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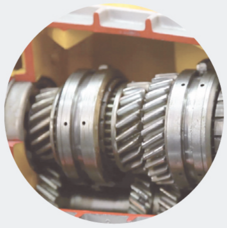

MELHORIA CONTÍNUA E DESENVOLVIMENTO DE KPI'S NA INDÚSTRIA DE CABLAGENS METÁLICAS

JOÃO MANUEL CORREIA LOPES PEREIRA

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POLITÉCNICO
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CONTINUOUS IMPROVEMENT AND DEVELOPMENT OF KPI'S IN THE METALLIC CABLES INDUSTRY

João Manuel Correia Lopes Pereira

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ISEP – School of Engineering, Polytechnic of Porto

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Dissertation presented to ISEP – School of Engineering to fulfill the requirements necessary to obtain a Master's degree in Mechanical Engineering, carried out under the advisor of Doctor Francisco José Gomes da Silva, Adjunct Professor of Mechanical Engineering Department of ISEP, and co-advisor of Master João Augusto de Sousa Bastos, Adjunct Professor of Mechanical Engineering Department of ISEP.

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KEYWORDS

Automotive industry; Continuous Improvement; Lean Thinking; Lean Manufacturing; Waste; Six Sigma; A3 methodology.

ABSTRACT

The automotive industry, and in particular the production of components for the automotive industry, is one of the most demanding sectors of the global market, with the different companies needing to continuously be evolving and quickly adapt themselves. The response capacity and flexibility of companies represent a key factor for their success. Through the last decades, a growing concern with the creation of a mentality of excellence and vision of continuous improvement, with actuation on the optimization of equipment, processes, tools and people skills, has expressed its efforts in terms of cost reduction and increased competitiveness.

This dissertation was developed during an internship period, in an industrial context, carried out in the company *Fico Cables*, producer of components as metallic cables and comfort systems for the automotive industry. This work was incorporated in the Production and Continuous Improvement departments.

The developed work focused on the optimization of a specific assembly line, with the support of various tools included in the *Lean Thinking* and *Lean Manufacturing* concepts, with the identification and elimination of different types of wastes (*mudas*) and the balancing of operations between the different workstations in order to increase the global efficiency and productivity. A f

Through the application of a different methodology, as *Six Sigma*, it was carried out a different improvement project with the aim to reduce the quantity of scrap on the most critical sector of *Fico Cables*, and the achievement of a better comprehension of the flows, process characteristics and different variables associated to the scrap production.

In every company, having information by itself is not advantageous if it is not properly handled and filtered in order to direct efforts towards the real and most critical problems. In this way, it was also part of the developed work, the implementation and improvement of a problem-solving A3 methodology to manage different production-related Key Performance Indicators (KPI), with the adequate stratification of information, improvement actions plan and validation of results.

The realization of these improvement projects allowed the company to achieve relevant productivity gains on the assembly line, a solid path to achieve the purposed goals on the diminution of the quantity of scrap and a better management of KPIs information.

PALAVRAS CHAVE

Indústria automóvel; Melhoria Contínua; Lean Thinking; Lean Manufacturing; Desperdício; Six Sigma; Metodologia A3.

RESUMO

A indústria automóvel, e em particular a produção de componentes para a indústria automóvel, é um dos setores mais exigentes do mercado global, com as diferentes empresas a necessitarem de evoluírem constantemente e se adaptarem rapidamente. A capacidade de resposta e flexibilidade das empresas representa um fator chave para o seu sucesso. Durante as últimas décadas, uma crescente preocupação com a criação de uma mentalidade de excelência e visão de melhoria continua, com a atuação na otimização de equipamentos, processos, ferramentas e habilidades de pessoas, tem expressado os seus esforços em termos de redução de custos e aumento de competitividade.

A presente dissertação foi desenvolvida durante um período de estágio, em contexto industrial, na empresa *Fico Cables*, produtora de componentes como cablagens metálicas e sistemas de conforto para a indústria automóvel. Este trabalho foi incorporado no departamento de Produção e Melhoria Contínua.

O trabalho desenvolvido focou-se na otimização de uma linha de montagem específica, com suporte de diversas ferramentas incluídas nos conceitos de *Lean Thinking* e *Lean Manufacturing*, com a identificação e eliminação de diferentes tipos de desperdícios (*mudas*) e balanceamento de operações entre os diferentes postos de trabalho, de forma a aumentar a eficiência global e produtividade.

Através da aplicação de uma metodologia diferente, como o *Six Sigma*, foi levado a cabo um projeto de melhoria com o objetivo de reduzir a quantidade de sucata no setor mais crítico da *Fico Cables*, e a obtenção de uma melhor compreensão dos fluxos, características do processo e diferentes variáveis associadas à produção de sucata.

Em todas as empresas, ter informação por si só não é vantajoso, se a mesma não for corretamente tratada e filtrada, de forma a direcionar esforços para os reais e mais críticos problemas. Desta forma, fez também parte do trabalho desenvolvido, a implementação e melhoria de uma metodologia de resolução de problemas A3 para a gestão de diferentes Indicadores Chave de Performance (KPIs) relacionados com a produção, com a adequada estratificação de informação, planos de ações de melhoria e verificação de resultados.

A realização destes projetos de melhoria permitiu à empresa alcançar relevantes ganhos de produtividade na linha de montagem, um caminho sólido para atingir os objetivos propostos na diminuição da quantidade de sucata e uma melhor gestão de informação de KPIs.

LIST OF SYMBOLS AND ABBREVIATIONS

List of abbreviations

5W2H	*5 Why's, 2 How's*
ABS	Anti-lock Braking System
ASIL	Automotive Safety Integrity Level
Av	Availability
CKD	Completely Knocked Down
CNC	Computer Numerical Control
CTQ	Critical to Quality
DMADV	*Define, Measure, Analyse, Design, Verify*
DMAIC	*Define, Measure, Analyse, Improve, Control*
DPMO	Defects per million Opportunities
DPO	Defects per Opportunity
DPU	Defects per Unit
DSI	Systems of Information Department
ESP	Electronic Stability Control
EU	European Union
FDI	Foreign Direct Investment
FPS	Fire Protection System
GDP	Gross Domestic Product
IATF	International Automotive Task Force
ISO	International Organization for Standardization
JIT	Just in Time
KPI	Key Performance Indicator
MOD	Direct Labour Deviation
MTM	Methods Time Measurement
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PDCA	Plan, Do, Check, Act
Pf	Performance
POM	Polyoxymethylene
PPH	Production per Hour
Q	Quality
SDCA	Standardize, Do, Check, Act
SPC	Statistical Process Control
SWOT	Strengths, Weaknesses, Opportunities, Threats
TCS	Traction Control System
TMC	Toyota Motor Corporation
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
TT	*Number of hours available to work*
VNA	Non-Value Added
WIP	Work in Progress

List of units

h	Hour
s	Seconds
min	Minutes
m	Meters
m^2	Square meters
kg	Kilograms

List of symbols

€	Euros
%	Percentage
◦C	Celsius degrees

GLOSSARY OF TERMS

Comfort systems	Type of product produced and that constitutes part of the automotive seat. It is a structure responsible for the comfort offered in the seat for the user.
Conduit	Component present in the most type of automotive cables and that results of the process of wire spiral.
Gemba	Term associated to the shop floor.
Kaizen	Results from the agglutination of two Japanese words: Kai, that means change, and Zen, that means for better, resulting in the continuous improvement concept.
Subgroup	Final product of an intermedium operation.
Setup	Represents the change of products, tools or adjustments performed at the beginning of the process.

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INTRODUCTION

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1 INTRODUCTION

1.1 Contextualization

The production of components for the automotive industry has been a key pillar for the Portuguese metal mechanical industry, with the low salaries and the crescent automatization of processes allowing the sector to gradually grown and to be competitive in the European panorama. This grown has been expressed with the increasing volume of exports and with the global recognition of the Portuguese automotive industry as an important player in the international context. However, with the geographical limitations such as the distances for the main assembly factories of the Original Equipment Manufacturers (OEM), the fulfillment of the customer deadlines and the quality requirements has been assuming a strong importance in order to keep the competitiveness of the national automotive industry.

Although the Portuguese automotive industry has been seeing a gradual transition for a capital-intensive model with the rising of mechanization and automatization of processes and equipment, promoted by the emergence of countries producers of components for the automotive industry with lower labor costs, it is still a reality the presence of an essentially labour-intensive model, with an installed politic of low salaries practised by the different Portuguese companies in order to keep a low internal cost of the products and the international competitiveness of the sector.

Fico Cables is a company of the group *FICOSA*, established on Maia, and a producer of components for the automotive industry, that follows a labor-intensive model. In this type of companies, the assurance of final product quality as well as the continuous elimination of inefficiencies assume a higher importance in order to have production costs as minimal as possible without compromising the quality.

In a company as *Fico Cables*, with a high number of workers distributed by several assembly lines and different manufacturing technologies, the optimization of the available resources (materials, equipment, people, etc.) assumes a key importance to keep production costs low, to meet the quality requirements standards and the customer’s deadline.

In this work were applied different production management tools for two different case studies, inserted in different contexts, and with the aim of reducing inefficiencies and optimizing the available resources in order to produce the higher number of products with the maximum quality possible. Also, it was developed and improved a methodology to follow the information associated with the main production and quality related KPIs and to allow to focus efforts and resources on the most critical situations.

1.2 Host company

The present dissertation was developed in the ambit of the Master's in Mechanical Engineering, specialization on Industrial Management, at the ISEP – School of Engineering, Polytechnic of Porto. This work was fulfilled in the context of an internship carried out at the *Fico Cables* company, located in Maia, between December of 2017 and July of 2018, and under the Main Supervision of Prof. Francisco J. G. Silva and Co-Supervision of Ing. João Bastos, at ISEP, and Ing. Horst Mattausch and Ing. Francisco Ferreira, at Fico Cables.

1.3 Goals

The present work addresses three different case studies, each one with different goals. For the first one, the case of a *productivity improvement project* for a specific assembly line, the main goals are described below:

- Analyse the previous status of the assembly line, with the measurement of the different operations performed, visualization of the previous assembly line balancing and calculation of the possible output;
- Critical analysis of the results and identification of justified improvement opportunities;
- Create conditions and follow the implementation of the defined improvement opportunities;
- Verify the success of the improvement actions implemented;
- Identify possible future opportunities for the second stage of improvement.

In a second case study, related to the *reduction of the quantity of scrap produced*, it was possible to define the following targets:

- Identify and understand the causes, and the equipment associated, for the excessive scrap production on the most critical module;
- Discuss, with workers and maintenance teams, possible improvements and modifications that could be realized on the most critical equipment;
- Follow the implementation, verify and control the result of the improvement actions implemented.

A third case study could be seen as a way to consolidate the work developed in the previous two case studies, with the improvement of a previous defined A3 methodology to monitor the most important KPIs. The defined goals are described below:

- Identification of the fundamental KPIs related to the production management of *Fico Cables* and to apply/improve the A3 methodology associated;
- Improvement of the level of automatization of the respective documents related to the data collection process;

- Interconnect the different A3 documents, in order to allow the user to easily switch between them.

1.4 The methodology used in the Dissertation

The initial steps for the elaboration of the present work are similar for the different case studies approached:

- Study of the state of art referred to the problems analyzed;
- Study and visualization, on *gemba*, of the real situation in order to have a better perception of the different processes and respective problems;

For the case study of the *productivity improvement project* for a specific assembly line, the methodology used traced the following path:

- Observation of the different activities on the assembly line in order to better understand the detected problems;
- Time measurement of the different activities;
- Observation of the previous assembly line balancing;
- Observation and identification of wastes existent on the assembly line;
- Collection and discussion of possible improvement actions in order to reduce these wastes;
- Implementation of the defined improvement actions;
- Time measurement after the implementation of the defined improvement actions;
- Observation of the new assembly line balancing and validation of the implemented improvement actions.

