are too specific and cannot be inserted in none of the categories previously existing. In other case, what can occur is that the assigned code corresponds to a defect that is too general, which can mislead the reader / receiver of this information, that is, assume that it was a defect, instead of another.

In Figure 34, the document made in January 2021 with the proposal of New HV Defect Codes is presented. For the elaboration of this document, it was necessary to:

- Analyze what defects occurred at Customer X and the team was unable to assign one of the current codes.
- Collect photos that demonstrate the defect and through which it is possible to perceive and comprehend the defect description that we intend (OK product / NOK product).
- Assign categories and description to these defects.
- When possible, inform what defect was currently being used for the classification.

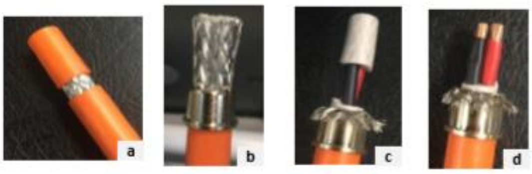
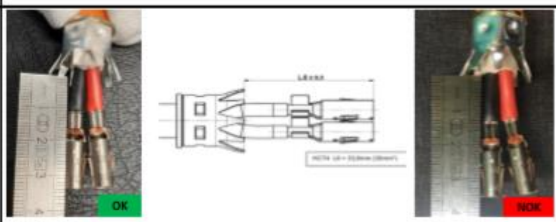
In all these points, the collaboration of the quality and production team was requested, as they are the ones who work daily in the field with these codes. After collecting all this information, the document was formatted, the information was introduced and then approved by the LQC and the Quality Team Leader.

The document was sent to the YEL Central Quality team to approve the proposed defects. Once approved, this classification of defects will be applied to all Yazaki plants.

DAIMLER

YAZAKI

NEW DEFECT CODING - HV

CATEGORY	DEFECT	COD	PHOTO	OBSERVATION
STRIPPING	Incorrect Length: a) Insulation b) Shield wire c) Inner insulation d) Inner striping			current AA35 (poor striping)
SHIELD CRIMP	Incorrect Length (Supplier spec.)			current AB38 (wrong size contact gap)
INTERLOCK ERROR	Missing Alignment			current is considered a terminal

Prepared by: Alexandra Sá (Internship - Central Quality Yazaki Europe Limited)
27/01/2021

1

Figure 34- New Defect Coding - HV

4.3.4. Quality Data System (QDS)

One of the aims of this project is improving the management and performance of internal defects, through an upgrade in the system's functionalities, compared to the current database. In addition, with this new database, homogeneity of management and operation among all Yazaki factories at European and North Africa levels is intended.

4.3.4.1. UML Language: Class Diagram and Relational Model

In a way to better explore the QDS functionalities, an analysis with UML language was completed. First, it is presented a requirements specification, which describes the functionalities of a defect report to be registered in the QDS. After, a Class Diagram and a Relational Model is presented, to demonstrate the relation between the classes involved.

Requirements Specification

When a defect occurs, a team member inserts it in the QDS. If it is the line operator, he immediately inserts the defect in the "Add defect in shopfloor". If the defect is inserted after, it will be inserted by a member of the Quality team in the 'Add defect in Office'.

To register the defect, a new Defect Report is created, in such a way that each registered defect has a unique report number. In this Defect Report, the following information is recorded:

- The date when the defect was detected.

- The production shift that provoked the defect. If the person inserting the data does not have this information, he/she needs to insert the shift where the defect was detected. The shift must be defined in Page definition in section 'Shift' with the information: shift name, start time, finish time, break time duration, time zone, area and status (if is active or inactive).

- The operator that provoked the defect. If the person registering the defect does not know who provoked the defect, he/she has the option 'Unknow' operator. The operator information must be defined in Page definition in section 'Personnel' with the information: personnel ID, name, area and position.

- The station name of the operator that provoked the defect, which must be defined in Page definition in section 'Station', mainly for subassembly and line conveyor.

- The Line Leader information of the shift that provoked the defect should be identified and the same information characterization of the operator included.

- The station where the defect was detected must be defined in Page definition in the section 'Observed station' with the information: process code, process description and the information if it is an inspection station or not.

- The source of the defect, which represents where the defect is suspected to come from. It must be defined on the Page definition in section 'Observed station' with the information: process code and process description.

- The name of the defected product and product No.

- The wiring unique serial number, that correspond to the S/No present in the label when the wiring passes the electrical inspection.

- The defect code of the Defect Coding Catalogue (For Wire Harnessed), applied by Yazaki. It must be defined in Page definition in section 'Defect codes' with the information: class, classification, defect code number and defect description.

- A reason code which represents an optional describing reason for the defect. It must be defined in Page definition in section 'Reason Codes' with the information: reason code ID and the reason description.

- The workcenter of the line where the defect product is produced. This ID creates a point between SAP and Prodmon system to update the production values on QDS. It must be defined in Page definition in section ‘Workcenter’, with the information: workstation ID, workcenter name, family, project code, project description, customer, area, type, and status (active or inactive).

- The area where the defect was observed.

- The quality staff of the shift where the defect was detected. The same information characterization of the operator should be defined and included.

- The customer’s name of the defected product. It must be defined in Page definition in section ‘Customer’ with the information: customer name and customer number.

- The project name of the defected product. It must be defined in Page definition in section ‘Cutlead and Customer’ with the information: cutleadNo, projectCode and customer name.

- The cutlead number, which is the defined snumber of the product from P1.

- The total quantity of defect wirings.

- The defect quantity type, that can take two values: single or lot.

- From the total quantity of defect wiring, specifying how much is going to scrap.

- The work force loss, with man and hour information.

- The defect description, where the following information can be registered: the twig number (branch number), the connector number, the number of circuits, a problem description, and the team.

- The 4M actions, allowing to register 4M transition in case done. The 4M englobes man, machine, method, and material.

Besides the previous description, the mandatory options to fill are the observed date, shift, operator, observed station, source of defect, defect code and defect quality type, where only one option can be chosen in each defect report. Also is important to refer that each collaborator has an associated username and password to login the database, and that if the workcenter option is registered, immediately generate the area, costumer name and project name options.

All the previous definitions are presented in both report options. The difference is that besides these definitions, The Office report have additional registration options, presented next:

- An optional product description, englobing the information: machine number (P1 and P2), the wire and kind, the applicator name, terminal name accessory name, SFG ID, the press direction and terminal state.

- A five why method for optional root cause analysis, with the defect name and five reasons fields.

- An optional section with the name Root cause of defect, with comments and precautions of the operator and line leader.

- An optional section with the name Repair/Evaluation for Product1, with the following information: Evaluation by product engineering, industrial engineering repair method, CAO stock correction and four material options.

Class Diagram

A Class diagram was developed to help understand the relationship between the data requested and necessary to create a defect report. The Class Diagram was created using the Visual Paradigm software and is presented in Figure 35.

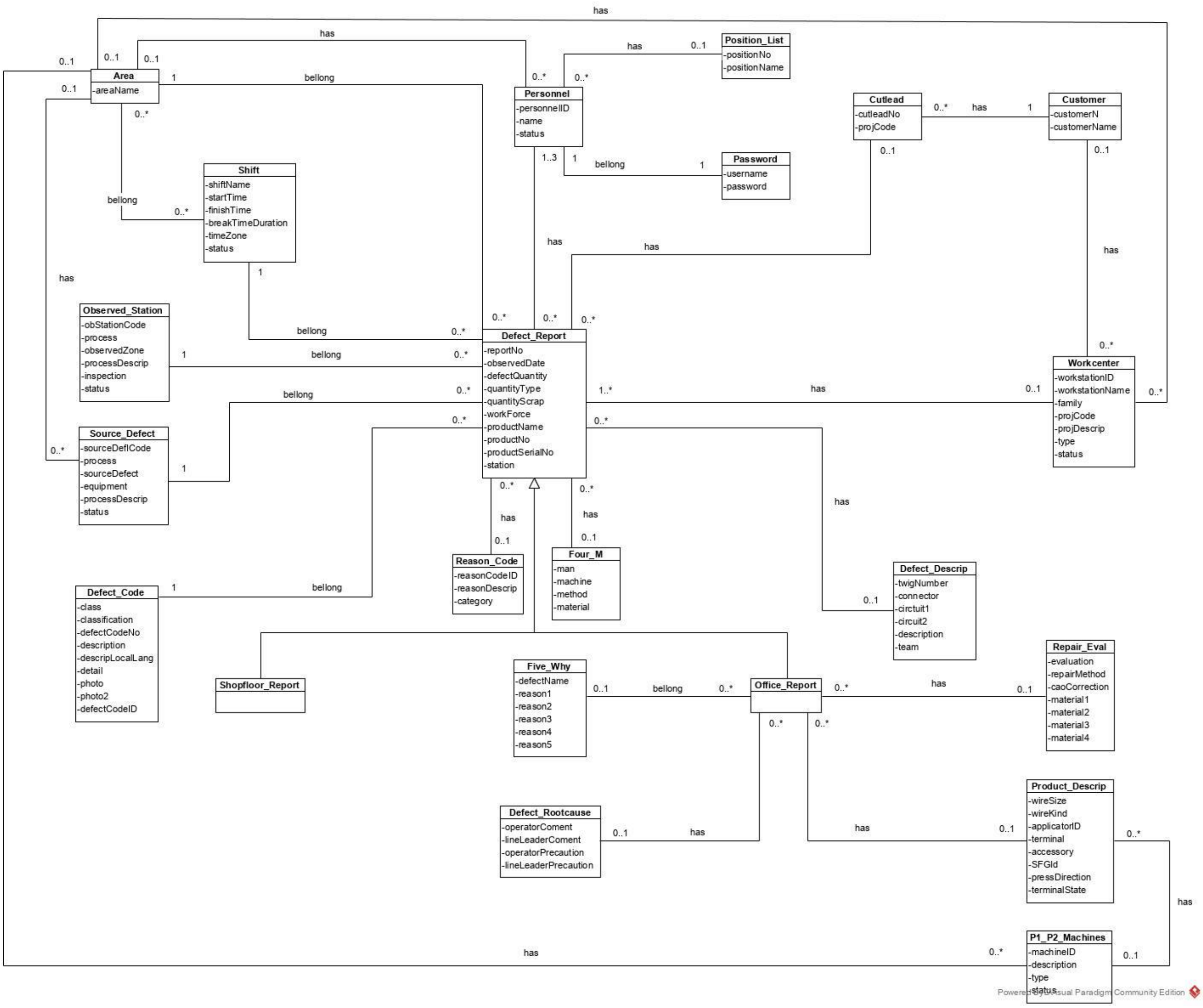


Figure 35- QDS Class Diagram

Relational Model

The relational model is the data model to be implemented in the relational database for the Quality Data System. It can be transposed directly form the Class Diagram, and the tables are presented following. Primary keys are in bold and underlined, while foreign keys are identified in italic. For the conception of this model, the different rules associated with the cardinality of the relations between classes had to be considered.