On the other hand, for the case study approaching the *reduction of the quantity of scrap produced*, the methodology used assumed the following steps:

- Observation and identification of the major source for the scrap production;
- Observation of the processes associated with the respective source;
- Identification of the possible variables associated with the scrap production along the corresponding processes;
- Identification and analysis of possible causes for the scrap production;
- Discussion of possible improvements and modifications to equipment and procedures;
- Validation of the effectiveness and results obtained after the implementation of the defined improvement actions.

The final steps of the methodology used in this dissertation relate to an improvement of the previous A3 methodology to monitoring the different production KPIs and could be described as:

- Observation the of existent documentation related to KPIs production monitoring;
- Define other relevant KPIs to apply the same A3 methodology;
- Search for ways to increase the automatization of the data collection process by the user;
- Determine the relevant information to be presented on each A3 document;
- Interconnect the different A3 documents between them.

This methodology ends with the writing of the present dissertation.

1.5 Dissertation structure

This work was based on two parts: an initial *Bibliographic Review*, which purpose is to provide a framework for the reader on the topics covered in this dissertation, which required a review of published technical and scientific developments on the subject in question, and, finally, the *Development* of practical work, where the work done on the ground, the problems felt, the results obtained, suggestions for future improvements and conclusions are addressed and explained.

BIBLIOGRAPHIC WORK

2.1 Automotive Industry

2.2 Production management in the automotive industry

2.3 Six Sigma

2 LITERATURE REVIEW

2.1 Automotive Industry

2.1.1 History of the Automotive Industry

The automobile is the center of mobility of people and goods and the automotive industry is one of the most important industrial activities worldwide, with a key role in countries' economies. It is the real "industry of industries" and it is the convergent point of the most varied industrial sectors [1].

2.1.1.1 The global context of the Automotive Industry

Some of the biggest changes of the industry development are reflected in the history of the automotive industry, from manufacture to mass production, and, most recently, the *Lean Production,* where management practices like Total Quality Management (TQM) were applied and developed [2].

Depending on the different dynamics of regional markets, many manufacturers started to acquire other corporations as a boost to compete worldwide. The global growth achieved through mergers and acquisitions led to a more consolidated and rationalized value chain. Also, the use of strategies like modularization, outsourcing, platform and component sharing allowed to establish economies of scale and efficiency in assembly, but also to share responsibilities with suppliers in design, development, and manufacturing [3].

In the timeline shown in Figure 1, it is represented some of the biggest milestones of Automotive Industry through the years, as well as the evolution of the different production systems from the craft production period to a modern standardized era [4].

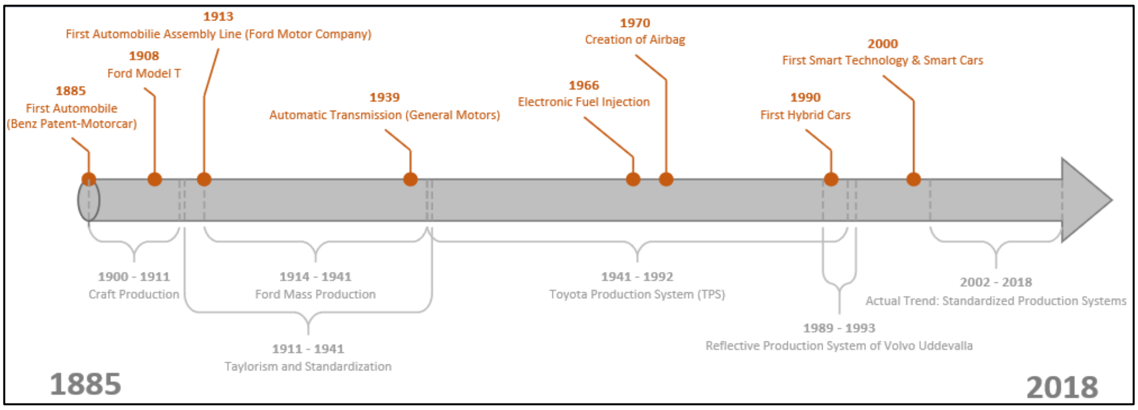


Figure 1 - Key milestones (above) and main production systems (below) of Automotive Industry [4]

In Table 1 it is described the different production systems that are represented in Figure 1.

Table 1 – Different production systems adopted in the Automotive Industry [4]

Period	Production System	Description
Until 1911	Craft Production	Production based on hand manufacturing and on worker's skills, experience, and knowledge. In order to be applied in different production circumstances, standards (plans, drawings, measurements, specifications, among others) needs to be documented.
1911	Taylorism and Standardization	Aimed to standardize work sequences and tasks within the production process with the use of standardized machines, tools, measurements, among others. The main goal is to increase production efficiency.
1914	Ford's Mass Production	First formalized production system, it combines the Taylorism principles with technological advancement and was developed in the era of mass production. Its key components are technical and process, work and social standards.
1941-1992	Toyota Production System (TPS)	Focus on the reduction of every form of waste (time, movements or resources). TPS standards provide an improvement opportunity, allowing the experience and know-how of the worker to refine the manufacturing processes, letting the constant revision of the standards. This leads to the creation of a learning environment and a continuous improvement culture.
1989-1993	Reflective Production System of Volvo Uddevalla	Emerged as an alternative to the traditional system of mass production and the TPS. It replaces the extensive system of standards that regulate production processes and resources for standards, which aim to regulate and control the work according to the individual skills of the workers and teams.
2002-*today*	Current trend: Standardized Production Systems	The majority of car manufacturers production systems are based on the TPS and on the principles of *Lean Thinking.*

2.1.1.2 Automotive Industry in Portugal

The evolution of the automotive industry in Portugal can be analyzed through two perspectives: the political and sectoral policy under the guidance of government and national authorities; and the strategies of OEM with the support of Foreign Direct Investment (FDI), particularly regarding the installation of local assembly units. These are the true anchors for the development of the automotive industry's components, but they are always conditioned by the international situation of the country, in this case, the process of integration of Portugal in European Union [5].

With just a few decades of history, the automotive industry in Portugal evolved from a dispersed, unskilled and technologically underdeveloped industry to a very dynamic and competitive sector from a global perspective [1].

Considering the period before the 1960s as the emerging phase of the automotive industry development in Portugal as it was when the ruling of free importation of vehicles started, some failures related to the manual automobile manufacturing, we could establish a period of history posterior to this phase, marked by three different stages, as shown in Table 2:

Table 2 - Three main stages of the automotive industry evolution in Portugal [6]

Period	Description
Completely Knocked Down (CKD) Mounting Units *(1960 – 1976)*	Characterized by a sectorial policy orientation for the replacement of importation, resulting in the proliferation of inefficient national assembling units and in the absence of a true industry for components.
Renault Project *(1977 – 1988)*	Marked by a sectorial policy of promotion of exportations, that led to shutting down many national assembling units and to the development of the Portuguese industry of components boosted by the Renault Project.
AutoEuropa Project *(1989 – today)*	Characterized by a sectorial policy of re-opening of the market and marked by the launch of AutoEuropa project, that led definitively to the development of the sector, introducing an "automobile culture" on the enterprises.

The evolution of these three stages is represented in Figure 2. The development process of automobile components industry occurred gradually and cumulatively, through the technological, organizational and commercial learning processes induced by "customers" (Foreign Direct Investment) and leveraged by public policies [6].

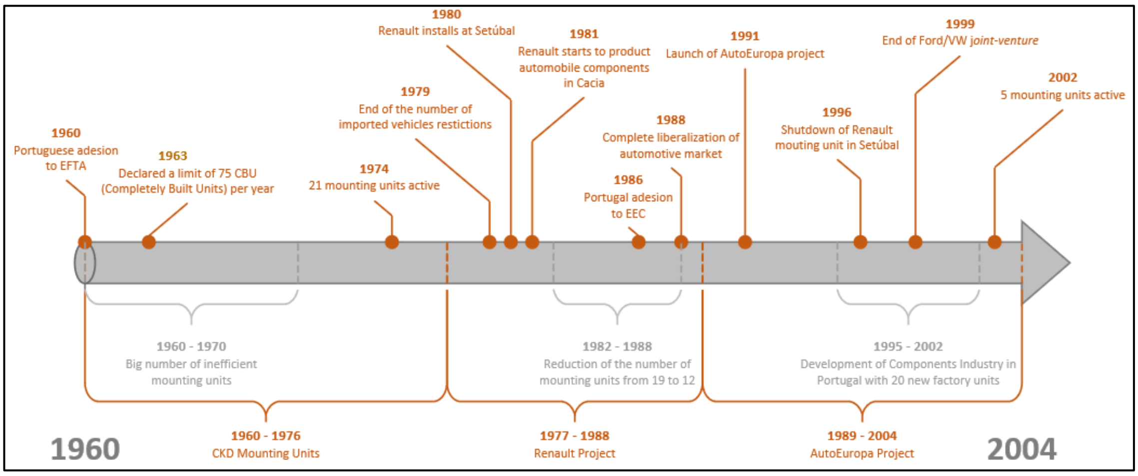


Figure 2 - Evolution of the automotive industry history in Portugal [6]

2.1.2 Economic indicators of the automotive industry

The automotive industry contributes largely to the global economic activity in the country, with wide upstream and downstream connections to the different sectors. This makes this industry the best way for countries that aim to develop through industrialization [7].

Although the global financial crisis of 2008, causing an unprecedented market crash, car production has recovered gradually since the latter half of 2009, due to the direct support of governments and the boost of demand [8]. Economic indicators as production, sales, value added to Gross Domestic Product (GDP) and unemployment, allow us to understand the status of the sector [9].

In the last twenty years, the main global protagonists of the motor vehicle production have changed. Although Europe was the core manufacturer, with the United States and Japan/Korea next to it, China assumes now the position of major automobile manufacturer (Figure 3) [10].

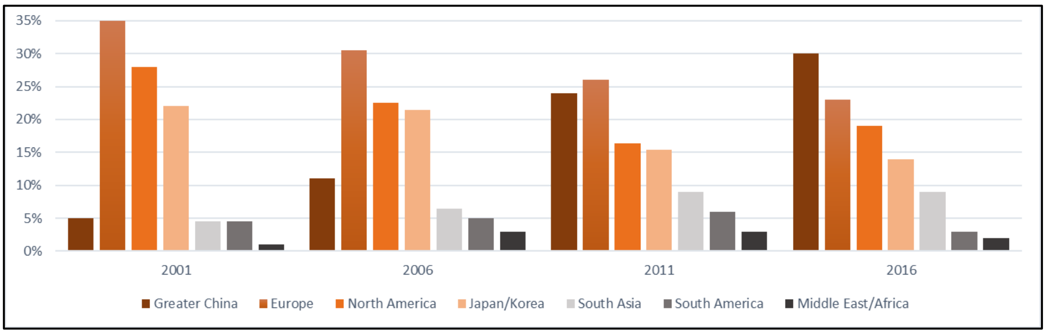


Figure 3 - Percentage of share relative to worldwide motor vehicle production [10]

Although the protagonists have changed, the automobile production has continuously increased (Figure 4), reaching the highest peak ever in 2017, with 73.5 million cars produced worldwide and, with the increased demand, especially in Asian markets, it is expected that production will increase by around 11 percent in 2018 [11].