Relational Model:

Defect_Report = (**reportNo**, observedDate, defectQuantity, quantityType, quantityScrap, workforce, productName, productNo, productSerialNo, station, areaID, *shift_ID, obStationCode, sourceDefCode, defectCodeID*)

Area = (**areaID**, areaName)

Shift = (**shiftID**, shiftName, startTime, finishTime, breakTimeDuration, timeZone , status)

Area_Shift = (**areaID, shiftID**)

Personnel = (**personnelID**, name, status, *username*)

Personnel_Defect_Report = (**personnelID, reportNo**)

Area_Personnel = (*areaID, personnelID*)

Password = (**username**, password)

Position_List = (**positionNo**, positionName)

Personnel_Position_List = (*personnelID, positionNo*)

Observed_Station = **obStationCode**, process, observedZone, processDescrip, inspection, status)

Source_Defect = (**sourceDefCode**, process, sourceDefect, equipment, processDescrip, processDescrip, status)

Area_Source_Defect = (*areaID, sourceDefCode*)

Defect_Code = (class, classification, codeNo, description, descripLocal, detail, photo, photo2, **defectCodeID)**

Reason_Code = (**reasonID**, reasonDescrip, category)

Defect_Report_Reason_Code = (*reportNo, reasonID*)

Workcenter = (**workstationID**, workstation, family, projCode, projDescrip, type, status)

Defect_Report_Workcenter = (*reportNo, workstationID*)

Area_Workcenter = (*areaID, workstationID*)

Cutlead = (**<u>cutleadNo</u>**, projCode*, customerID*)

Defect_Report_Cutlead = (*reportNo, cutleadNo*)

Customer = (**customerID**, customerName, customerN)

Customer_Workcenter = (*customerID, workstationID*)

Defect_Descrip = (**<u>defectDescripID</u>**, twigNumber, connector, circuit1, circuit2, description, team)

Defect_Report_Defect_Descrip = (*reportNo, defectDescripID*)

Four_M = (**<u>fourMID</u>**, man, machine, method, material)

Defect_Report_Four_M = (*reportNo, fourMID*)

Shopfloor_Report = (***<u>reportNo</u>***)

Office_Report = ***<u>(reportNo</u>***)

Five_Why = (**<u>fiveWhyID</u>**, defectName, reason1, reason2, reason3, reason4, reason5)

Five_Why_Office_Report = (*fiveWhyID, reportNo*)

Defect_Rootcause = (**<u>defectRootcauseID</u>**, operatorComent, lineLeaderComent, operatorPrecaution, lineLeaderPrecaution)

Defect_Rootcause_Office_Report = (*defectRootcauseID, reportNo*)

Repair_Eval = (**<u>repairEvalID</u>**, evaluation, repairMethod, caoCorrection, material1, material2, material3, material4)

Office_Report_Repair_Eval = (*reportNo, repairEvalNo*)

Product_Descrip = (**<u>productDescripID</u>**, wireSize, wireSize, applicatorID, terminal, accessory, sfgID, pressDirection, terminalState)

Office_Report_Product_Descrip = (*reportNo, productDescripID*)

P1P2_Machine = (**<u>machineID</u>**, description type, status)

Area_P1P2_Machine = (*areaID, machineID)*

Product_Descrip_P1P2_Machine = (*productDescripID, machineID*)

4.3.4.2. Quality Indicators

After the registration of each defect reports, the QDS offers various analysis options, with data presented in table to be filtered and graphic tools. In Table 11, the main quality indicators that can be obtained with the data registered in QDS are summarized.

Table 11- QDS quality indicators

Quality indicators	Description
DPM (defects per million) chart	P3: $DPM * 10^3 = \frac{\text{Number of P3 defects}}{\text{\# W/H produced}} * 10^3$
PPM (part per million) chart	Customer: $PPM = \frac{\text{\# of CO Defects pieces}}{\text{\# of shipped W/H to customer}} * 10^6$
Action Plan and PDCA status	
Top five defects	Pareto chart
Top five operators	Pareto chart
Top five line leaders	Pareto chart
Customer analysis	Pareto chart
Area analysis	Pareto chart
Workstation analysis	Pareto chart
Defect code analysis	Pareto chart

4.3.4.3. QEDS versus QDS

A comparison between the current system – the QEDS – and the new system – the QDS – was performed. The functionalities of each database were explored and the advantages and disadvantages identified. The main ideas are summarized in Table 12 and explored in the next topics.

- QDS provides standardization of quality data collection, processing, and analysis, which leads to the improvement of internal information consistency and accuracy.

- QDS enables real-time internal performance monitoring to support failure prevention. The data registration and updating can be performed at any time, allowing to act on the defects in a timelier manner and to avoid defect occurrences. In this way, it overcomes the inconvenience of the current system, where it is only allowed to update the data monthly.

- Support of action prioritization and problem-solving reactivity. Existence of an extra section in the QDS that allows using, for example, the PDCA analysis tool and the 5Why Method (Appendix J), to study the root cause of the identified defect and immediate act, to introduce this type of information while the defect is being registered. The introduction of these tools is very important in this area because some defects that currently occur turn into recurrences, where it was still not possible to identify why this analysis had not yet been considered a priority, being analyzed only several days after having occurred, or only monthly when it was introduced in the QDS.

- In QDS, all YEL manufacturing plants data collection databases are linked, easy and accessible for any one at any time. It also allows for easier and better analysis of results through the uniformity of collected data, between the diverse plants. On the contrary, the QEDS is only applied in the YSE plant.

- QDS provides time saving and paperless process, because it decreases the number of documents to register and some possible of semi-automatic and automatic registration exists. These two improvements lead to cost saving, because of the reduction of man work hours and the savings on paper.

- QDS gives the possibility of manual, semi-automatic and automatically defect registration. At the Electric Test workstation, for example, the objective is that the new QDS automatically identifies and records defects, without the need for an employee to intervene. Automation at the Electric Test station allows employees to reduce time and work. In QEDS, is only possible to use manual registration.

- QDS makes available more detailed information. For example, QEDS does not have a defect description, however, QDS allows us to visualize a description of the type of defect, prevent the exchange of the code applied.

- QDS details the information about who provoked the defect but does not request information about who registered the defect. On the other hand, QEDS does not provide information about who provoked the defect but identifies who registered it.

- QDS, through the SAP and Prodmon systems, makes possible to update the production quantities on a daily basis, allowing to calculate ratios and output production information which can replace the documents that the production register, for example, FTT and DPU data results.

- QDS is a database of easy and flexible utilization. It can be designed in a Web page and can be accessed from the line production or from a computer outside the production area. When a defect occurs, a team member inserts the defect in the QDS. If it is the line operator, he immediately inserts the defect in the “Add defect in shopfloor” option. If the defect is inserted at a later time, it will be performed by a member of the Quality team in the “Add defect in Office” option. In “Add defect in Office” and “Add defect in shopfloor” options, only the six fields with the red asterisk are mandatory. These two registration options can be observed in Appendix K.

Table 12- QEDS vs QDS: advantages and disadvantages

QEDS		QDS	
Advantages	Disadvantages	Advantages	Disadvantages
		Standardization of data collection, processing and analysis	
	Only allows to update the data monthly	Real-time internal performance monitoring	
	Does not have action and root cause investigation tool	Support of action prioritization and problem-solving reactivity	
	Only used in YSE	All YEL manufacturing plants data collection databases linked	
	Only used in YSE	Uniformity of collected data between all pants	
	Necessity of documents update outside shift schedule; All manual registration	Time saving	
	High number of documents involved	Paperless (reduction of used documents)	
	All manual registration	Manual, semi-automatic and automatically defect registration	
		More detailed information	
Information about who registered the defect	Does not detail the information about who provoke the defect	Detail the information about who provoke the defect	Does not have information about who registered the defect
	Just provide defect information output	Production information update and ratios calculation	
	Only office registration option	Two option for defect registration (shop floor or office)	

With this information, it is clearly to verify the significant improvement of QDS in comparison with the QEDS used up to the moment in EDS at YSE.

4.3.4.4. Database Implementation Methodology

As this implementation is being performed in two plants ate the same time - one of them is YSE – several meetings between these plants and members at the Quality Central team occurred.

The main phases of preparation will be applied using the four steps of the PDCA cycle, presented in Figure 36.

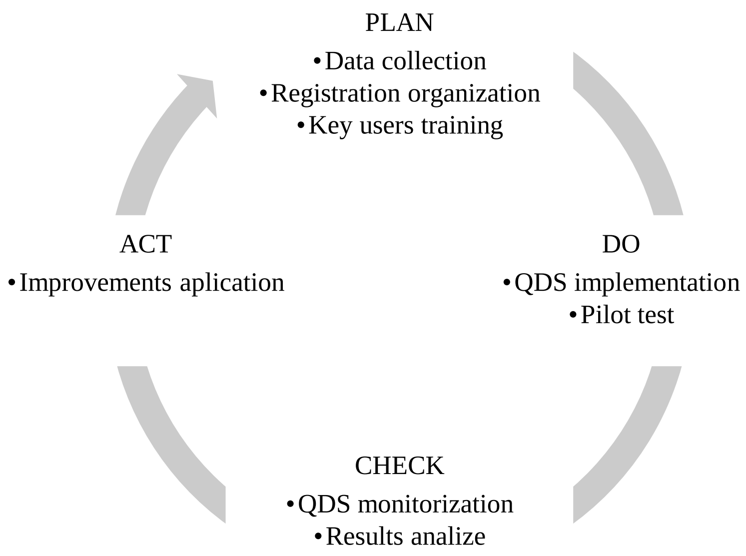


Figure 36- PDCA cycle for QDS implementation

The stage after planning the implementation steps, is to collect all the necessary data to upload in the QDS system, to be use in the YSE pilot area The gathering of information was performed according to the Class Diagram classes and attributes, and in Appendix L three examples of the data collected for the pilot area are presented.

Then it was necessary to define the needs of training in the QDS usage and implementation for YSE, and to define necessary Software and Hardware requirement to install the QDS into YSE Server. A training with a member of the Turkey quality team was performed, the only European plant that already has the QDS implemented. This training was important to comprehend the system's functionality and to better understand the necessary data to be inserted in the system, in contextualization with this plant experience with the system.

The pilot test of the QDS in YSE was performed in May 2021, during the entire month. The QDS system was applied in parallel with the QEDS system, in such a way to compare the results of the two systems and obtain a comparation with the initial situation. During this pilot test, the defects were only inserted in the ‘Add defect in Office’ section, by the assembly LQC in a daily basis.

A daily monitoring of the QDS was performed, to understand and identify eventually roadblocks or issues that we need to solve for an effective use.

In the first week of June 2021, the reports data of the QEDS and QDS related to May 2021 were collected and the results where compared, through the report extracted related to assembly area. The two reports are presented in Appendix M. As can be observed, in the 31 days that were studied, a total of 420 defects were detected, in a total of 31593 produced wirings.

QEDS

There were four QEDS reports analysis, two related to PROJ1 and another to related to PROJ2. The Pre-P3 reports are referent to the defects detected before the final inspection workstation, and the P3 reports are related to the defects detected in the final inspection workstations. In each of the QEDS reports, we can observe the four major defects of the month and a PDU ratio of each month of the term (‘Yazaki year’). The defect information identified is the defect code, the description of the defect (defect name) and the total of each defect.

QDS

The QDS report, presents Pareto diagrams with information about the customer, area, workstation, defect coding, and line leader. It was possible to conclude that:

- Line 3 was where more defects were identified, in a total of 125 defects.

- The AU21 – Incorrectly Torqued was de major defect identified, with a total of 114 defects. These 114 defects correspond to 41 reports.

- Collaborator nr 758 was the line leader present in the shift where more defect provoked, which correspond to a total of 73 defect report.

- Customer X and P3 where the only customer and area identified because are the pilot production area.

It was not possible to calculate some quality indicators, such as DPM and PPM in QDS because of the necessity to install the Prodmon system in the plant, which will be the bridge between SAP and QDS to provide the production quantities.

It was also observed that QDS provides the possibility of a daily, weekly, or monthly analysis, and QEDS only provide a monthly analysis.

The fourth stage of the PDCA cycle, ‘Act’, involves the proposal and implementation of improvements for an effective use of the QDS.

To start using the option “Add defect in shopfloor” an observation on the resource’s lines was realized to identify which workstations have a computer able to use the QDS. The information collection was gathered and is presented in Appendix N. It was defined to be each line operator of the second visual inspection to register the defect in the “Add defect in shopfloor”. These operators will be trained, so that they can be able to correctly use the QDS. In this stage, the Promon system implementation will also be performed.

4.3.4.5. Lessons Learned

With the QDS implementation, the main benefits observed were to obtain and to visualize a daily updated data flow and an improved data report.

It was not possible to see in practice all the QDS functionalities, because of the delays in the QDS implementation and Prodmon implementation, related to the multinational scenario of this implementation that was affected by the Covid-19 Virus pandemic. However, it was possible to observe the positive impact that this quality database analysis can provide in comparison with the previous one. The future work will consist in exploring and implementing the rest of the QDS functionalities together with the Prodmon system implementation, in such a way to reduce the amount of used paper and to reduce the internal defects through an increased and improved routine investigation.

5. Conclusions and Future Work

The quality objective in companies is mostly zero defects, and they operate with a special focus. In the automotive industry, quality control plays a fundamental role in maintaining the level of product quality, preventing defects, and preventing possible serious accidents.

BPM is a visual tool that helps to understand the processes and to identify possible points for enhancement, which together with quality tools allows the improvement of organizational management and the prevention of defects. Through the AS-IS Model created with BPMN 2.0, in addition to helping to better know the process under analysis, it was possible to identify problems in the initial situation and propose improvements.