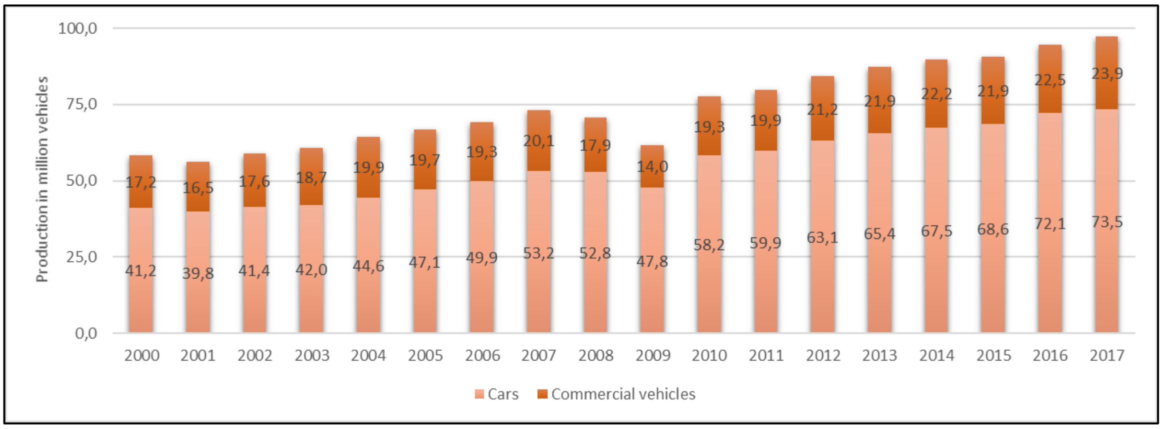


Figure 4 - Worldwide automobile production in millions of vehicles [11]

Along with the recovery in the automotive industry, it is forecasted that increased demand in North America and Asia regions will successfully counterbalance with Russia and Brazil, declining sales and help automobile manufacturers sell over 81 million vehicles in 2018, around 28 million units more than in the years between 2000 and 2013. The rise of the Asian market, and in particular China, is visible in Figure 5, with sales almost quadrupling since the last ten years to a staggering volume of around 25 million vehicles in 2017 [12].

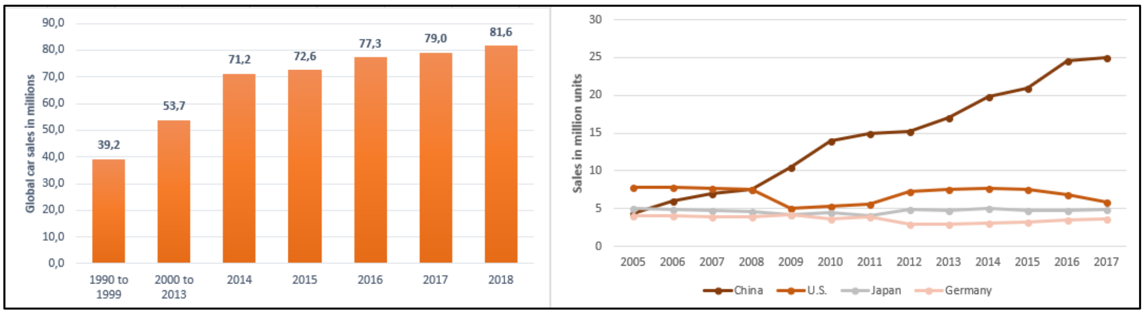


Figure 5 – Worldwide car sales from 1990 to 2018 (left) [12] and sales of passenger vehicles of selected countries from 2005 to 2017 (right), in million units [11]

In Portugal, the effects of the economic crisis were stronger, having caused a bigger sales breakdown, which is only gradually recovering since 2012, reaching the same volume as in the pre-crisis period. However, ACAP [13] expects that the growth rate will decrease, reflecting economic and employment dynamics of Portugal. This evolution is presented in Figure 6.

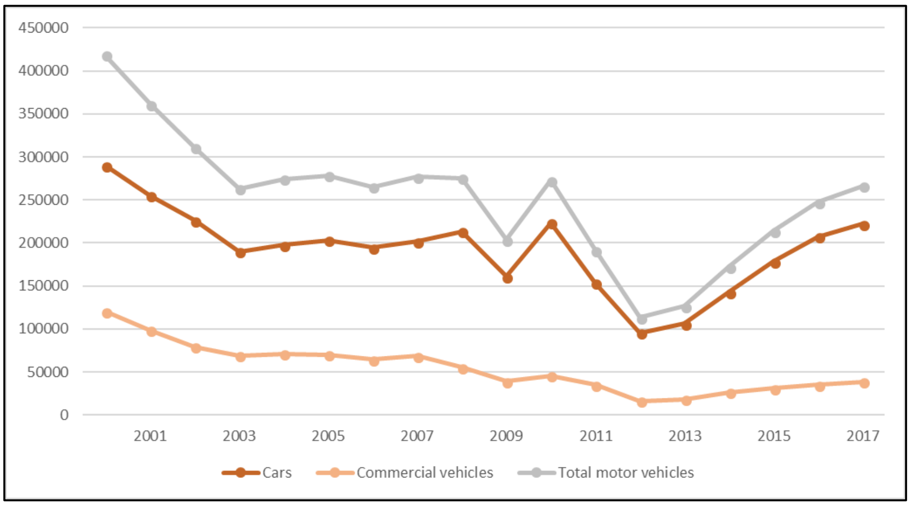


Figure 6 - Evolution of car sales volume in Portugal (2000-2017) [13]

The importance of the automotive industry for economies can be measured by the percentage of contribution of GDP, as well as the employment rate, as shown in Table 3. Globally, this sector contributes roughly to 3% of all GDP output [14], with this share being even higher in emergent markets.

The employment is another important economic indicator. Automotive industry plays a crucial role in job creation (Figure 7), where car manufacturing has an employment multiplier level of five to seven, whereas other industries normally have a value of around three. This means that each direct job induces, at least, five indirect jobs [15].

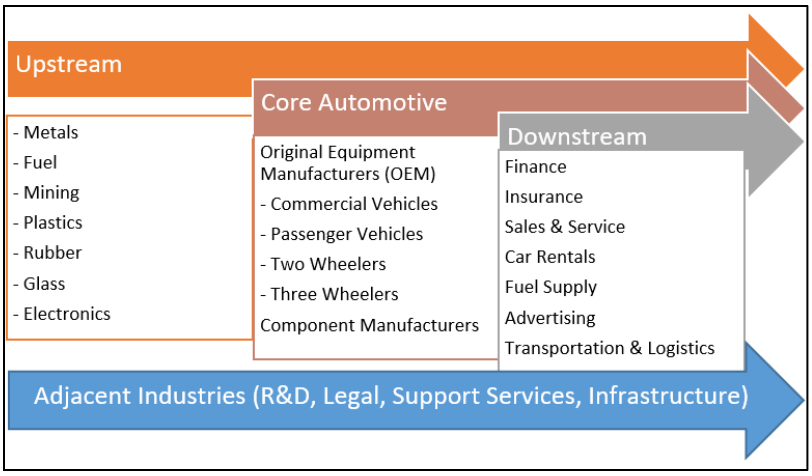


Figure 7 - Automotive value chain [16]

In Table 3, it is represented the percentage of contribution of GDP and employment related to the automotive industry for the major car manufacturing economies.

Table 3 - Percentage of automotive industry contribution for GDP and employment for major economies [10]

Country or region	% GDP (2017)	% of employment (2017)
United States	3%	4.9%
Europe	4%	5.7%
China	7%	4.9%
India	7.1%	7% to 8%
Japan	13.3%	8.7%

2.1.3 The industry of components for the automotive area

Today's automotive industry is characterized by a redistribution of responsibilities along the value chain and with a scope for international markets once closed to international trade and foreign direct investment. It is a highly competitive industry, clearly global, but subject to different dynamics of the regional markets that lead to different strategies of manufacturers and suppliers. This competition leads to a saturated market, with an exceeding diversification of products and that causes a high discrepancy between supply and demand. Strategies for modularization, outscoring, platform and components share, allow to establish complexed supply chains along with scale economies and increase communication between OEMs and suppliers [1].

Throughout OEMs globalization, suppliers have seen their responsibilities increase. From various factors, that reveal the growing importance and presence of suppliers in the supply chain, one could highlight these [17]:

- Manufacturers were continuously pressured for model restyling, that led automakers to start share components and systems among cars and models, through modularization and standardization;
- OEMs started to focus their attention on designing, assembling and marketing vehicles and serve the customer, leaving the design, engineering, and manufacture of the systems and components to their suppliers;
- The increase of supplier's investment, given their major presence on the production process;
- A wave of consolidation, with a serious number of joint-ventures and acquisitions between European and American suppliers;
- Opened a new field of opportunities on emerging markets for smaller suppliers that were increasingly tapped in local markets.

The capacity of some suppliers to become integrators and system manufacturers, capable of directly supply assembly lines and performing design and development tasks, is a proof of this evolution and responsibility transfer, that is represented in Figure 8 [18].

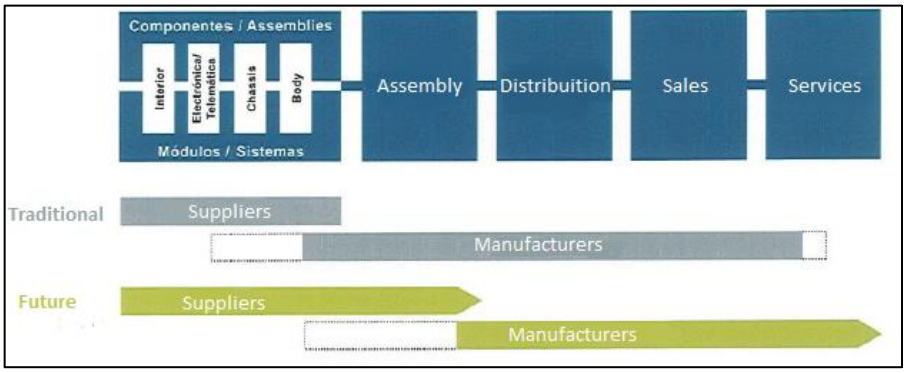


Figure 8 - Evolution of responsibility transfer from manufacturers to suppliers (Adapted from [19])

This evolution led to a change in the supply chain's structure that splits from the traditional organization in 1st, 2nd and 3rd/4th tiers [17]. Suppliers are increasingly characterized and distinguished by their functions and capabilities rather than by their location in the global supply chain, giving rise of the division presented in Table 4 [20].

Table 4 – Type of suppliers division [20]

Type of supplier	Description
Component manufacturers	Specialists in a particular process (for example stamping), most of which considered OEMs indirect suppliers, since their customers are other suppliers at a higher level in the hierarchy.
Assembler manufacturers	Process specialists with additional machining and assembly skills. Usually responsible for the design and testing of the component they manufacture, but not for the design of a small module or other components that are a part of it, being typically indirect suppliers.
System manufacturers	Integrates suppliers capable of developing complex design and production tasks. They can supply directly to the OEM or indirectly through "system integrators".
System integrators	Suppliers capable of integrating components, sub-assemblies, and systems into modules, being directly suppliers of the OEMs assembly lines.

With the need to achieve high-efficiency levels, the industry of components has been submitted to pressures of OEMs and higher-level suppliers to adapt their organization models and production methodologies. This pressure was felt both at the level of cost and final prices, as well as at the level of the overall quality of the products, and extended also to subcontractors [21].

The bigger suppliers, named as Tier 1 suppliers, followed the same tendencies as OEMs, subcontracting the bottom line suppliers, usually called Tier 2 suppliers. However, Tier 1 suppliers were unwilling to give up of innovation and technological skills for Tier 2 suppliers, where the pressures placed were focused not only in the capacity to reduce costs, but also in the response capacity and flexibility, according to the requirements of quality and deadlines (Figure 9). The final consumer played also an important role, with expectations in a high exigence level [18].

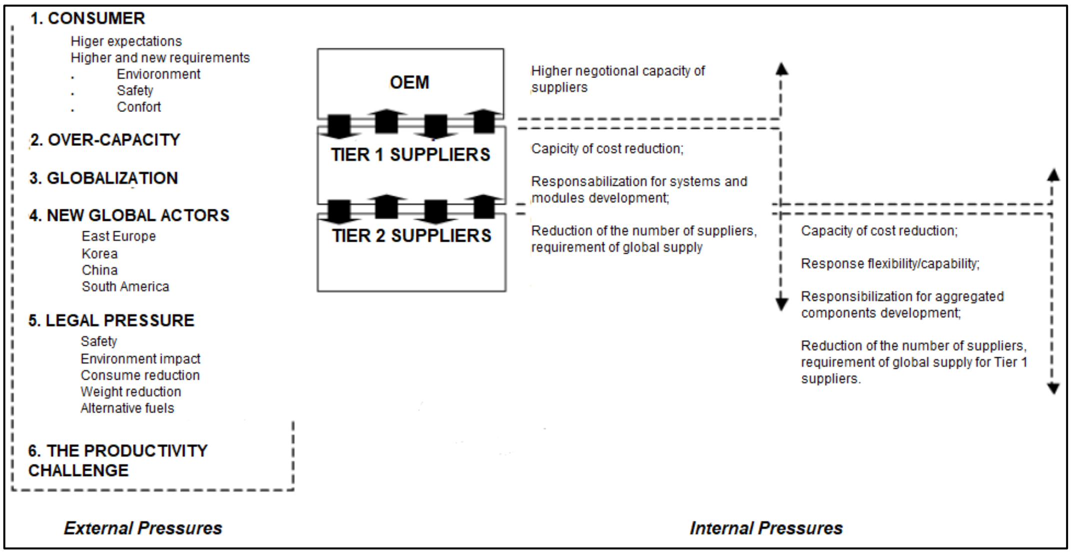


Figure 9 - Pressure on components suppliers in the automotive industry (Adapted from [18])

Currently, and in face of this trends, suppliers seek for a new and safer position in the industry by implementing three alternative strategies that are described in Table 5 [17]:

Table 5 – Different strategies implemented by suppliers [17]

Strategy	Description
Sale of the business	Selling the company to other suppliers. The attractiveness of small and medium-sized suppliers leads to their acquisition by large companies as a way of consolidating their position.
The rise in the hierarchy	Delivery of components manufactured for manufacturing and assembly and, consequently, for systems manufacture or even for their integration. In this context, production, design, engineering, project management and flexibility to changes in consumer preferences being key skills.
Position consolidation	Integrates a constant demand for product development in materials, project and manufacturing capacity, involving also the development and implementation of a competitive strategy based on time, quality, flexibility, and cost critical decision. The geographical presence in the major economies is essential.

The previous tendencies pointed out are common around the world but, simultaneously, they depend on the specific local and regional markets, both in terms of preferences and purchasing power of the consumers and in terms of the industry's capacities and government intervention or even in purely geographic terms [22].

2.1.4 Main requirements of the automotive industry

Regarding the legal framework, the automotive industry is highly restrictive, especially in terms of quality and safety. Standardization promotes cost reduction for suppliers and customers, increases market transparency, and helps to create and preserve businesses, assuring the proper level of quality, safety, and respect for the environment of products and services [23].

2.1.4.1 Quality requirements in the automotive industry

The overall quality of a project can be seen in different ways, depending on who evaluates the quality and how this evaluation is based. However, the bottom line of project quality is always determined by customers' requirements (Figure 10) [24].

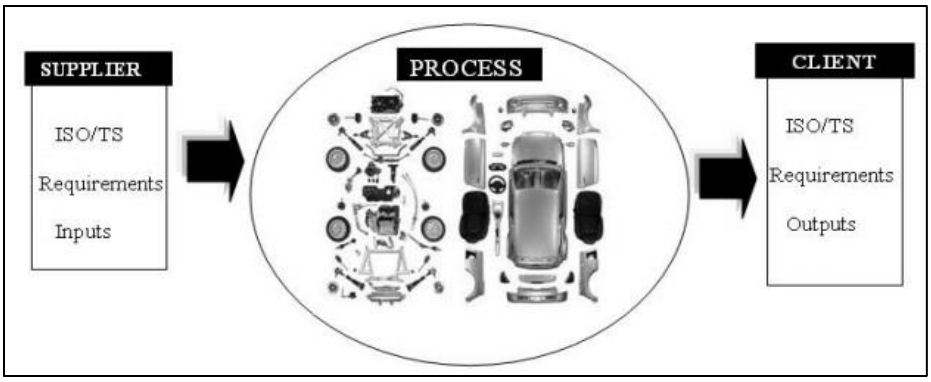


Figure 10 - ISO TS process approach [25]

With the aim of achieving the required level for product quality, productivity, competitiveness, and continuous improvement, manufacturers request that suppliers follow the tight technical specifications established by quality management standards. The International Automotive Task Force (IATF) created a normalization model, recognized by the different manufacturers, and nowadays the industry has its own specifications, with the ISO/TS 16949 standard, based on the ISO 9001 model, with specific requirements for the automotive industry as the development, production and after-sales, and based on the non-recognized quality assurance standars, as QS-9000 (US), VDA 6.1 (Germany), EAQF (France) and AVSQ (Italy) [25].

The process of creation of this normalization model is represented in Figure 11.

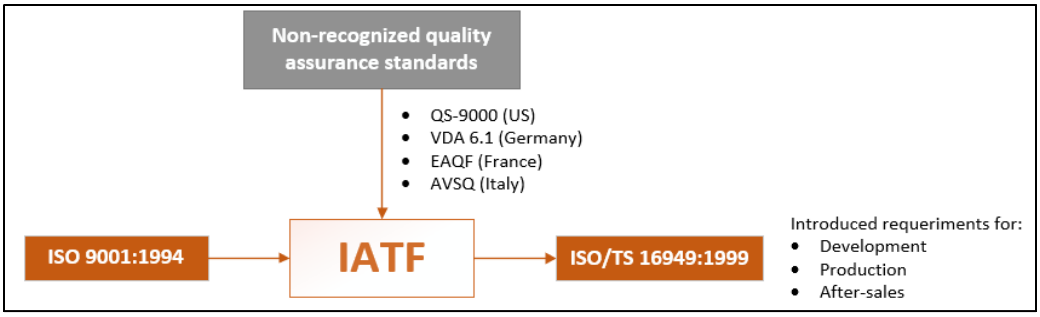


Figure 11 - Process of creation of ISO/TS 19949

This specification identifies the requirements that have to be met by quality systems for design/development, manufacture, installation and service of any automotive related product. Competitiveness stands out once more in the automotive market, as it led to the certification of suppliers becoming a requirement for customers and not optional [26].

In summary, ISO/TS 16949 certification means [27]:

- Improved product and process quality;
- Additional confidence in global procurement;
- Common quality system approach for subcontractor development, allowing organizations to work together more effectively;
- Reduction of variation and increased efficiency;
- Reduction in second party system audits;
- Reduction in multiple third-party registrations, allowing the release of time and resources for other quality-related activities and improvement opportunities that bring added value to the business;
- Common language to improve understanding of quality system requirements, facilitating the implementation and maintenance of the quality systems.

2.1.4.2 Safety requirements in the automotive industry

Today there is a very high attention to the car safety subject, that is a field in constant evolution, where the technical requirements for the vehicles are always changing. Safety standards have seriously decreased the number of accidents, and car manufacturers are trying to gain competitive advantage with are concerned with this issue, that is used sometimes as a competitive advantage between brands [28].

Mainly, the safety requirements in the automotive industry could be resumed in road safety, active and passive safety, the ISO 26202 and other vehicle standards. These requirements are described in Table 6.

Table 6 – Safety requirements for the automotive industry

Safety Requirement	Description
Road safety	Mainly, manufacturers are aiming to reduce the number of accidents through technologies that actually prevent crash avoidance and also active safety technologies [29].
Active safety	Type of safety that will help to prevent accidents and it is divided on: • *Travel safety:* Steering, brakes, suspension and wheel chassis; • *Conditional safety:* The psychological condition of the driver; • *Perceptual safety:* Lighting, visibility of equipment and sound warning; • *Operator safety:* Driving with no stressful factor. Examples: Anti-lock Braking System (ABS), Electronic Stability Program (ESP), Traction Control System (TCS) [28].
Passive safety	Minimization of the consequences after an accident happens. It can be divided on: • *External safety:* Features of the car that will determine the deformation of the vehicle during a crash; • *Internal security:* it is used to mitigate the acceleration and internal force the passengers will experience during a car crash. Examples: airbags, safety belts and Fire Protection System Safety (FPS) [28].
ISO 26262	Created to ensure there is a standard that presents the industry standard for managing risk for electronic vehicle systems [30]. The key aspects of this standard are [31]: • Provides a supportive automotive safety lifecycle (management, development, production, operation, service, deactivation); • Provides a specific risk-based approach, with the objective of determining the classes of risks (ASILs - Automotive Safety Integrity Levels); • Uses ASILs to specify the security requirements needed to achieve acceptable residual risk; • Provides the requirements for confirmatory and validation measures to ensure that a sufficient level of security is being achieved.
Vehicle standards	The United Nations World Forum for Harmonization of Vehicle Regulation has put together a few safety standards that the Member States can choose to follow or not [32]: • Frontal and side impact protection in case of a crash at specific speeds; • Electronic Stability Control; • Increased pedestrian protection through softer bumpers and modification to the front ends of vehicles; • Having seat-belts and seat-belt anchorage; • Being equipped with ISOFIX child restraint anchorage points that secure the restraint directly to the frame of the vehicle.

2.1.4.3 Environmental requirements in the automotive industry

Because the automotive industry has a lot of environmental impacts, whether it is in terms of production processes or in terms of the product itself, it is fundamental to improve processes to make them less harmful to the environment and implement certain enhancements to the product to make it less pollutive.

Since the process of developing a car or just parts for it is very intricate as it uses numerous resources and a lot of different technologies there are a lot of threats to some of the main components of the environment. The introduction of European Union (EU) regulations has shaped this industry in terms of practices in the area of materials management and help to combat threats and car manufacturers developed some ways to stop doing such harm to the environment. This process of environmental management is represented in Figure 12 [33].

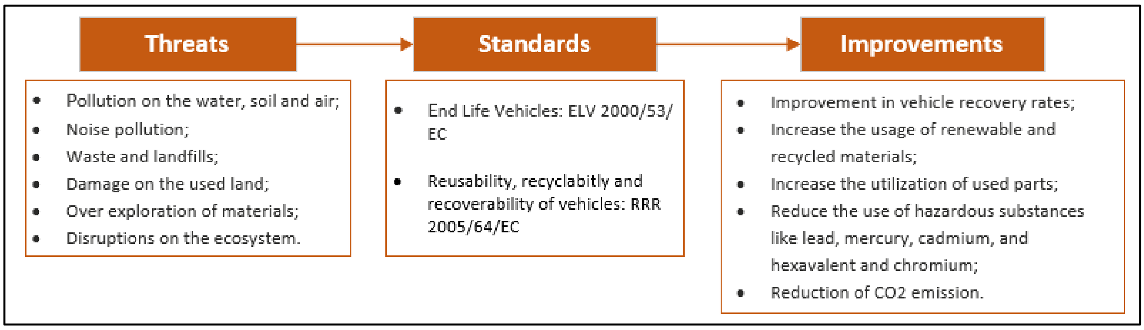


Figure 12 – Process of environmental management in the automotive industry [33]

2.1.5 Automation of components production for the automotive industry

Throughout the times the automotive industry has been trying to increase its efficiency using as fewer resources as possible and making a rational use of them, whether they are energetic, material or human resources. This type of industry involves high production rates followed by very high standards of precision that aim to ensure the levels of customer satisfaction are guaranteed, as well as competitive costs [34].

Currently, manufacturers must be flexible and able to embrace a large product variety to remain competitive. Indeed, market continuous changes obligate companies to adapt and some technological progress allows to improve largely the supply chain control, leading to a more flexible car manufacturing system [35]. This leads to the decision that organizations are currently facing: chose to replace intensive human labor by capital-intensive approaches, increasing their use of technologies such as robots and fully automated assembly equipment to replace the workers [36].

2.1.5.1 Labour-intensive models versus Capital-intensive models

The existence of capital and the quantity of labor classifies a company according to the model adopted. A company with an intensive capital model is based on a more automated production and lower emphasis on the workforce, although poorly automated firms are often considered to have a labor-intensive model (Figure 13) [37].

Figure 13 - Labour-Intensive versus Capital-Intensive [38, 39]

Several industries have a great tendency to follow the evolution of technology and move from the labor-intensive to the capital-intensive model and, despite the automotive industry has high employment rates, it is highly automatized, so it can be considered that it follows a capital-intensive model, with the continuously seek to automate the production process [36]. This focus on developing the technological level of assembly lines is crucial to keep being competitive with non-industrialized countries, with lower production costs due to lower labor costs [35]. The differences between the two models are resumed in the Table 7.