Currently, the quality area is living the Total Quality Management dimension, with a special focus on people in the organizations. With this focus, the implementation of the Whiteboard in the production area was a successful strategic way to improve the communication between departments in the organization, and, at the same time, helped with the internal defect investigation and reduction, allowing sharing knowledge and increasing the awareness of operators in the quality of their work.

In relation to the analysis of the investigation of the wiring air leak defect, the quality tools which were applied were useful to analyse every possible root cause, and to organize the information in an intuitive visual approach. The purpose of the investigation was achieved, the root cause was identified, and the percentage of defects and the quantity of scrap material were reduced. It is worth noting the lack of existing tools to analyze defects in high voltage wiring, in a multinational company which is known worldwide, where the ideal scenario would be having the possibility to analyze these types of defects with non-destructive tests.

With the QDS implementation, it was concluded that its application is more advantageous than the previous database, the QEDS. From the application of the two databases in parallel for one month, with the registration of 420 defects, it was found that QDS provided more graphic results than the previous database, and also provided the possibility of a daily analysis, as opposed to the monthly single analytics option of the QEDS. The future work will consist in exploring and implementing the rest of the QDS functionalities together with the Prodmon system implementation, in order to reduce the amount of used paper and to reduce the internal defects because through an increased routine investigation.

In summary, the research question and aim objective of this practical project, the improvement of the internal defect management and the data flow was achieved. However, there are still opportunities for future continuous work improvement.

The main activities considered important to proceed with the work described n this document, should focus on:

- Improvement of the HV wire and harness rectification sheet with better organization, in a way to reduce the time that the rectifier operator spends with this document registration, making him/her available to focus more on the defect analysis activity.

- Regarding QDS, the future work should go through the complete implementation of the TO-BE model in the Customer X production lines, with the defect registration in the “Add defect in shopfloor” section. This implementation should be performed together with the implementation of the Prodmon system, in a way to provide the production information. The next step should be the implementation of the new system in all EDS production lines.

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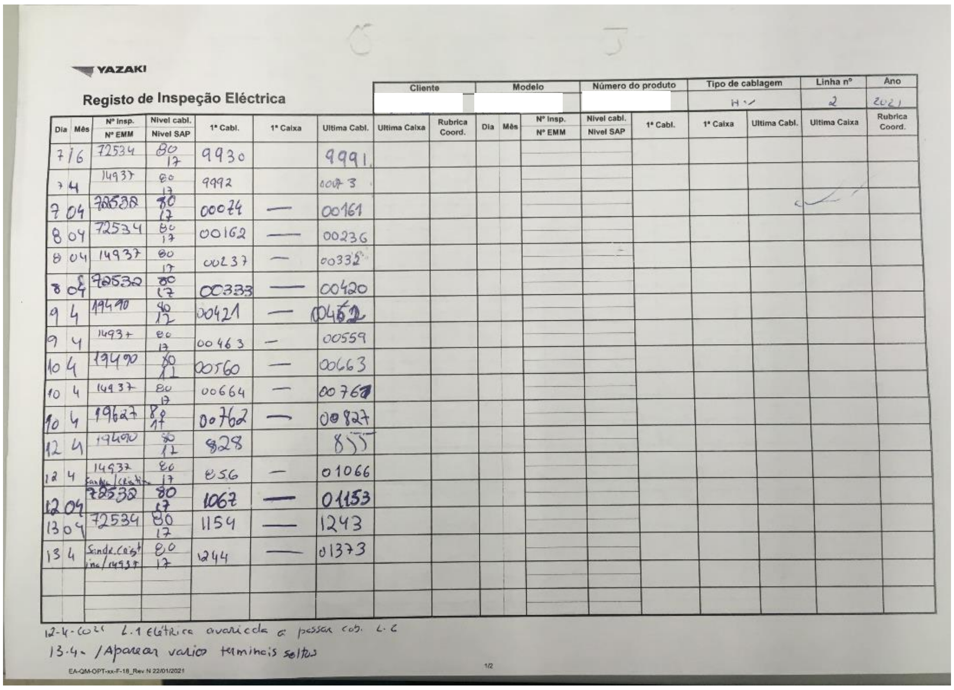
Appendixes

Appendix A – Electrical inspection sheet



YAZAKI

Registo de Inspeção Eléctrica

Cliente	Modelo	Número do produto	Tipo de cablagem	Linha nº	Ano
			H·V	2	2021

Dia	Mês	Nº Insp. / Nº EMM	Nível cabl. / Nível SAP	1ª Cabl.	1ª Caixa	Ultima Cabl.	Ultima Caixa	Rubrica Coord.
7	6	72534	80 / 17	9930		9991		
7	4	14937	80 / 17	9992		0073		
7	04	72532	80 / 17	00074	—	00161		
8	04	72534	80 / 17	00162	—	00236		
8	04	14937	80 / 17	00237	—	00332		
8	04	72532	80 / 17	00333	—	00420		
9	4	19490	80 / 12	00421	—	00462		
9	4	14937	80 / 17	00463	—	00559		
10	4	19490	80 / 11	00560	—	00663		
10	4	14937	80 / 17	00664	—	00768		
10	4	19627	80 / 11	00762	—	00827		
12	4	19490	80 / 12	828		855		
12	4	14937	80 / 17	856	—	01066		
12	04	72532	80 / 17	1067	—	01153		
13	04	72534	80 / 17	1154	—	1243		
13	4	Sandra Cristina / 14937	80 / 17	1244	—	01373		

12-4-2021 L.1 Elétrica avariada e passar cos. L.C

13-4- /Aparecer vario terminais soltos

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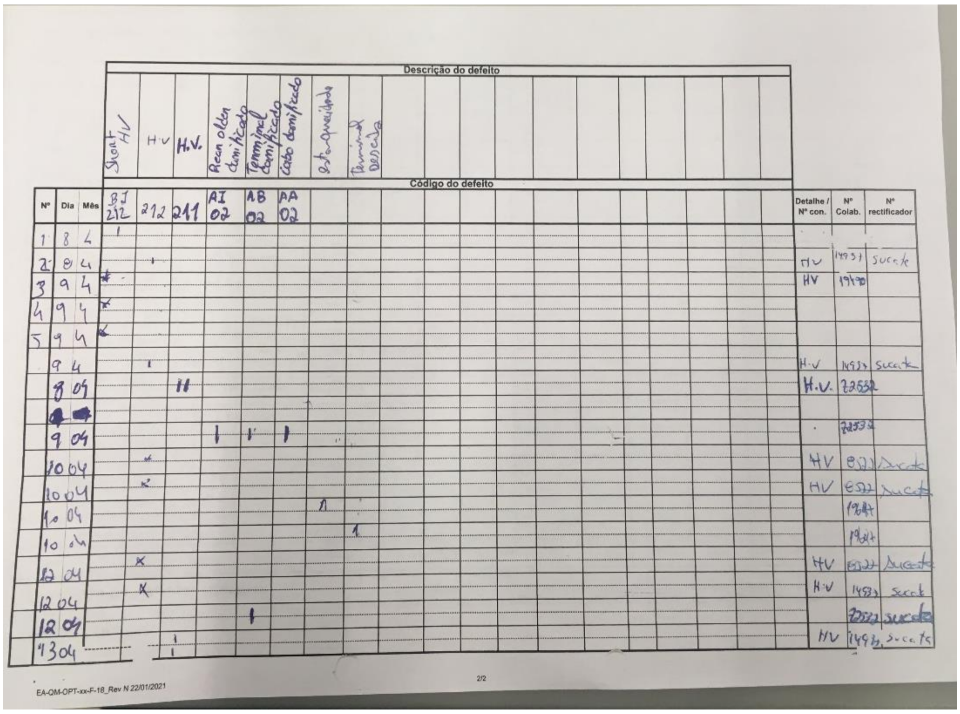

Descrição do defeito: Short HV | H·V | H.V. | Rean olden danificado | Terminal danificado | Cabo danificado | Sobre-aquecido | Terminal dobrado

Código do defeito: BJ 212 | 212 | 211 | AI 02 | AB 02 | AA 02

Nº	Dia	Mês	Detalhe / Nº con.	Nº Colab.	Nº rectificador
1	8	4			
2	8	4	HV	14937	Sucata
3	9	4	HV	19490	
4	9	4			
5	9	4			
	9	4	H·V	14937	Sucata
	8	04	H.V.	72532	
				72532	
	9	04			
	10	04	HV	8327	Sucata
	10	04	HV	8327	Sucata
	10	04		19627	
	10	04		19627	
	12	04	HV	8327	Sucata
	12	04	H·V	14937	Sucata
	12	04		72532	Sucata
	13	04	HV	14937	Sucata

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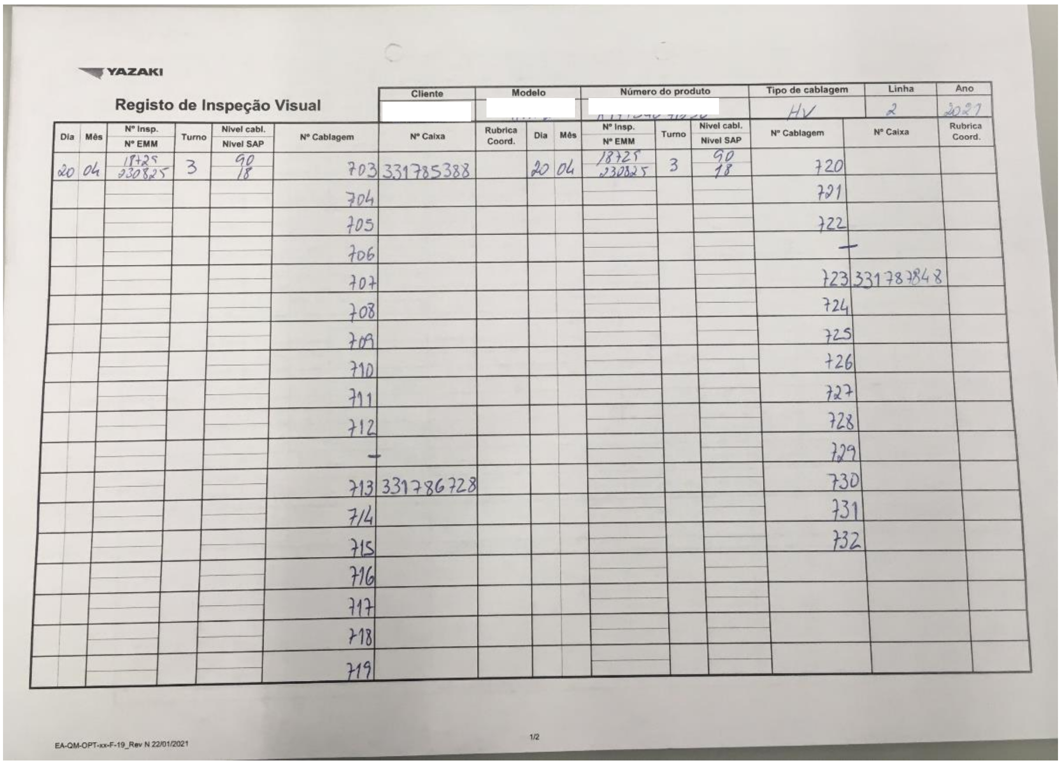
Appendix B – Visual inspection sheet



YAZAKI

Registo de Inspeção Visual

Cliente	Modelo	Número do produto	Tipo de cablagem	Linha	Ano
			HV	2	2021

Dia	Mês	Nº Insp. / Nº EMM	Turno	Nivel cabl. / Nivel SAP	Nº Cablagem	Nº Caixa	Rubrica Coord.	Dia	Mês	Nº Insp. / Nº EMM	Turno	Nivel cabl. / Nivel SAP	Nº Cablagem	Nº Caixa	Rubrica Coord.
20	04	18+25 / 230825	3	90 / 18	703	331785388		20	04	18+25 / 230825	3	90 / 18	720		
					704								721		
					705								722		
					706								–		
					707								723	331787848	
					708								724		
					709								725		
					710								726		
					711								727		
					712								728		
					–								729		
					713	331786728							730		
					714								731		
					715								732		
					716										
					717										
					718										
					719										