Table 7 - Advantages and disadvantages of labor-intensive model versus the capital-intensive model [37]

MODEL	LABOUR-INTENSIVE	CAPITAL-INTENSIVE
Advantages	Teams, contrarily to machines, can be flexibly used to respond to variable demands	Reduces human error (more precise production)
	It can provide specific products and services tailored to different customer needs	More performance/velocity and capacity of production
	The worker can give feedback and contribute with ideas for continuous improvement	Reduction of cost per unit
Disadvantages	Relatively expensive in long-term with a higher cost per unit due to lower levels of productivity	Big initial investment
	Relatively inefficient in situations that require high physical effort	
	Problems with workers (strike actions)	Low flexibility to make changes in response to a specific demand
	Risk of inexistence of sufficient skilled labors	

2.1.5.2 Automatization: dedicated or flexible models?

In an industry as the automotive industry, with such a high number of components needed to assemble the final product and with the various possible models that are available, there is a huge need for the development of automation systems capable to increase productivity and flexibility. Companies apply projects that will increase their level of automation driven by the following set of reasons described in Table 8 [40]:

Table 8 - Reasons for companies increase the level of automation [40]

Reason	Description
Increase productivity	Automating a production system normally increases the production rate. This will imply a higher output of products per unit of time.
Reduce production costs	Labor costs can be reduced with the replacement of manual operations to automatized operations where fewer workers will be needed.
Optimize the tasks	Boring routine tasks can be improved by being automated.
Increase worker's safety	Supervise rather than perform dangerous tasks for the worker.
Improve product quality	Make the process more uniform and in conformity with the demanded quality standards.
Reduce lead times	Help to reduce the time spent between the customer's order and the shipping, leading to a reduction on work-in-process inventory.
Allow processes that cannot be performed manually	There are certain operations that cannot be performed without machines. These are processes that require a lot of precision making it difficult to be done manually.
Avoid non-automation costs	Since automation as a lot of implications like, for example, increasing sales and quality of the products, not having it will be a serious cost of opportunity for the company. They will not have an as much competitive advantage as they could have when facing the industry.

According to Groover [40], there is three types of automation: fixed, programmable and flexible automation, that are represented in Figure 14.

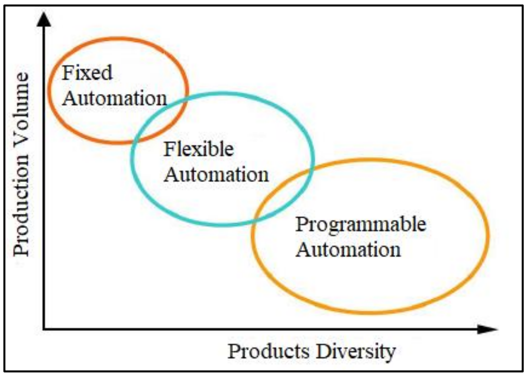


Figure 14 - Types of automation relating to quantity and variety of products (Adapted from [40])

These three types of automation depending on the diversity and volume of production. When there is a need for a large number of products but a reduced variability, the most suitable type will be fixed or dedicated automation. However, if the diversity between products is high and the quantities reduced, with automation dedicated to each series, the most viable model is programmable automation. If we are faced with an intermediate situation, regarding product variability and production volume, the most recommended model is flexible automation, so it is possible to have a right adaptation to product changes [41]. The main differences between these three types of automation are described in Table 9.

Table 9 - Main differences between fixed automation, programmable automation and flexible automation (Adapted from [40])

	Fixed Automation	**Programmable Automation**	**Flexible Automation**
Description	A system where the sequence of operations is fixed by the configurations of the equipment.	A system where the sequence of operations could be modified by the configurations of the equipment.	A system where the configurations of the equipment could be modified with no loss of production time.
Investment	High (equipment design)	High (equipment design)	High (custom system design)
Flexibility	Reduced	Average	High
Production rates	High	Average	Average
Type of production	Continuous/Flow (Same products)	Suitable for batch production	Continuous/Flow (Different products)

2.2 Production management in the automotive industry

In order to prevent conflicts between the different disciplines of manufacturing processes – design, process planning, costing, marketing, customer relations, inventory control, material handling and so on – it must be considered their interests and compromises must be made weighing the specific requirements of the problems that are being analyzed.

Through the years, many different methods were developed to improve the manufacturing cycle, each one aimed to improve a certain aspect of it: lead-time reduction, inventory reduction, customer satisfaction, among others. This variety makes it difficult for a manager to decide which method best suits his/her business [42]. In Figure 15 it is represented the historical evolution of the main production management approaches and its key characteristics.

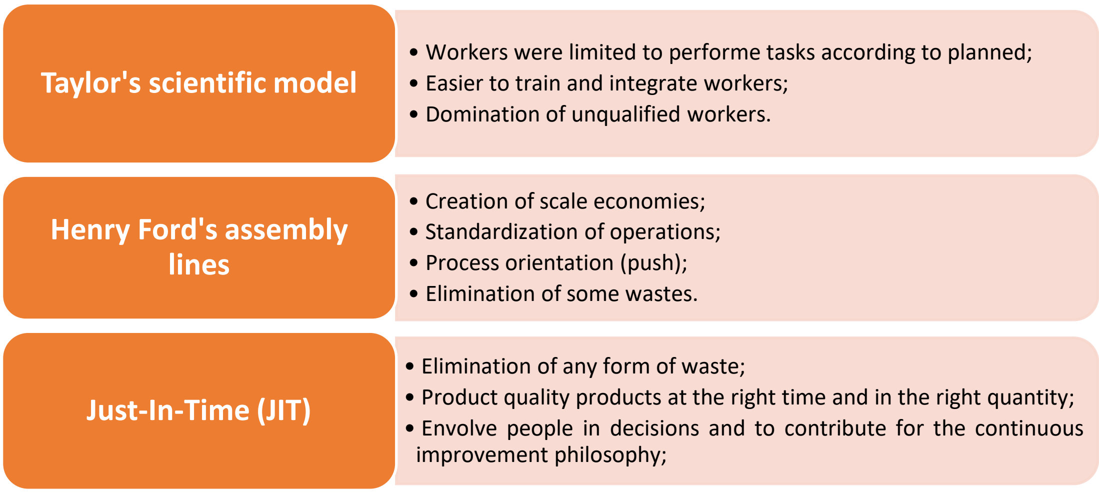


Figure 15 - Historical evolution of production management [43]

2.2.1 Quality management in the automotive industry

The quality concept has taken a new meaning in the automotive industry, evolving from a simple statistical scorecard on freedom from defect to a much broader approach, involving the company and customer's requirements. This new meaning takes in the basis of performance, comfort, environmental, suitability, and affordability, but also adds two key points known as "production quality", relating to the manufacturer's ability to continuously perform better, and "ownership quality", dealing with customer satisfaction [44].

Two other significant and recent paradigm changes, raising the level and consciousness of quality and quality in the automotive industry are described in Figure 16.

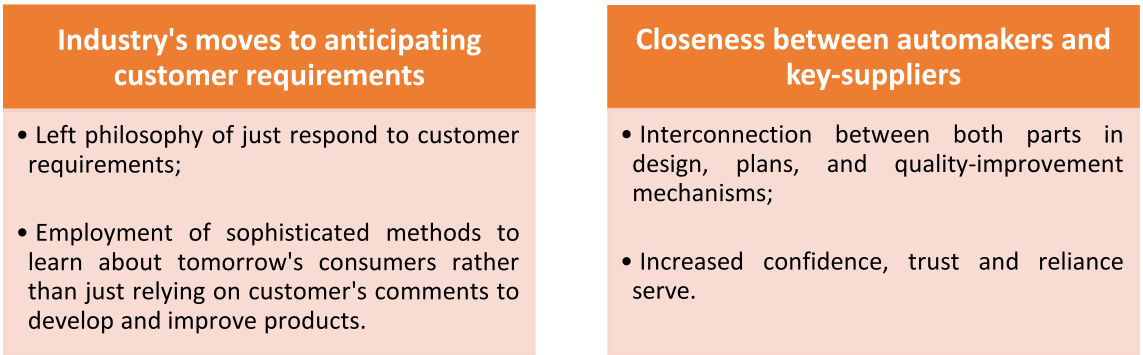


Figure 16 - Description of two important changes relating to the quality management of automotive industry [44]

Quality management theory has been influenced by the contributions made by quality leaders (Table 10). Each of them shows both strengths and weaknesses, and none of them offers all the solutions to a company's problems. However, some common issues can be observed, as management leadership, training, employee's participation, process management, planning and quality measures for continuous improvement [45].

Table 10 - Key contributions of quality leaders [45]

Quality leader	Key contributions
Crosby	• Top management involvement • Four absolutes of quality (conformity with requirements, prevention, zero defects, measurement of quality is the price of non-conformity)
Deming	• PDCA • Continuous improvement
Feigenbaum	• Total Quality Management (TQM)
Ishikawa	• Cause-Effect diagram • Quality control all abroad the organization • Intern client
Juran	• Quality trilogy (Planning, Control, Improvement) • A measure of quality costs • Pareto analysis

2.2.1.1 *Quality improvement tools*

Quality improvement tools are numeric and graphics devices that are used to help individuals and teams work with, understand, and improve processes. The development of the first quality improvement tools began with Shewhart and Deming in the 1930s and 1940s, which allowed a better understanding of processes. In the 1950s, the Japanese began to apply the statistical quality control tools and thinking taught by Kaoru Ishikawa, that was further expanded.

In the 1960s were introduced the following seven basic quality control tools [46]:

1. Cause-and-effect diagram (Ishikawa diagram);
2. Run chart;
3. Scatter diagram;
4. Flow process chart;
5. Pareto chart;
6. Histogram;
7. Control chart.

However, in this work were only applied some of the seven basic tools of quality – Ishikawa diagram, Pareto chart, and Control chart that will be described further.

2.2.1.1.1 Cause-and-effect diagram (Ishikawa diagram)

The cause-and-effect diagram is also known as Ishikawa, due to his creator, or as “fishbone” diagram, due to its skeletal appearance. The purpose of the diagram is to promote a brainstorm and to enable a team to identify and graphically display, in high detail, the root causes of a specific problem [47].

This type of diagram shows the positive or negative factors that are thought to affect a particular output in a system. These factors are commonly shown as groupings of related subfactors that act in concert to cause the overall effect of the group. The diagram helps show the relationship between the parts (and subparts) to the whole by [46]:

- Determining the factors that cause a positive or negative effect;
- Focusing on a specific issue without distractions and irrelevant discussion;
- Determining the root causes of a given effect;
- Identifying areas with a lack of data information.

The basic steps involved in the creation of an Ishikawa diagram are identified in Figure 17.

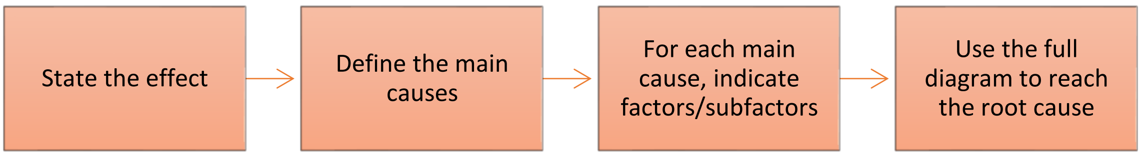


Figure 17 - Methodology to create a cause-and-effect diagram [46]

This type of diagram is typically used during the measurement and analysis phase of a project. Their wide application area covers Six Sigma, TQM or Continuous Improvement teams as part of brainstorming exercises with the aim to identify the root causes, rather than symptoms, for a specific problem [47]. An example of an Ishikawa diagram is shown in Figure 18.