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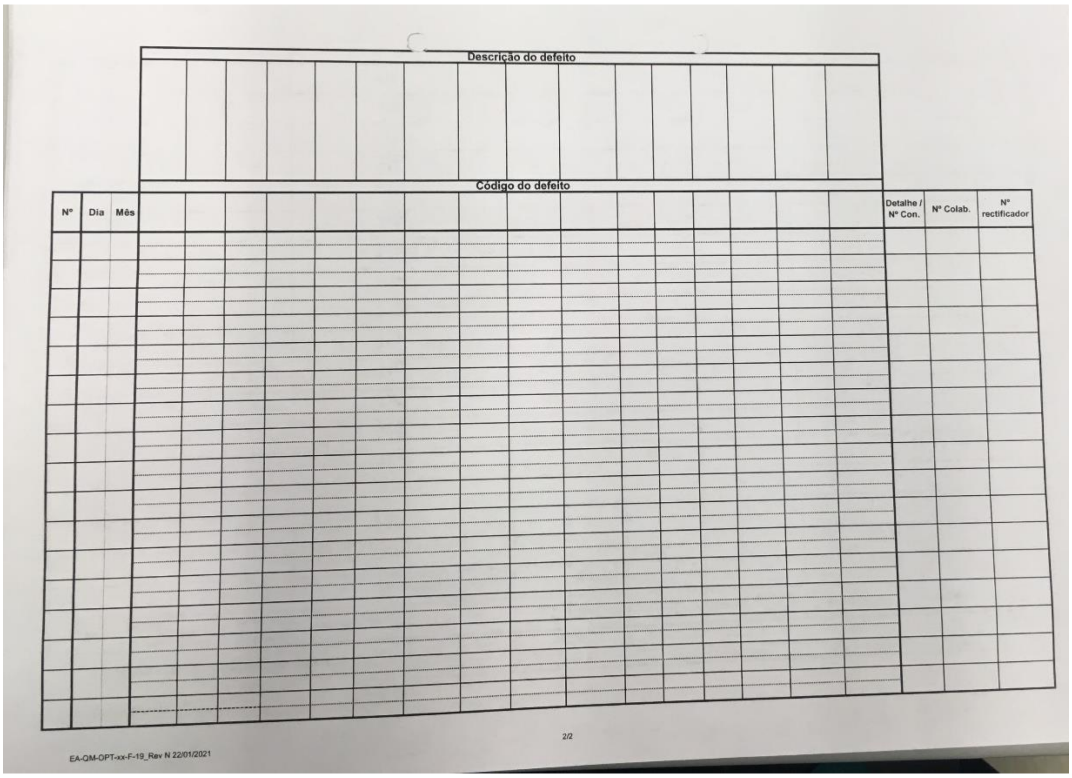
1/2



Descrição do defeito

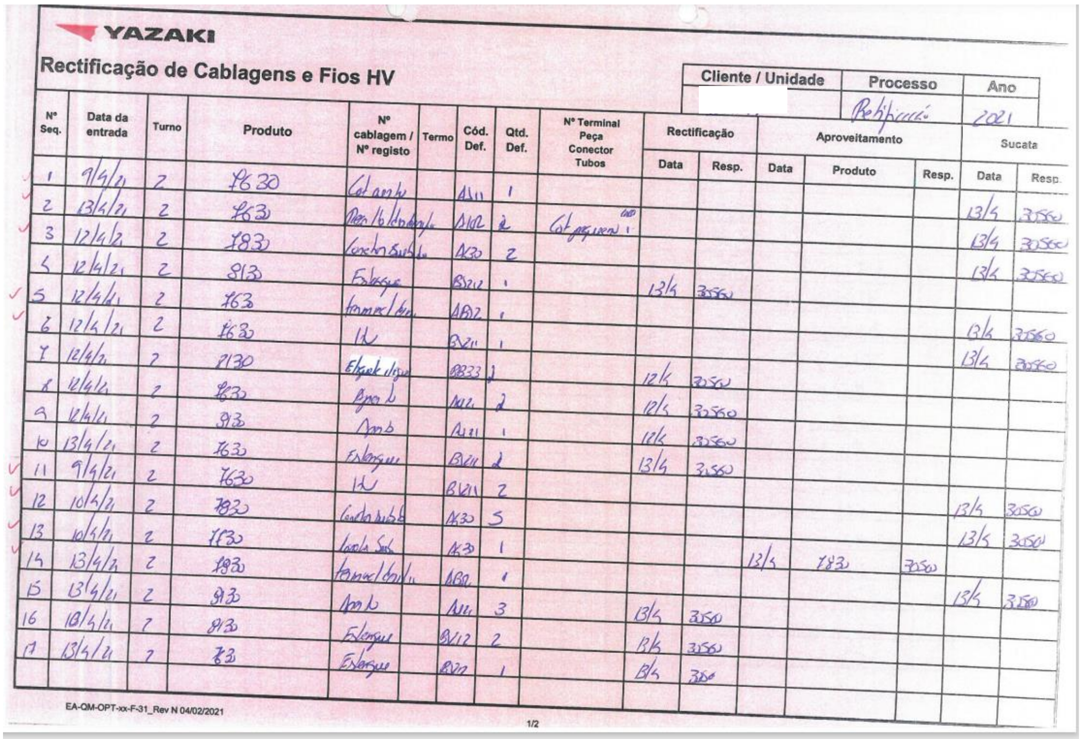
Código do defeito

Nº	Dia	Mês		Detalhe / Nº Con.	Nº Colab.	Nº rectificador

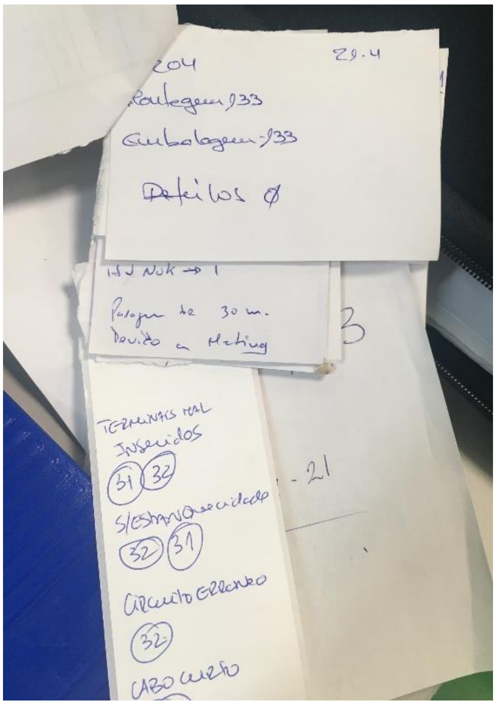
EA-QM-OPT-xx-F-19_Rev N 22/01/2021

2/2

Appendix C – HV wire and harness rectification document



Appendix D – Scrap line papers



Appendix E – Aleatory Internal Defect sheet (Daily Log sheet)

YAZAKI — **REGISTO DE DEFEITOS INTERNOS ALEATÓRIOS (Montagem / Auditoria)**

CLIENTE	MODELO	FAMILIA	LINHA	TURNO	ANO	MÊS	ELABORADO	VERIFICADO
			17	(DIA) NOITE	21	04	[illegible]	[illegible]

								TOTAL
DIA	7	8	12	13	14	15	16	
Nº DE CABLAG. INSP. - ELÉCTRICA								
Nº DE CABLAG. INSP. - VISUAL								
Nº DE CABL. INSP. AUDITORIA								
Nº DE DEFEITOS	1	1	6	1	6	1	5	
Nº de DE FALHAS (DPU $^{-3}$)								

COD	Desc. do defeito:								Total
	Cabo direcção errada	1							
	Cabo medida errada		1						
	Malha medida errada			3					
	Soldadura danif.			2	1		1	2	
	Conector danif.			1					
	Ângulo errado [illegible]					6			
	Malha danif.							1	
	Cabos danif.							2	

Nº Revisão: 2
Descrição da Iteração:Itens(cod/total)
Data da aprovação : 05-02-2019
Elaborado por : Maria Martins
Aprovado por : Carla Almeida

QMI-6033
Arquivo : 5 Anos

YAZAKI — **ANÁLISE E TRATAMENTO DE DEFEITOS INTERNOS**

UNIDADE/CLIENTE:		PROCESSO:		TURNO:		LINHA:		FAMÍLIA:	

DATA	TIPO DE DEFEITO	LOCALIZAÇÃO	DETALHE	Nº COLAB.	CAUSAS	ACÇÃO CORRECTIVA – DESCRIÇÃO	ACÇÃO CORRECTIVA – DATA	EFEITO
7-4-21	Cabo direcção errada	5304	1	3900				
8-4-21	Cabo medida errada	2405	1 (9402)	19610				
12-4-21	Malha medida errada	2405	1(9402) 2(3240)	19610 / 3240				
12-4-21	Soldadura danif.	5204	2	19498				
12-4-21	Conector danif.	5204	1	19498				
13-4-21	Soldadura danif.	5304	1	19404				
14-4-21	Ângulo errado	5204	6	19498				
15-4-21	Soldadura danif.	5304	1	7043				
16-4-21	Malha danif.	9402	1	19610				
16-4-21	Cabo danif.	5304	2	19404				
16-4-21	Soldadura danif.	5204	2	19478				

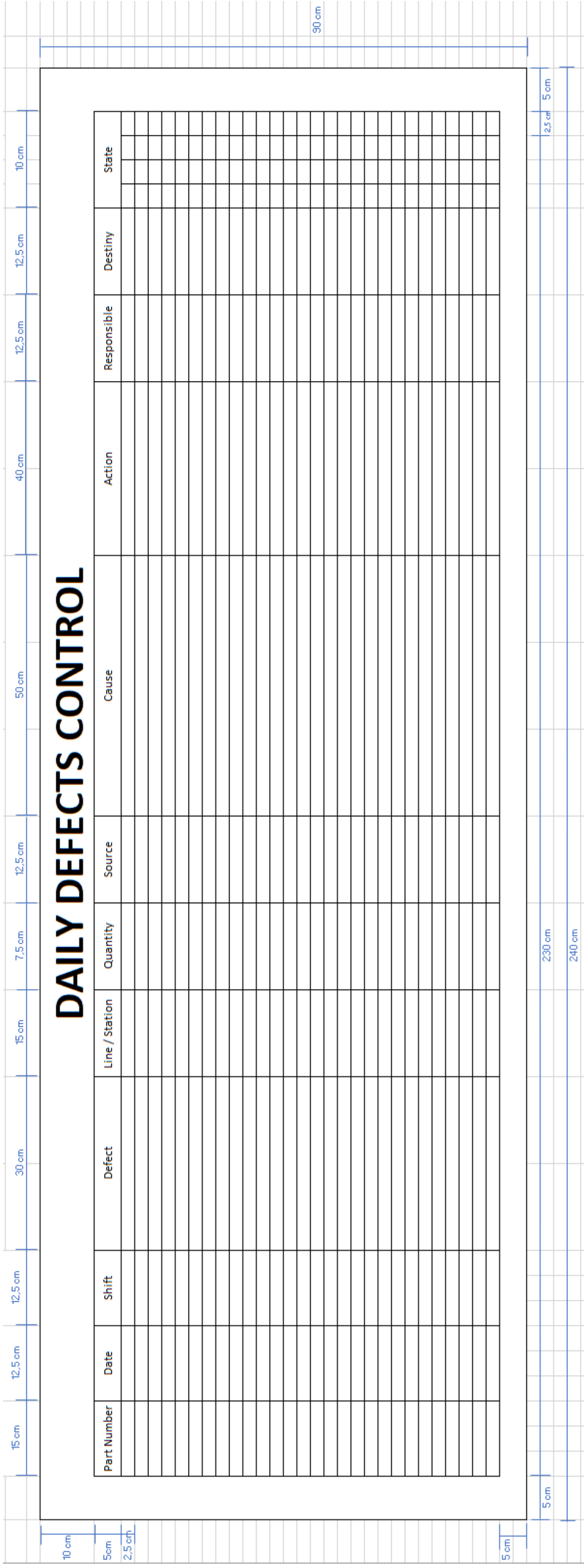
Nº Revisão: 2
Descrição da Iteração:Itens(cod/total)
Data da aprovação : 05-02-2019
Elaborado por : Maria Martins
Aprovado por : Carla Almeida

QMI-6033
Arquivo : 5 Anos

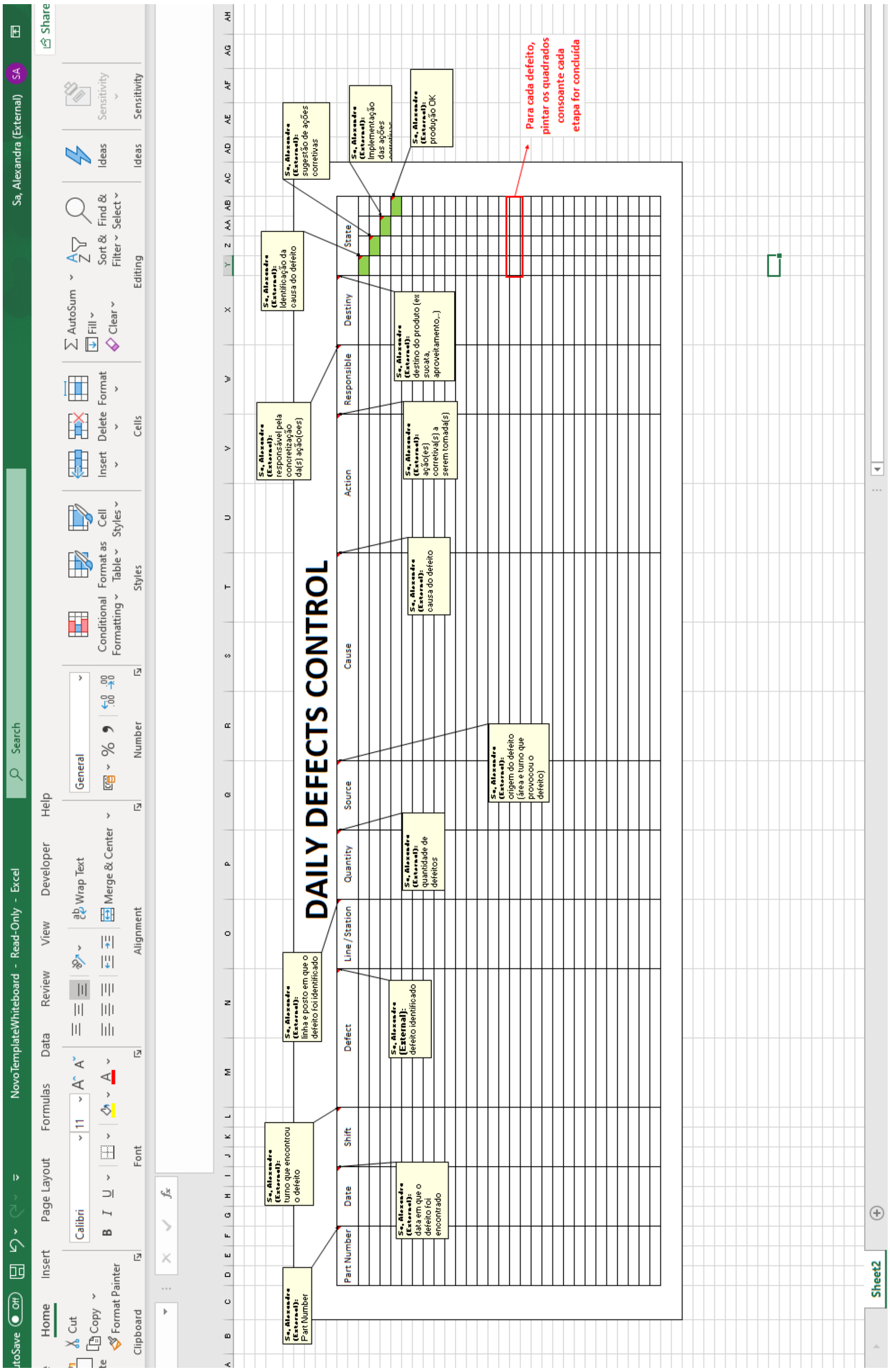
Appendix F – Excel with production information

				1º TURNO					2º TURNO					3º TURNO		
		jan-21														
	W 31			A	B	C			A	B	C			A	B	C
																0,95%
	W 15			A	B	C			A	B	C			A	B	C
	12-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
SEGUNDA	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204	140	143		3		70	70					0			
	5304	136	136				80	80					0			
	9002	200	201	1				0					0			
	9402		0					0					0			
	2405	180	184	1	3			0					0			
	2305	134	136	2				0					0			
	TOTAL	790	800	4	6	0	150	150	0	0	0	0	0	0	0	0
	13-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
TERÇA	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204	120	122	2			70	70					0			
	5304	125	126		1		75	75					0			
	9002	182	182				18	18					0			
	9402		0					0					0			
	2405	180	182	2				0					0			
	2305	133	133					0					0			
	TOTAL	740	745	4	1	0	163	163	0	0	0	0	0	0	0	0
	14-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
QUARTA	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204	115	121		6		70	70					0			
	5304	125	125				37	37					0			
	9002	200	0	2				0					0			
	9402		0					0					0			
	2405	180	181	1				0					0			
	2305	129	131	2			38	38					0			
	TOTAL	749	558	5	6	0	145	145	0	0	0	0	0	0	0	0
	15-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
QUINTA	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204	140	140				70	70					0			
	5304	150	151		1		35	35					0			
	9002	200	201	1				0					0			
	9402		0					0					0			
	2405	175	175					0					0			
	2305	167	167					0					0			
		832	834			0	105	105	0	0	0	0	0	0	0	0
	16-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
SEXTA	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204	140	142		2		70	70					0			
	5304	150	153	1	2		35	35					0			
	9002	200	200					0					0			
	9402		0					0					0			
	2405	180	184	3	1			0					0			
	2305	180	180					0					0			
	TOTAL	850	859	4	5	0	105	105	0	0	0	0	0	0	0	0
	17-abr	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos	QTYS-que passam à 1ª	CAB . Produzidas	Def. Electrica	antes da elect.	Outros Defeitos
SABADO	3104		0					0					0			
	3204		0					0					0			
	6104		0					0					0			
	5204		0					0					0			
	5304		0					0					0			
	9002		0					0					0			
	9402		0					0					0			
	2405		0					0					0			
			0					0					0			
	TOTAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL W 15		3961	3796	17	18	0	668	668	0	0	0	0	0	0	0	0
				Total EVA1 dia + noite			4629	6464							% def	35
																0,78%

Appendix G – New Whiteboard template



Appendix H – Whiteboard filling standard



Appendix I – Defect coding catalogue (for wire harnesses)

YAZAKI — DEFECT CODING CATALOGUE (FOR WIRE HARNESSES)

AA	WIRE	00	Corroded
		01	Cut Through
		02	Damaged
		12	Incorrect ID Mark
		15	Incorrect Length
		17	Incorrect Position
		24	Loops
		35	Poor Striping
		39	Wrong Type
		50	Additional
		61	Incorrect Twisting
		62	Incorrect Routing
		66	Missing ID Mark
		67	Insuficient ID Mark
AB	TERMINAL	00	Corroded
		02	Damaged
		05	Deformed
		07	Foreign Substance Present
		14	Incorrect Insertion
		16	Incorrect Orientation
		26	Missing
		36	Push Out
		38	Wrong Size Contact Gap
		39	Wrong Type
		[illegible]	[illegible]
AC	CRIMPING	03	Defective Crimp
		09	IDC Crimp Defective
		[illegible]	[illegible]
		32	Open
		37	Wrong Crimp Dimension
		41	Incorrect Back Burr
		42	Incorrect Bridge
		43	Strands Out
		44	Incorrect Bellmouth
		45	Insulation in the Copper Crimp
		46	Cut Strands
		48	Empty Crimp
		52	Copper Crimp Deformed
		53	Insulation Crimp Deformed
		54	Incorrect Wire Position in Double Crimp
		55	Bellmouth Deformed
		56	Tensile Test Not Good
		63	Insulation Crimp Loose
		70	Missing Wire in Double Crimp
AD	WIRE SEAL	02	Damaged
		16	Incorrect Orientation
		17	Incorrect Position
		25	Loose
		26	Missing
		39	Wrong Type
		59	SPA (Seal Presence Analyse) & SPM Errors (Seal Presence Monitoring)
AE	SPLICE JOINT (Ultrasonic Resistance/ Crimping)	00	Corroded
		03	Defective Crimp
		04	Defective Insulation
		07	Foreign Substance Present
		17	Incorrect Position
		23	Insufficient
		24	Loops
		26	Missing
		34	Strands Separated
		39	Wrong Type
		47	Burned Strands
		56	Tensile Test Not Good
		58	Hardness Test NOK
		68	Strands Stretched
		69	Wire Torn Out
		208	Incorrect Compacting Height
		209	Incorrect Welding Height
		210	Incorrect Welding Energy
		[illegible]	[illegible]
		[illegible]	[illegible]
AF	SOLDERING	06	Excessive
		07	Foreign Substance Present
		23	Insufficient
		26	Missing
AG	CONNECTOR	02	Damaged
		06	Excessive
		07	Foreign Substance Present
		12	Incorrect ID Mark
		16	Incorrect Orientation
		17	Incorrect Position
		26	Missing
		27	Missing Material
		30	Not Fully Inserted
		32	Open
		39	Wrong Type
		66	Missing ID Mark
		67	Insufficient ID Mark
AH	TAPING	02	Damaged
		06	Excessive
		11	Incorrect Dimension
		16	Incorrect Orientation
		17	Incorrect Position
		23	Insufficient
		25	Loose
		26	Missing
		31	Not to Specification
		39	Wrong Type
		50	Additional
AI	SPACER/ Secondary Lock	02	Damaged
		05	Deformed
		07	Foreign Substance Present
		14	Incorrect Insertion
		26	Missing
		32	Open
		39	Wrong Type
		[illegible]	[illegible]
AJ	TUBE (Shrink tube, Sleeve, Zipper tube)	02	Damaged
		[illegible]	[illegible]
		10	Incorrect Cut
		11	Incorrect Dimension
		17	Incorrect Position
		25	Loose
		26	Missing
		32	Open
		39	Wrong Type
		50	Additional
		64	Excess of Glue
		65	Leak Test Not Good
AK	CLIP / STRAP	02	Damaged
		16	Incorrect Orientation
		17	Incorrect Position
		20	Incorrectly Fitted
		25	Loose
		26	Missing
		32	Open
		39	Wrong Type
		50	Additional
		51	Incorrect Cut
AI	PROTECTOR [illegible]	02	Damaged
		16	Incorrect Orientation
		17	Incorrect Position
		26	Missing
		32	Open
		39	Wrong Type
AM	GROMMET (Rubber Seal)	02	Damaged
		05	Deformed
		10	Incorrect Cut
		16	Incorrect Orientation
		17	Incorrect Position
		25	Loose
		26	Missing
		39	Wrong Type
		16	Incorrect Orientation
		17	Incorrect Position
		25	Loose
		26	Missing
		39	Wrong Type
AN	GREASE/ GEL	06	Excessive
		23	Insufficient
		26	Missing
AO	FUSE/ FUSE LINK/ FUSE BOX	02	Damaged
		17	Incorrect Position
		26	Missing
		29	Non Functional
		30	Not Fully Inserted
		39	Wrong Type
		50	Additional
AP	RELAY	02	Damaged
		17	Incorrect Position
		26	Missing
		29	Non Functional
		30	Not Fully Inserted
		39	Wrong Type
		50	Additional
AR	BUSBAR	00	Corroded
		02	Damaged
		11	Incorrect Dimension
		17	Incorrect Position
		26	Missing
		39	Wrong Type
AS	MOLDING/ FOAMING	02	Damaged
		05	Deformed
		06	Excessive
		07	Foreign Substance Present
		08	Short Shot
		17	Incorrect Position
		23	Insufficient
		26	Missing
		60	Bubbles
AU	BOLT/ SCREW/ NUT/ WASHER	00	Corroded
		02	Damaged
		14	Incorrect Insertion
		21	Incorrectly Torqued
		26	Missing
		39	Wrong Type
AV	BRACKET	00	Corroded
		02	Damaged
		16	Incorrect Orientation
		17	Incorrect Position
		26	Missing
		39	Wrong Type
AW	CIRCUIT	26	Missing
		32	Open
		40	Crossed
		71	Short
AZ	BRANCHES/ TRUNK	11	Incorrect Dimension
		12	Incorrect ID Mark
		16	Incorrect Orientation
		19	Incorrect Take Out position
		26	Missing
		50	Additional
		66	Missing ID Mark
BA	PACKAGE	02	Damaged
		07	Foreign Substance Present
		18	Incorrect Quantity
		26	Missing
		28	Mixed Parts
		[illegible]	[illegible]
		[illegible]	[illegible]
BB	PRODUCT LABELING	02	Damaged
		13	Incorrect Information
		17	Incorrect Position
		20	Incorrectly Fitted
		26	Missing
		33	Illegible
		39	Wrong Type
BC	COVER	02	Damaged
		16	Incorrect Orientation
		26	Missing
		32	Open
		39	Wrong Type
		66	Missing ID Mark
		[illegible]	[illegible]
		[illegible]	[illegible]
BD	SUB ASSEMBLY	14	Incorrect Insertion
		15	Incorrect Length
		17	Incorrect Position
		26	Missing
		29	NON Functional
		39	Wrong Type
		50	Additional
BG	SEALANT	06	Excessive
		[illegible]	Foreign Substance Present
		23	Insufficient (Leakage)
		26	Missing
BH	PLUG/ SEAL	02	Damaged
		14	Incorrect Insertion
		17	Incorrect Position
		26	Missing
		39	Wrong Type
		50	Additional