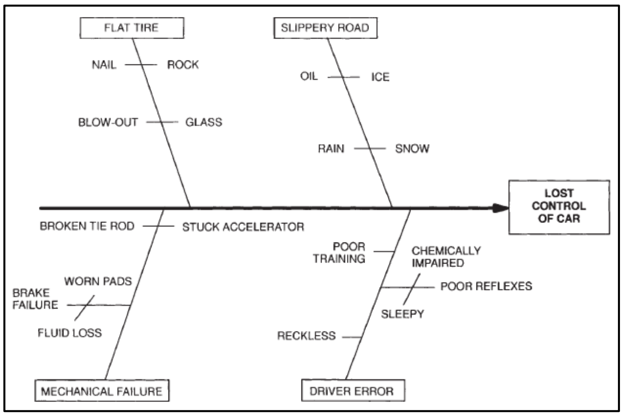


Figure 18 - Cause-and-effect diagram for lost control of car [44]

2.2.1.1.2 Pareto charts

A Pareto chart (Figure 19) traduces in a graphic representation of the frequency with certain events occurs. It is a rank-order chart that shows the relative importance of variables in a dataset and may be used to set priorities for improvement and where to put an initial effort to get the most gain. The name came after the Italian economist Wilfried Pareto observed that 80% of the effects – the "useful many" – are caused by 20% of the causes – the "vital few" [46].

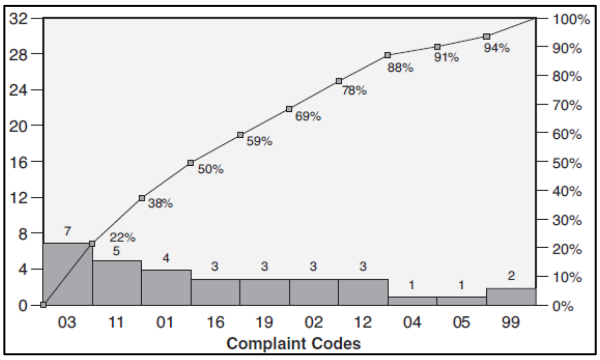


Figure 19 - Pareto chart applied to customer complaints [46]

Pareto charts are extremely useful when relating to optimizing efforts and "going for gold". They have both advantages of being easy to understand and to apply [47]. The basic steps to prepare a Pareto chart are represented in Figure 20.

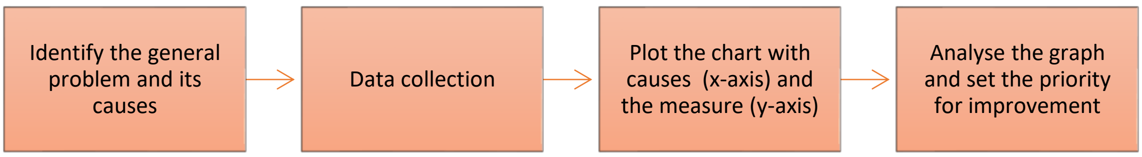


Figure 20 - Methodology to create a Pareto chart [47]

2.2.1.1.3 Control charts

Control charts are a sophisticated quality improvement tool, englobed on Statistical Process Control (SPC), and its used to measure process performance and variability. It is the best-known quality tool, the most useful, and most difficult-to-understand.

The underlying concept of control charts is that processes have statistical variation. This tool (Figure 21) allows determining if this variation is inherent to process (common causes) or if something happened that led the process to go "out of control" (special causes).

Control limits are mathematically defined at three standard deviations, upper and lower the average. Shewhart indicated that 99.73 percent of common cause variation would fall between these limits. Besides these calculated limits, that are inherent to the process, specification limits are also present and are based on product or customer requirements [46].

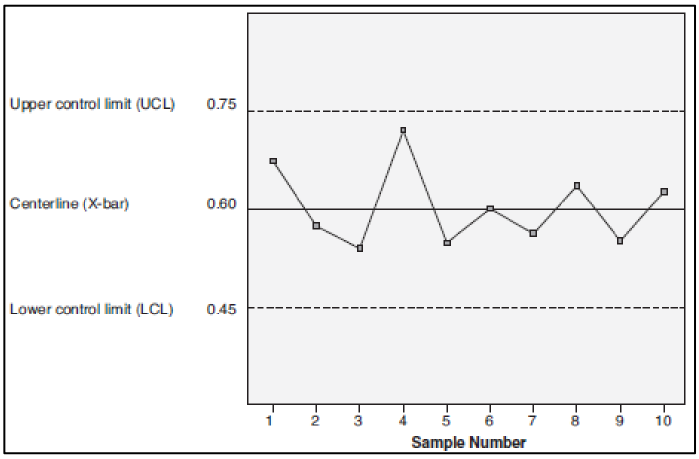


Figure 21 - Control chart [46]

Control charts have been successfully applied in both quality control and improvement. According to Basu [47], some of the reasons for the success of control charts are that they:

- Allow to establish what parameter is controlled;
- Focus attention on the process rather than on the product;
- Could be real-time fueled;
- Comprise a set of prescribed techniques that can be applied by people with appropriate training in a specific manner;
- Prevent organization in trying to fix a process affected only by common causes;
- Determine whether the improvements made are having the expected effects.

The basic steps to build a control chart are shown in Figure 22.

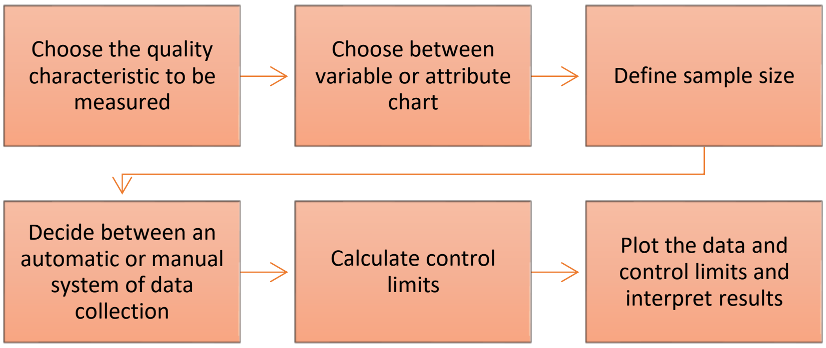


Figure 22 - Methodology to create a control chart [47]

2.2.1.1.4 5 Why's

The "five whys" is one of the simplest and most used techniques to identify the root causes of a problem, by consequently asking "why". With the root cause identified, the aim is to eliminate its occurrence or minimize its effects. The number of times to ask why depends from problem to problem, but usually, most of the problems solved before reaching the fifth why [48].

This technique could also be used as a support to more complex tools, give its simplicity, effectiveness and transversal nature in organizations, making this one the biggest reasons for its success [47]. Figure 23 represents an example of the application of this technique for a problem related to the delay in the deliveries of goods to clients.

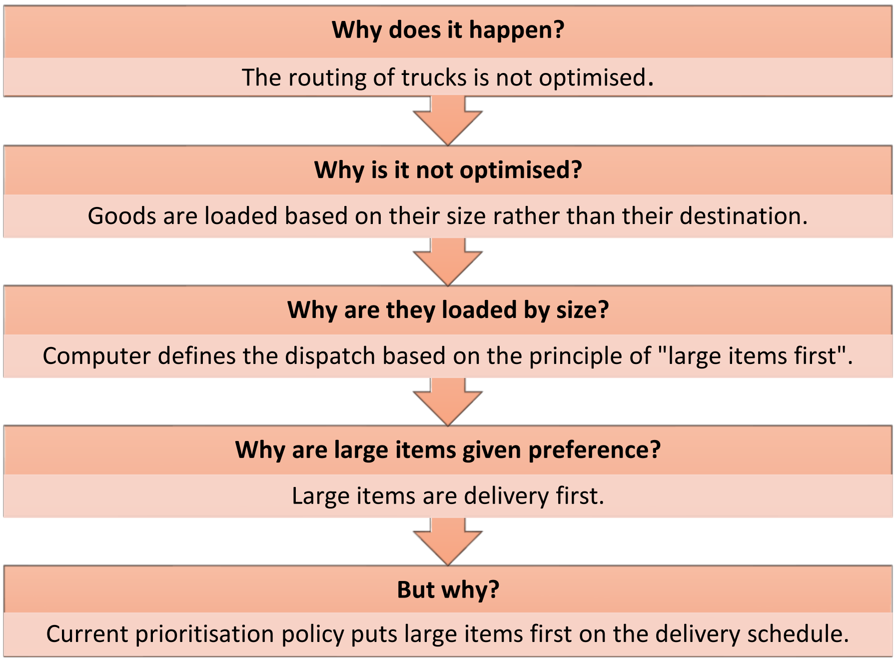


Figure 23 - 5 Why's methodology application example for a problem of delay on deliveries [47]

2.2.1.1.5 Brainstorming

Brainstorming is a simple tool with the flexibility to be used in every situation. This technique works better with groups, where everyone should be involved and aligned with the cause that is being analyzed [49]. It unlocks the creative power of the people included in the session, through the synergistic effect, stimulating the production of ideas [50]. The key aspects involving the realization of a brainstorming session are described in Table 11 [49].

Table 11 - Key aspects of a brainstorming session [49]

Key aspect	Description
Ambient	It should be comfortable, preventing inhibition in the group and stimulating the spontaneity, variety, and creativity of ideas.
Group	It should be varied, so ideas could be richer. Everyone should be aimed at the defined goal, allowing the objectify and commitment of the group.
Conduct	The presence of a conductor it is vital for the objectivity and spontaneity during the session, avoiding criticizing the exposed ideas in order to prevent inhibition of participants.

It could be defined, as represented in the Figure 24, following sequence to realize a brainstorm session [49]:

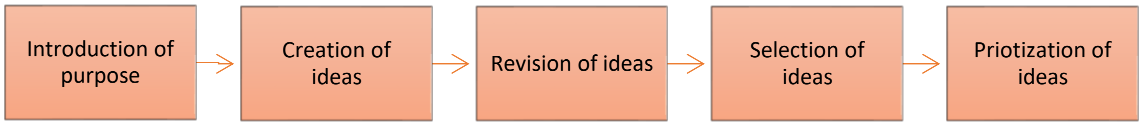


Figure 24 – Methodology to realize a brainstorm session [49]

2.2.1.1.6 SWOT analysis

A SWOT (strengths, weaknesses, opportunities, and threats) refers to a tool for analyzing an organization's competitive position in relation to its competitors. However, this tool could also be adapted to analyze a project or idea and work as a decision support technique [47].

This analysis is divided between internal factors (weaknesses and strengths) and external factors (opportunities and threats). Internal factors could be controllable by the organization since this is the result of strategic actions defined. It refers to the positive or negative aspects of an organization that could, or not, give a competitive advantage to the main competitors. External factors could not be controlled by the organization, but its better knowledge could help to seize opportunities and avoid threats (or minimize their effects) to improve their performance [51]. The structure of this analysis is represented in Figure 25.

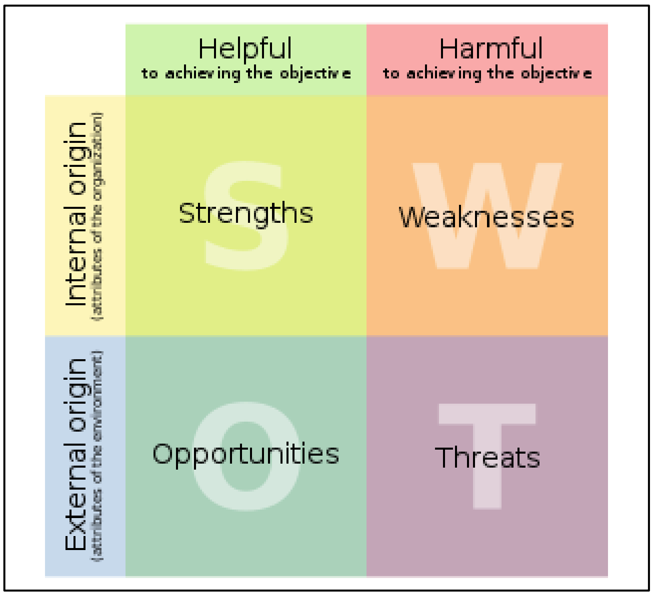


Figure 25 - SWOT analysis structure [52]

The main advantages and limitations of this methodology can be summarized as follows in Table 12:

Table 12 - Main advantages and disadvantages of SWOT analysis [51]

Advantages	Disadvantages
Simplicity	Produces a superficial and imprecise list of factors
Wide application	Relies on the subjective perception of each member who contributed to the SWOT development
Helps to get a better knowledge of business	Lacks factor prioritization regarding the importance of each SWOT factor
Helps to set goals for strategic planning	Static view (“photography”)

2.2.1.1.7 PDCA cycle

The PDCA cycle, created by Shewhart in the 1930s and popularized by Deming in the 1950s, is a development cycle with a focus on the continuous improvement and that could be applied for each process or for the system as a whole, with the aim of preventing stagnation of processes and reach a state of perfection. It is composed of four major stages: Plan, Do, Check, Act, but could be divided into sub-stages, as described in Figure 26 [50].