For internal defects only for HV production

BI	CFM Errors	49	Good Crimp Rejected by the CFM
BJ	HV Process	211	HV test failure - AC or DC
		212	Airleak test failure
		213	Connectivity error
		216	Retention test NOK
BZ	SQC Error	217	Smp Quality Check Error

Only to be used for external defects registration while analysis is on going

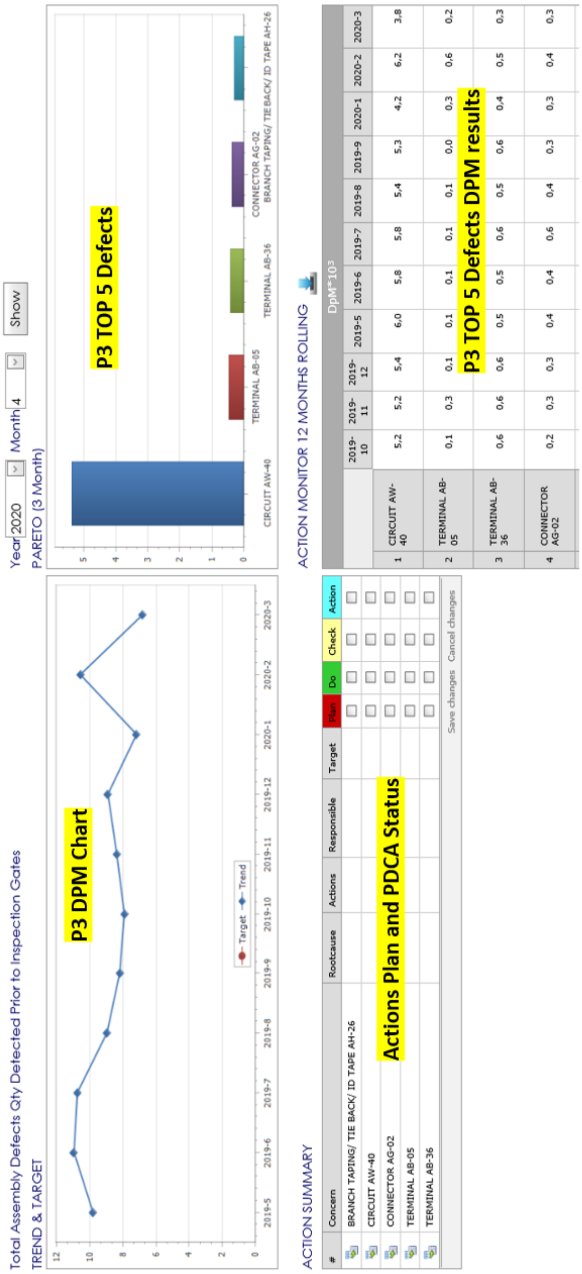
[illegible]	[illegible]	[illegible]	[illegible]

New Defects
Modified the description of the defects
Moved from another category

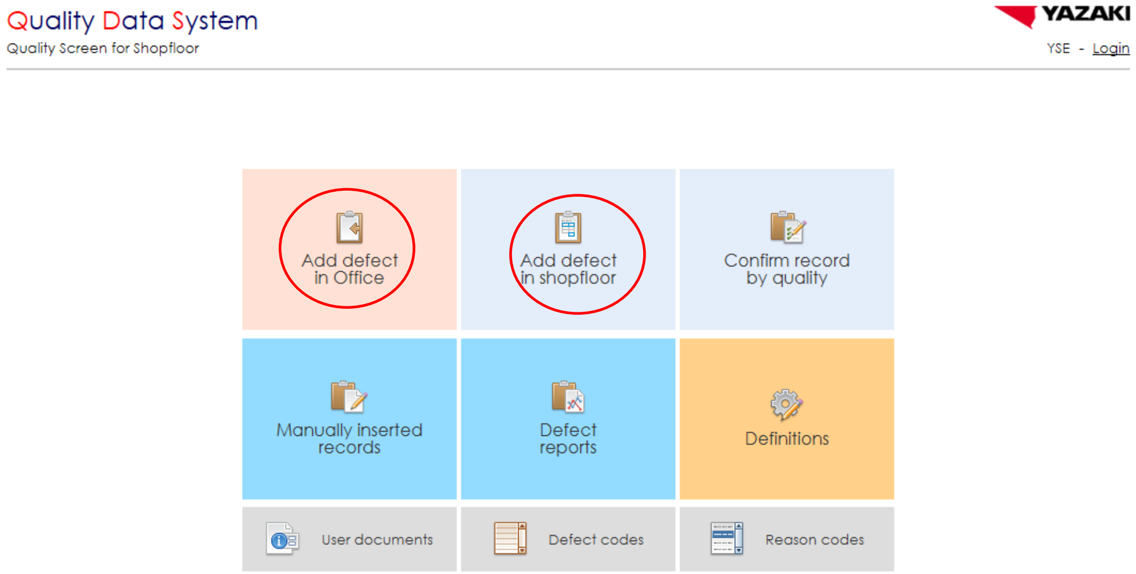
EA-QM-WH-P-361-A-01 Rev.N 07.JUL.2020

1/1

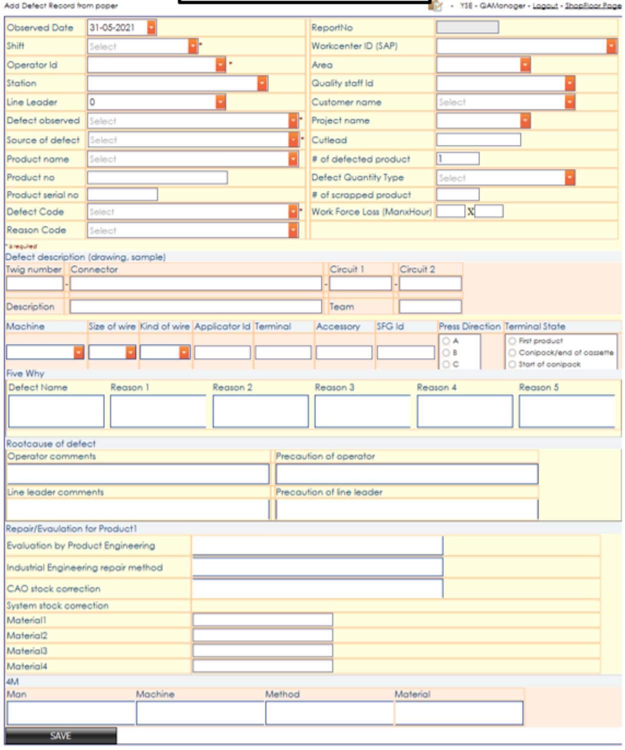
Appendix J – QDS report with PDCA tool



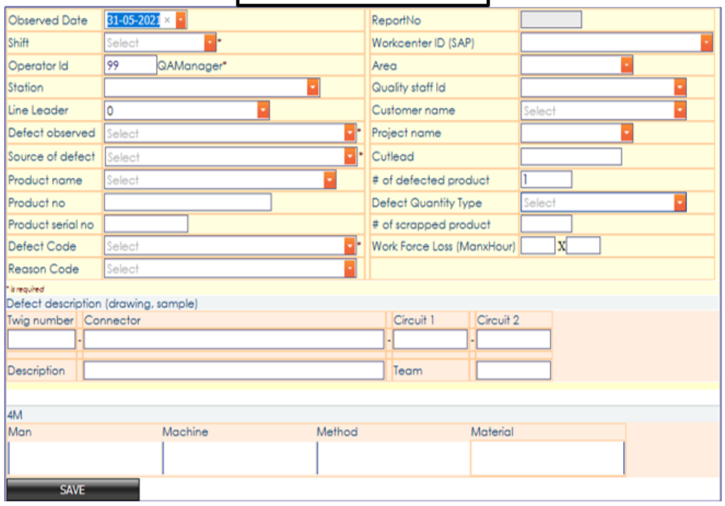
Appendix K – QDS registration options: office and shop floor



Add defect in Office



Add defect in shop floor



Appendix L - Example of QDS collected data

	Personnel ID	Name Surname	Area	Line Leader	Position	Passive	Inserted By	Inserted At
1	0	UNKNOWN	P3	0	Operator	☐	QAManager	3/16/2021 11:00:25 AM
2	99	QAManager			QA Manager	☐	QAManager	3/16/2021 11:00:25 AM
3	441	CLAUDINA COSTA	P3	0	QA Staff	☐		3/26/2021 9:50:04 AM
4	758	ELISA MOREIRA	P1	0	LineLeader	☐		3/26/2021 9:51:00 AM
5	1100	QUITERIA SOUSA	P2	0	Operator	☐		3/26/2021 9:51:03 AM
6	1173	ISABEL ROCHA	P3	0	LineLeader	☐		3/26/2021 9:51:05 AM
7	1713	GRAÇA CARVALHO	P2	0	Operator	☐		3/26/2021 9:51:08 AM
8	2078	LUISA PINTO	P3	0	Operator	☐		3/26/2021 9:51:10 AM
9	2521	FILOMENA SILVA	P3	0	QA Staff	☐		3/26/2021 9:51:12 AM
10	2952	ARMINDA BARBOSA	P3	0	Operator	☐		3/26/2021 9:51:15 AM
11	3107	EMILIA LOPES	P3	0	LineLeader	☐		3/26/2021 9:51:17 AM
12	3187	PAULA GONÇALVES	P3	0	Operator	☐		3/26/2021 9:51:19 AM
13	3241	LURDES ALVES	P3	0	Operator	☐		3/26/2021 9:51:22 AM
14	3348	JOSE NUNES	P3	0	Operator	☐		3/26/2021 9:51:24 AM
15	3900	CARLA NEVES	P3	0	Operator	☐		3/26/2021 9:51:26 AM
16	4368	SUSANA	P3	0	Operator	☐		3/26/2021 9:51:29 AM
17	4401	FERNANDA DUARTE	P2	0	Operator	☐		3/26/2021 9:51:31 AM
18	4672	MANUELA SILVA	P3	0	Operator	☐		3/26/2021 9:51:34 AM
19	5199	ANA SOARES	P3	0	LineLeader	☐		3/26/2021 9:51:36 AM
20	5243	ANA FERNANDES	P3	0	Operator	☐		3/26/2021 9:51:38 AM
21	5460	DORA SOARES	P3	0	Operator	☐		3/26/2021 9:51:41 AM