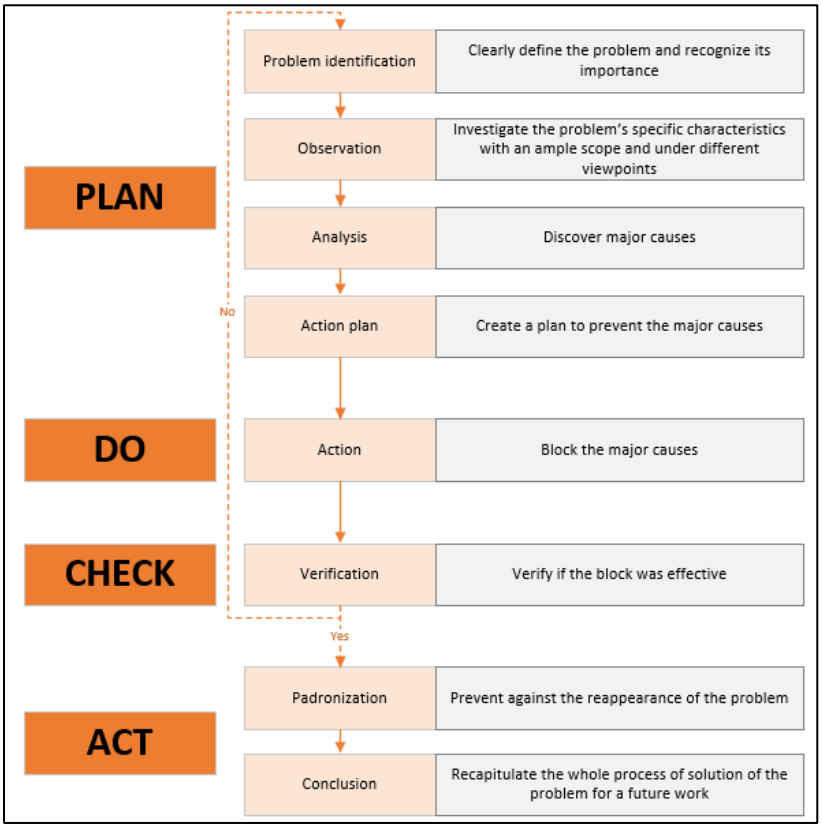


Figure 26 - Steps for the application of PDCA cycle (Adapted from [53])

According to Pinto [54], after the implementation phase, it is expected to observe some fluctuation and instability in the process, but it should not be started a new PDCA cycle without the implemented improvement being stable. Instead, PDCA could be adapted to the generation of a standardization cycle (SDCA - Standardize, Do, Check, Act). The SDCA allows the uniformization of processes and practices, creating a "stable soil" to start a new cycle of improvement (Figure 27). Summarizing, the SDCA cycle uniformizes and stabilizes the process while the PDCA cycle incrementally improves it.

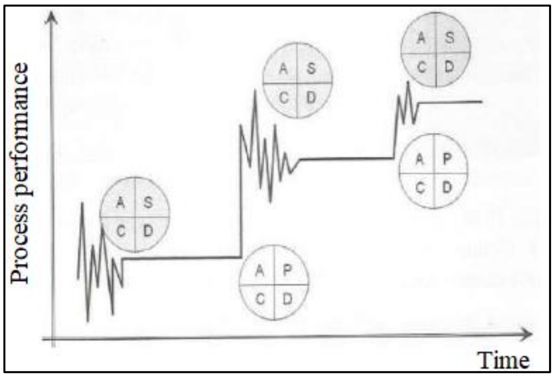


Figure 27 - Application of PDCA and SDCA cycles [54]

2.2.2 The *Lean Thinking* Concept

Lean Thinking a management philosophy based on TPS, that aims to create value through the systematic elimination of every type of waste. The concept of waste refers not just to the human activities that do not add value, but also to all other types of activities and resources that are used inadequately, leading to bigger costs and time spent, and not contributing to improving customers satisfaction [55].

2.2.2.1 TPS – Toyota Production System

After the World War II, Eiji Toyota and Taiichi Ohno from Toyota Motor Corporation (TMC) decided to heavily invest in the automobile production. Fascinated with the results of Ford, Eiji Toyota was 3 months in Ford to study their production system and concluded that mass production was not the correct path for Japanese automotive industry since the intern market was too small and that it was a diversified demand of vehicles. Although, Eiji Toyota concluded that was possible to improve the current production system, implementing a series of innovations, and giving rise to the TPS [56].

Fujio Cho, an ex-director of Toyota, structured the "house of TPS" (Figure 28) that has two main pillars: JIT production and the *Jidoka* concept. These pillars focus essentially on the elimination of wastes on the value chain and englobe the main tools and solutions that lead to continuous improvement of processes and people [57].

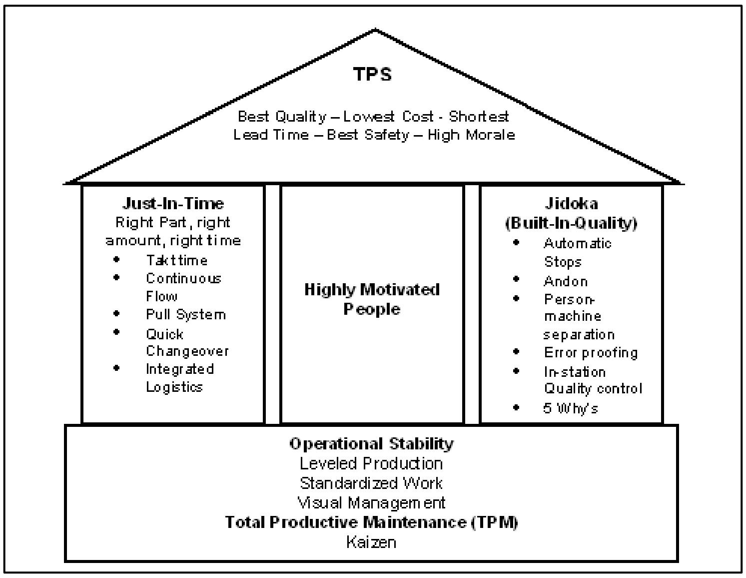


Figure 28 - House of TPS [57]

The principles associated with the main components of the "house of TPS" are described in Table 13.

Table 13 – Description of the House of TPS components [48]

House component	Principles/Tools	Purpose
Foundations	Visual management Leveled production (*Heijunka*) Standardized work 5S	Principles of stable processes and prepare it to improve their performance.
Pillars	Just in Time (JIT)	Delivery of products at the right time, in the right place and in the necessary quantity.
	Jidoka	Endow equipment with systems capable of detecting any defect, stopping the production and preventing non-conform production, eliminating that losses in the root.
Center	Highly motivated people	The continuous improvement, the motivation, and involvement of workers, the problem solving and the continuous elimination of waste.
Roof	The final result of the system	Get quality products or services, at its lower cost and according to the customer requirements.

TPS could be summarized in fourteen principles (Table 14), divided into four categories designated of *4 P*: Philosophy (principle 1), Process (principles 2 to 8), People and Partners (principles 9 to 11) and Problem Solving (principles 12 to 14) [57]:

Table 14 – TPS principles [57]

No.	Principle description
1	Base management decision on a long-term philosophy.
2	Create continuous process flow to bring problems to surface.
3	Use pull systems to avoid overproduction.
4	Level out the workload (*Heijunka*).
5	Build a culture of stopping to fix problems, to get quality right the first time.
6	Standardized tasks allow the continuous improvement and employee empowerment.
7	Use visual control so no problems are hidden.
8	Use only reliable, thoroughly tested technology that serves your people and processes.
9	Leaders who thoroughly understand the work, live the philosophy and teach it to others.
10	Develop exceptional people and teams who follow your company's philosophy.
11	Respect your extended network of partners by challenging them and helping them improve.
12	Go and see for yourself to thoroughly understand the situation (*genchi genbutsu*).
13	Make decisions slowly by consensus; Implement decisions rapidly (*nemawashi*).
14	Become a learning organization through relentless reflection (*hansei*) and continuous improvement (*Kaizen*);

The TPS is on the basis of *Lean Thinking*, that was later (the 1990s) called *Lean Production* or *Lean Manufacturing*. Although based on different approaches, both systems have the same goals with *Lean* exploring the various concepts of TPS: eliminate wastes, motivate and involve workers, optimize equipment, reduce costs and improve customers satisfaction [54].

2.2.2.2 Basic principles of Lean

The concepts and principles that allows creating value through the systematic elimination of every type of waste are seven (although they were five at the beginning), and they are described in Table 15 [48].

Table 15 – Basic principles of *Lean* [48]

Principle	Description
Know stakeholders	Know and comprehend all the stakeholders, instead of focusing only on the final customer.
Define value	Identify the needs of the customer and what they are disposed to pay.
Define the value chain	Accurately identify and map the entire value stream of the product.
Optimize streams	Find the ideal uninterrupted sequence of steps that create value, synchronizing elements involved in creating value for all parts.
Implement the pull system	Let stakeholders pull the processes stream, avoiding companies to push for them what they think to be their necessaries.
Pursuit for perfection	Commitment to the pursuit of perfection, knowing that interests, needs, and expectations of stakeholders are in constant evolution.
Always innovate	Innovate with the aim of creating new products and services and, consequently, value for the stakeholders.

2.2.2.3 Concept of waste

The elimination of all forms of waste is a key goal of the *Lean* philosophy. However, before eliminating the wastes, organizations need to identify them first, using approaches that have the same goal: reach a condition where company's processes, materials, people and technologies produce, at the right time, the right quantity of product and/or service requested by the client. The gap between capacity and load represents waste [50].

Toyota managers and employees use the Japanese word *muda* when refer to waste and eliminating *muda* is the focus of most *Lean Manufacturing* efforts. However, there are other two other Ms: *muri* and *mura*; that are a key factor to make *Lean* work. This three Ms fit together as a system and could be described as in Table 16 [57].

Table 16 - The three M's [57]

M	Category	Description
Muda	Waste	Different wastes in organizations, that does not add value to the final product (extra movements, extra inventory, among others).
Muri	Overburdening people or equipment	Push a person or machine beyond natural limits, that could result in safety and quality problems (people) or breakdowns and defects (machines).
Mura	Unevenness	Results from an irregular production schedule or fluctuating production volumes, that traduces in high and lower peaks of production.

Taiichi Ohno and Shigeo Shingo, on the development of TPS, has identified seven major types of non-value-adding waste (According to Liker [57], there is an eighth waste) in business or manufacturing processes, which are described in Table 17.

Table 17 - Eight types of waste [57, 58]

No.	Waste name	Description
1	Overproduction	Producing more than is immediately needed by the next process in a sequence of operations.
2	Waiting	A time when information, material, people or equipment are not ready (wait for material to produce, wait for a production order, wait for the previous operation to complete, wait for a repair, among others).
3	Transportation	Carrying Work In Process (WIP) for long distances, moving materials/parts/finished products into or out of storage or between processes.
4	Over-processing	Produce more than demanded or before it is needed, consuming capacity. Overproduction is frequently used to anticipated demands or prevent breakdowns, but instead, it contributes to all other wastes.
5	Inventory	Excess raw materials, WIP, or finished products that causes longer lead times, obsolescence, damaged products, transportation and storage costs, and delay.
6	Motion	All the unnecessary motion that employees have to perform while performing their work (looking for, reaching for, stacking parts or tools, walks, among others)
7	Defects/rejects	Production of defective parts, repairs/reworks, replacement production, and inspection activities mean wasteful time and effort.
8	Unused employee creativity	Losing time, ideas, skills and improvements by not listening to employees and promote their involvement.