	Personnel ID	Name Surname	Area	Line Leader	Position	Passive	Inserted By	Inserted At
1	0	UNKNOWN	P3	0	Operator	☐	QAManager	3/16/2021 11:00:25 AM
2	99	QAManager			QA Manager	☐	QAManager	3/16/2021 11:00:25 AM
3	441	CLAUDINA COSTA	P3	0	QA Staff	☐		3/26/2021 9:50:04 AM
4	758	ELISA MOREIRA	P1	0	LineLeader	☐		3/26/2021 9:51:00 AM
5	1100	QUITERIA SOUSA	P2	0	Operator	☐		3/26/2021 9:51:03 AM
6	1173	ISABEL ROCHA	P3	0	LineLeader	☐		3/26/2021 9:51:05 AM
7	1713	GRAÇA CARVALHO	P2	0	Operator	☐		3/26/2021 9:51:08 AM
8	2078	LUISA PINTO	P3	0	Operator	☐		3/26/2021 9:51:10 AM
9	2521	FILOMENA SILVA	P3	0	QA Staff	☐		3/26/2021 9:51:12 AM
10	2952	ARMINDA BARBOSA	P3	0	Operator	☐		3/26/2021 9:51:15 AM
11	3107	EMILIA LOPES	P3	0	LineLeader	☐		3/26/2021 9:51:17 AM
12	3187	PAULA GONÇALVES	P3	0	Operator	☐		3/26/2021 9:51:19 AM
13	3241	LURDES ALVES	P3	0	Operator	☐		3/26/2021 9:51:22 AM
14	3348	JOSE NUNES	P3	0	Operator	☐		3/26/2021 9:51:24 AM
15	3900	CARLA NEVES	P3	0	Operator	☐		3/26/2021 9:51:26 AM
16	4368	SUSANA	P3	0	Operator	☐		3/26/2021 9:51:29 AM
17	4401	FERNANDA DUARTE	P2	0	Operator	☐		3/26/2021 9:51:31 AM
18	4672	MANUELA SILVA	P3	0	Operator	☐		3/26/2021 9:51:34 AM
19	5199	ANA SOARES	P3	0	LineLeader	☐		3/26/2021 9:51:36 AM
20	5243	ANA FERNANDES	P3	0	Operator	☐		3/26/2021 9:51:38 AM
21	5460	DORA SOARES	P3	0	Operator	☐		3/26/2021 9:51:41 AM

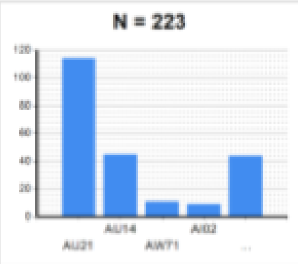
	Personnel ID	Name Surname	Area	Line Leader	Position	Passive	Inserted By	Inserted At
1	0	UNKNOWN	P3	0	Operator	☐	QAManager	3/16/2021 11:00:25 AM
2	99	QAManager			QA Manager	☐	QAManager	3/16/2021 11:00:25 AM
3	441	CLAUDINA COSTA	P3	0	QA Staff	☐		3/26/2021 9:50:04 AM
4	758	ELISA MOREIRA	P1	0	LineLeader	☐		3/26/2021 9:51:00 AM
5	1100	QUITERIA SOUSA	P2	0	Operator	☐		3/26/2021 9:51:03 AM
6	1173	ISABEL ROCHA	P3	0	LineLeader	☐		3/26/2021 9:51:05 AM
7	1713	GRAÇA CARVALHO	P2	0	Operator	☐		3/26/2021 9:51:08 AM
8	2078	LUISA PINTO	P3	0	Operator	☐		3/26/2021 9:51:10 AM
9	2521	FILOMENA SILVA	P3	0	QA Staff	☐		3/26/2021 9:51:12 AM
10	2952	ARMINDA BARBOSA	P3	0	Operator	☐		3/26/2021 9:51:15 AM
11	3107	EMILIA LOPES	P3	0	LineLeader	☐		3/26/2021 9:51:17 AM
12	3187	PAULA GONÇALVES	P3	0	Operator	☐		3/26/2021 9:51:19 AM
13	3241	LURDES ALVES	P3	0	Operator	☐		3/26/2021 9:51:22 AM
14	3348	JOSE NUNES	P3	0	Operator	☐		3/26/2021 9:51:24 AM
15	3900	CARLA NEVES	P3	0	Operator	☐		3/26/2021 9:51:26 AM
16	4368	SUSANA	P3	0	Operator	☐		3/26/2021 9:51:29 AM
17	4401	FERNANDA DUARTE	P2	0	Operator	☐		3/26/2021 9:51:31 AM
18	4672	MANUELA SILVA	P3	0	Operator	☐		3/26/2021 9:51:34 AM
19	5199	ANA SOARES	P3	0	LineLeader	☐		3/26/2021 9:51:36 AM
20	5243	ANA FERNANDES	P3	0	Operator	☐		3/26/2021 9:51:38 AM
21	5460	DORA SOARES	P3	0	Operator	☐		3/26/2021 9:51:41 AM

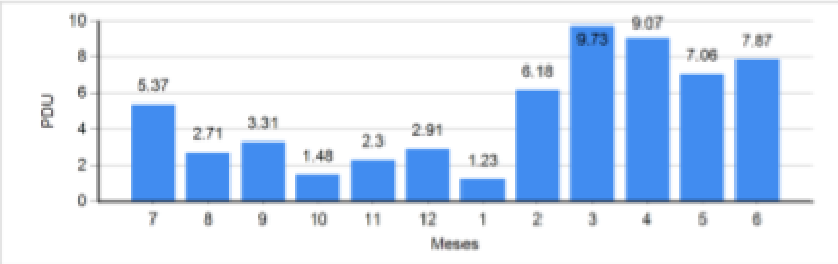
Appendix M – QEDS and QDS reports of May 2021

QEDS May 2021 results

YAZAKI DEFEITOS INTERNOS -- Montagem Mass Production

Pre-P3 [De:2021-05-01 Até:2021-05-31





Total	
Circuitos	31593
QTD. Defeitos	223
Defeitos Total (PDU)	7.06

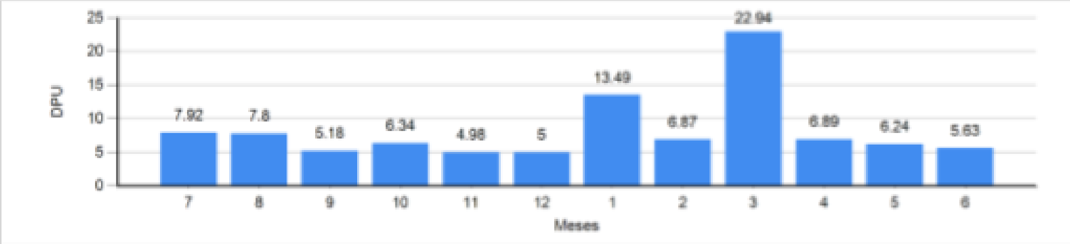
Top Defeitos		
Cod	Descricao	Total
AU21	Parafuso/Porca/Anilha Mal	114
AU14	Parafuso/Porca/Anilha	45
AW71	Short (inspecção eléctrica)	11
AI02	Spacer/Lock secundário	9
...	OUTROS	44

Pré-Eléctricos		
Cod	Descricao	Total
AU21	Parafuso/Porca/Anilha Mal	114
AU14	Parafuso/Porca/Anilha	45
AW71	Short (inspecção eléctrica)	11
AI02	Spacer/Lock secundário	9
...	OUTROS	44

COD.	DESCRICAO	E	TOTAL
		223	223
AA02	Fio Isolamento Danificado	8	8
AB02	Terminal Danificado	2	2
AB26	Terminal Em falta	1	1
AC09	Cravação IDC - cravação defeituosa	3	3
AD26	Bucha Em falta	0	0
AG02	Conector Danificado	4	4
AG30	Conector Mal inserido	9	9
AG32	Conector Aberto	3	3
AI02	Spacer/Lock secundário Danificado	9	9
AI14	Spacer/Lock secundário Inserção incorrecta	2	2
AI39	Spacer/Lock secundário Errado	2	2
AJ02	Tubo (Shrink/Sleeve/Zipper) Danificado	1	1
AJ11	Tubo (Shrink/Sleeve/Zipper) Dimensão incorrecta	5	5
AU14	Parafuso/Porca/Anilha Inserção incorrecta	45	45
AU21	Parafuso/Porca/Anilha Mal apertado (torque)	114	114
AW32	Circuito Aberto	0	0
AW40	Circuito Erróneo	3	3
AW71	Short (inspecção eléctrica)	11	11
BB33	Etiqueta do produto ilegível	0	0
BJ211	HV test Failure- AC or DC	0	0
BJ212	Airleak test Failure	0	0
BJ213	Connectivity Error	0	0
BJ214	Retention test NOK	0	0
BK215	Desconhecido- investigação em curso	1	1

YAZAKI DEFEITOS INTERNOS -- Montagem Mass Production

P3 | De:2021-05-01 Até:2021-05-31

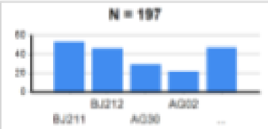


Total	
Cablagens Produzidas	31593
QTD. Defeitos	197
Defeitos Total (DPU)	6.24

Top Defeitos		
Cod	Descricao	Total
BJ21	HV test Failure- AC or	53
BJ21	Airleak test Failure	46
AG30	Conector Mal inserido	29
AG02	Conector Danificado	22
...	OUTROS	47

Eléctricos		
Cod	Descricao	Total
BJ21	HV test Failure- AC or	53
BJ21	Airleak test Failure	46
AG30	Conector Mal inserido	29
AG02	Conector Danificado	22
...	OUTROS	47

Eléctricos/Visuais		
Cod	Descricao	Total
AA02	Fio Isolamento	0
AB02	Terminal Danificado	0
AB26	Terminal Em falta	0
AC09	Cravação IDC -	0



Visuais		
Cod	Descricao	Total
AA02	Fio Isolamento	0
AB02	Terminal Danificado	0
AB26	Terminal Em falta	0
AC09	Cravação IDC -	0

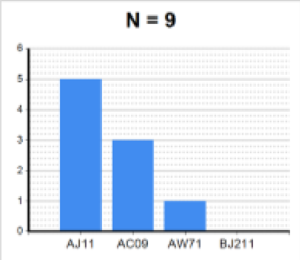
Auditoria		
Cablagens	196	
Cod	Descricao	Total
AA02	Fio Isolamento	0
AB02	Terminal Danificado	0
AB26	Terminal Em falta	0
AC09	Cravação IDC -	0
Total		0

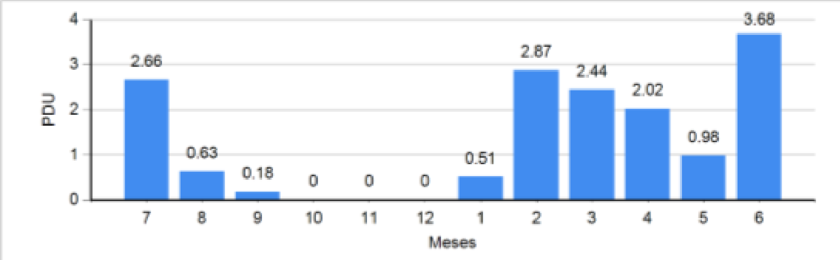
ISIR		
Cablagens	9	
Cod	Descricao	Total
AA02	Fio Isolamento	0
AB02	Terminal	0
AB26	Terminal Em falta	0
AC09	Cravação IDC -	0
Total		0

COD.	DESCRICAO	E	EV	V	AUD	ISIR	TOTAL
	TOTAL	197	0	0	0	0	197
AA02	Fio Isolamento Danificado	0	0	0	0	0	0
AB02	Terminal Danificado	3	0	0	0	0	3
AB26	Terminal Em falta	0	0	0	0	0	0
AC09	Cravação IDC - cravação defeituosa	0	0	0	0	0	0
AD26	Bucha Em falta	1	0	0	0	0	1
AG02	Conector Danificado	22	0	0	0	0	22
AG30	Conector Mal inserido	29	0	0	0	0	29
AG32	Conector Aberto	0	0	0	0	0	0
AI02	Spacer/Lock secundário Danificado	4	0	0	0	0	4
AI14	Spacer/Lock secundário Inserção incorrecta	3	0	0	0	0	3
AI39	Spacer/Lock secundário Errado	0	0	0	0	0	0
AJ02	Tubo (Shrink/Sleeve/Zipper) Danificado	0	0	0	0	0	0
AJ11	Tubo (Shrink/Sleeve/Zipper) Dimensão incorrecta	0	0	0	0	0	0
AU14	Parafuso/Porca/Anilha Inserção incorrecta	0	0	0	0	0	0
AU21	Parafuso/Porca/Anilha Mal apertado (torque)	0	0	0	0	0	0
AW32	Circuito Aberto	1	0	0	0	0	1
AW40	Circuito Errôneo	11	0	0	0	0	11
AW71	Short (inspecção eléctrica)	14	0	0	0	0	14
BB33	Etiqueta do produto ilegível	2	0	0	0	0	2
BJ211	HV test Failure- AC or DC	53	0	0	0	0	53
BJ212	Airleak test Failure	46	0	0	0	0	46
BJ213	Connectivity Error	5	0	0	0	0	5
BJ214	Retention test NOK	3	0	0	0	0	3
BK215	Desconhecido- investigação em curso	0	0	0	0	0	0

YAZAKI DEFEITOS INTERNOS -- Montagem Mass Production

Pre-P3 EVA1 D De:2021-05-01 Até:2021-05-31





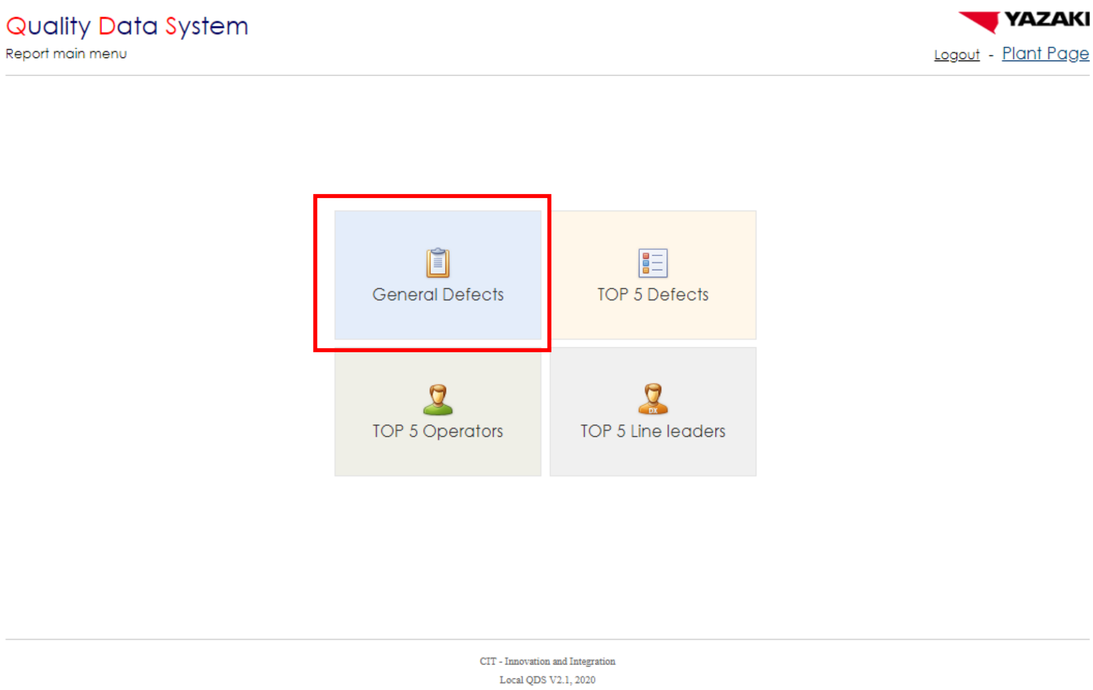
Total	
Circuitos	9214
QTD. Defeitos	9
Defeitos Total (PDU)	0.98

Top Defeitos		
Cod	Descricao	Total
AJ11	Tubo	5
AC09	Cravação IDC - cravação	3
AW71	Short (inspecção eléctrica)	1
BJ211	HV test Failure- AC or DC	0

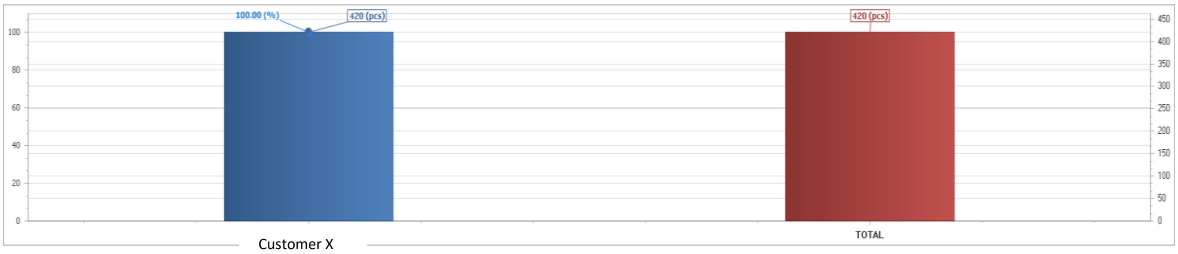
Pré-Eléctricos		
Cod	Descricao	Total
AJ11	Tubo (Shrink/Sleeve/Zipper)	5
AC09	Cravação IDC - cravação	3
AW71	Short (inspecção eléctrica)	1
BJ211	HV test Failure- AC or DC	0

COD.	DESCRICAO	E	TOTAL
		9	9
AB02	Terminal Danificado	0	0
AC09	Cravação IDC - cravação defeituosa	3	3
AG02	Conector Danificado	0	0
AI02	Spacer/Lock secundário Danificado	0	0
AJ11	Tubo (Shrink/Sleeve/Zipper) Dimensão incorrecta	5	5
AW40	Circuito Erróneo	0	0
AW71	Short (inspecção eléctrica)	1	1
BJ211	HV test Failure- AC or DC	0	0
BJ212	Airleak test Failure	0	0

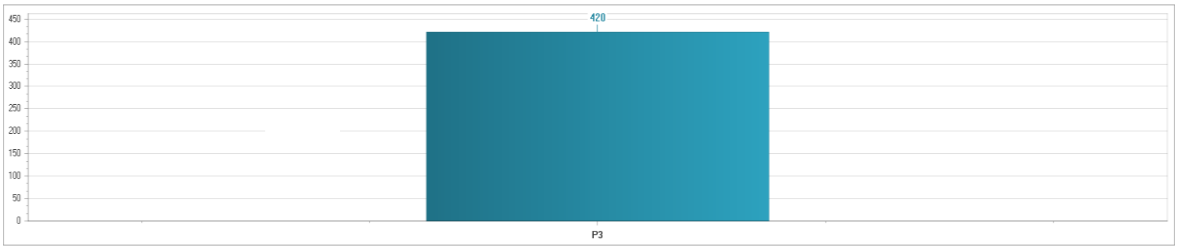
QDS May 2021 results



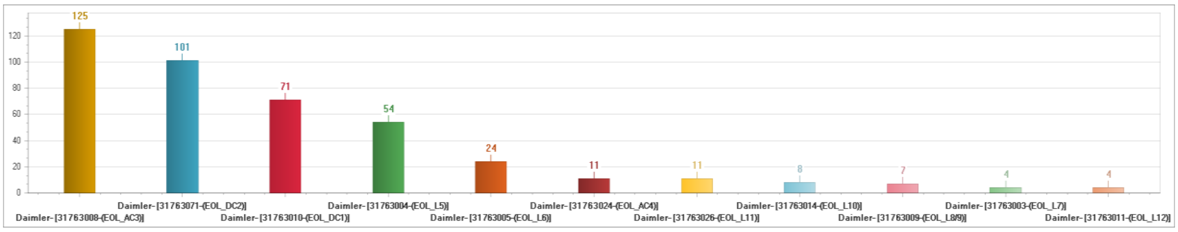
Customer analysis [# of defected product(s) (Pcs)]



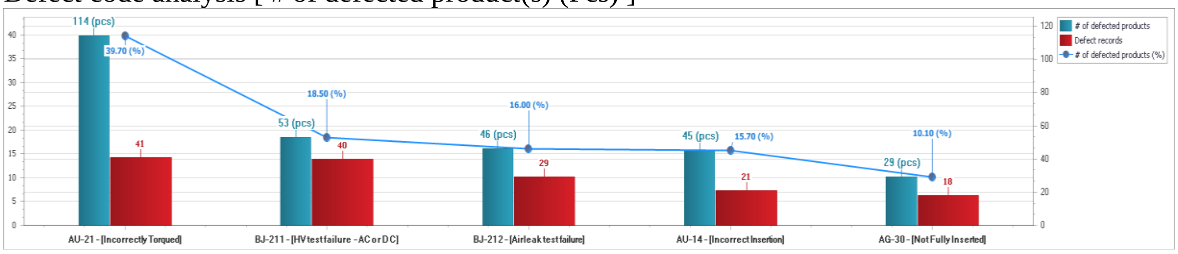
Area analysis [# of defected product(s) (Pcs)]



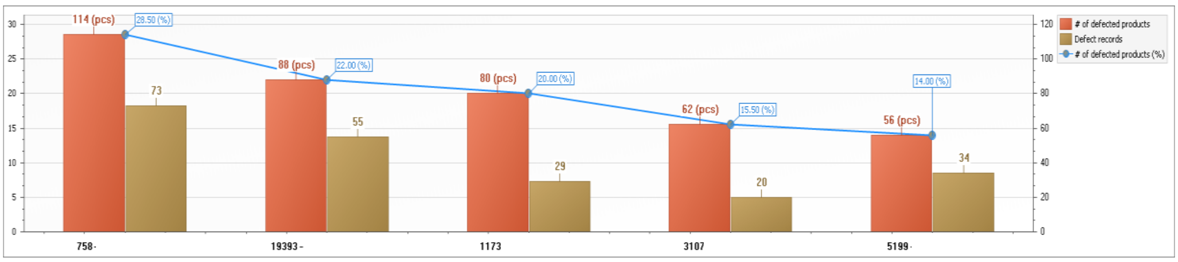
Workstation analysis [# of defected product(s) (Pcs)]



Defect code analysis [# of defected product(s) (Pcs)]



Line Leader analysis [# of defected product(s) (Pcs)]



Appendix N – Assembly area resources analysed

Process Code	Process	Computer: Screen	Computer: Keyboard	Observation	
C001	Maquete-1	x			
C002	DC1.1				
C003	DC1.2	x			
C004	DC2.1				
C005	DC2.2	x			
C006	DC3.1				
C007	DC3.2	x			
C008	DC4.1				
C009	DC4.2	x			
C010	Electrical Inspection-1	x	x		
C011	Maquete-2	x			
C012	DC1.1				
C013	DC1.2	x			
C014	DC2.1				
C015	DC2.2	x			
C016	DC3.1				
C017	DC3.2	x			
C018	DC4.1				
C019	DC4.2	x			
C020	Electrical Inspection-2	x	x		
C021	Maquete-3	x	x		
C022	AC1.2	x			
C023	AC2.1				
C024	AC2.2	x			
C025	AC3.1				
C026	AC3.2	x			
C027	Electrical Inspection-3	x	x		1
C028	Maquete-4	x	x		1
C029	AC1.2	x			
C030	AC2.1				
C031	AC2.2	x			
C032	AC3.1				
C033	AC3.2	x			
C034	Electrical Inspection-4	x	x		
C035	Electrical Inspection-5	x	x		
C036	Electrical Inspection-6	x	x		
C037	Electrical Inspection-7	x	x		
C038	Electrical Inspection-8	x	x		
C039	Electrical Inspection-9	x	x		
C040	Electrical Inspection-10	x	x		
C041	Electrical Inspection-11	x	x		
C042	Electrical Inspection-12	x	x		
C043	Firewall-6				
C044	Firewall-7				
C045	2º Visual Inspection-1	x	x		1
C046	2º Visual Inspection-2	x	x		1
C047	2º Visual Inspection-3	x	x		1
C048	2º Visual Inspection-4	x	x		1
C049	2º Visual Inspection-5	x	x		1
C050	2º Visual Inspection-6	x	x		1
C051	2º Visual Inspection-7	x	x		1
C052	2º Visual Inspection-8/9	x	x		1
C053	2º Visual Inspection-10	x	x		1
C054	2º Visual Inspection-11	x	x		1
C055	2º Visual Inspection-12	x	x		1
C056	Micronorma-11				
C057	Micronorma-12				
C058	Jib Board-5				
C059	Jib Board-6				
C060	Jib Board-7				
C061	Jib Board-8				
C062	Jib Board-9				
C063	Jib Board-10				
C064	Jib Board-11				
C065	Jib Board-12				
Line 3 and 4 (AC) - exist one computer in the midle of each line					2
					15