After being identified these major types of waste, it is necessary to define strategies to promote their elimination, in order to optimize production. This could be achieved by the application of some of the *Lean Manufacturing* tools [59].

2.2.3 Tools for production management

Throughout the development of this work were applied some tools presented in *Lean Manufacturing* philosophy, that will be further described in more detail:

- Visual standards;
- *Kanban* system;
- Standard work;
- 5S;
- *Kaizen*.

2.2.3.1 Visual standards

Visual standards are a simple and intuitive system, included in the management practices developed by TPS to make it easier to manage operations and support people and managers in their activities. Some examples of visual standards are light signals, sonorous signals or pavement marks [60].

The visual approach suggests to create the working condition where error and the occurrence of *muda* can be detected through our eyes, making information available, timely and understandable, so everyone along the process could be able to manage, improve, control and correct it [61]. Therefore, visual communication is not addressed just for individual parts, but for a group, whereas responsibility and knowledge need to be shared. This premise is represented on the visual management triangle (Figure 29).

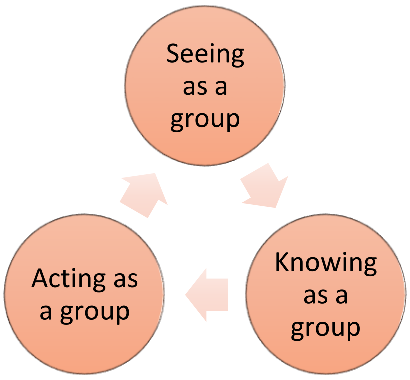


Figure 29 - The visual management triangle [61]

Visual management could also be integrated into more complete tools that communicate important information of the organization at a glance, helping to convey a relevant and easy to understand information in context. These tools follow the increasing modernization of the industry, with data being collected comes from multiple and heterogeneous sources. An example of these tools is the A3, that will be further explained [62].

2.2.3.2 Kanban system

Kanban (*kahn-bahn*) refers to the Japanese word that means "visible record" or "visible part". Generally, it refers to some kind of signal; thus, in manufacturing, it refers to *Kanban* cards, carts, marked floor, among others. It is one of the simplest operations control system, coordinating the materials and information flow throughout the manufacturing process and according to the pull system [60]. This system is based on a customer pulling a component from the supplier, where the customer could be an actual consumer of a finished product (external) or a production personnel at the next station of the assembly line (internal). The premise of this system is that the material will not be produced/moved until a customer sends a signal to it. This way, the *Kanban* informs the operators of the time to start the production and the quantity to produce, working in an opposite way of the productive flow. The operating mode of this system is represented in Figure 30 [63].

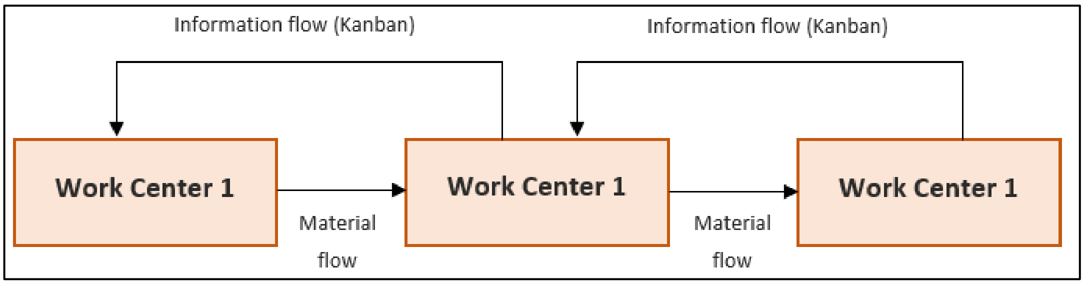


Figure 30 - Operating mode of the Kanban system (Adapted from [63])

This is one of the most important and effective tools to reduce overproduction and provides several benefits, for example [64]:

- Reduced inventories;
- The predictable flow of material;
- Simplified scheduling;
- Visual pull system at the point of production;
- Improved productivity.

This type of system should be one of the last steps in the JIT implementation process, since it quickly exposes the process inefficiencies, demanding the development of the productive process itself and good preparation of operations management to solve them [54].

2.2.3.3 Standard work

According to Ortiz [58], standard work is the best, most efficient, safest and most practical way to work. The concept is about documenting and standardize all tasks, so that authorized, standard procedures are always used, on all shifts and by all operators. The aim is that the best and most reliable methods are defined for all processes, leaving nothing to chance or personal preference, or if deviations occur, it allows an easier way to identify the root cause. The process of implementation, the way it applies to the daily work [58] and the benefits of its implementation [64, 65] and is described in Figure 31.

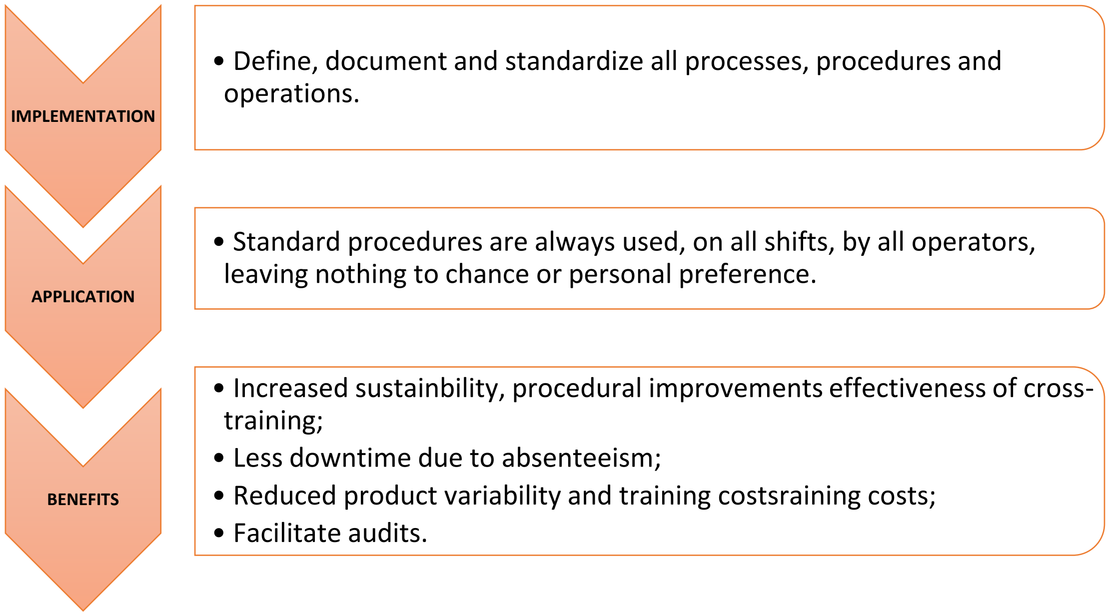


Figure 31 – Implementation, application to the daily work and benefits of standard work [58, 64, 65]

Although this methodology is the best approach to manufacturing as it can catapult organizations towards a world-class status, it is harder to implement as cultures have more resistance to the implementation of standard work rather than other *Kaizen* philosophies. However, with effective training, commitment to achieving results and correct implementation, standard work clarifies much of the confusion of *gemba* [58].

2.2.3.4 5S

The 5S methodology is a set of five basic principles that constitute the initial stage of a continuous improvement process. These five principles (described on the Table 18) must be transversal to the entire organization and must be part of the culture of all workers, with everyone responsible to adopt them on daily behaviors and work [43].

The main benefits of the implementation of 5S principles are [64]:

- Employee ownership of the workplace;
- Improved maintenance;
- Improved moral;
- Improved productivity;
- Improved safety;
- Improved transparency.

Table 18 - Description of different 5S [66]

S	Key-word	Description
Seiri	Sort	Removing what is not needed and clearing the workplace.
Seiton	Set to order	Preparing the necessary items, neatly and systematically, so that they can easily be taken and returned to the original place.
Seiso	Shine	Clean regularly equipment and workplace, identifying irregularities.
Seiketsu	Standardize	Documenting and standardize the method, using standard procedures that are clear and easy to understand.
Shitsuke	Sustain	Continuously maintaining established procedures, auditing work procedures, making 5S a habit and integrating into a culture.

2.2.3.5 Kaizen / Continuous Improvement

Kaizen is a Japanese term that means gradual unending improvement, obtained through constant little enhancements and by selecting and accomplishing progressively more developed standards [46]. Normally, this tool incentivizes the intervention of all levels of the hierarchy of the organization, from the top management to the smaller operator, allowing an optimization of the pull system and a reduction of waste [67].

These small incremental steps are called *Kaizen* events and are applied in a specific area in a short period of time. These events do not need to necessarily lead to a major improvement, but they are extremely important to identify problems in the organization that sometimes might not be immediately observable [48]. These *Kaizen* events are created bearing in mind five important elements described in Table 19 [68].

Thus, a *Kaizen* event could possibly be for example a weekly meeting with the team from a certain department in order to access all the performance problems they are facing and possible small improvements to try to avoid them. This will allow them to freely express their concerns and previous experience enriching everyone's knowledge [42].

Table 19 - Five key elements of *Kaizen* [68]

Kaizen elements	Description
Circles of quality	Group meetings to discuss quality levels in all the organization's aspects.
Improved morale	Crucial to reach high levels of efficiency and productivity.
Teamwork	Everyone works as a team instead of competing.
Auto discipline	Ensuring auto discipline in each individual will improve overall team performance.
Improvement suggestions	Asking for feedback from each member will guarantee all possible problems are addressed.

2.2.3.6 OEE (Overall Equipment Effectiveness)

OEE is an indicator that is used the measure the global efficiency of a specific equipment or process. It covers equipment's responsibility, the influence of labor and the produced defects. The OEE groups the six sources of losses with greater impact on the production process and categorizes them into three major parameters, as shown in Table 20 [69].

Table 20 - Loss categories of OEE [70]

OEE category	Type of loss	Loss source
Availability (Av)	Equipment stoppages	• Equipment breakdown, non-programmed maintenance
	Setups	• Change of reference
Performance (Pf)	Micro stoppages	• Obstructed productive flow • Variations on products characteristics • Cleaning needs
	Low operational velocity	• Equipment wear • Operator inefficiency • Rework
Quality (Q)	Start-up rejections	• Scrap • Rework • Scrap during setups
	Production rejections	• Same as start-up rejections

In order to determine the percentages of availability, performance, and quality, it is necessary to know how the total work time affects their inherent losses. This relation is expressed in Figure 32 [71].

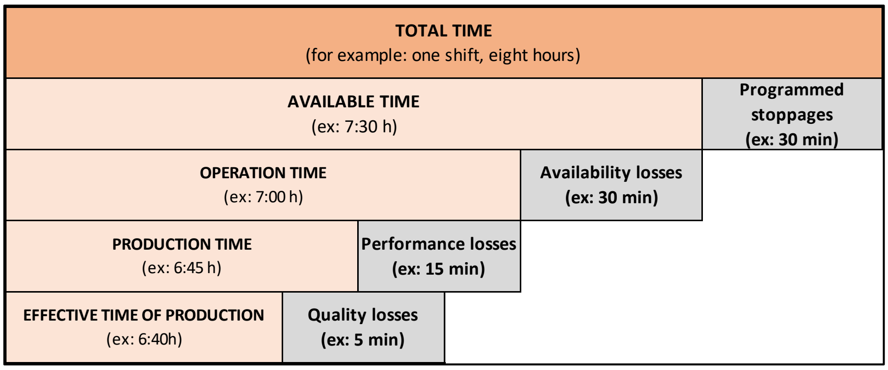


Figure 32 - Impact of time losses in production time (Adapted from [72])

The mean and the way to calculate these three parameters are described in Table 21. The OEE calculation is based on the multiplication of all these three parameters:

$$OEE = Availability \times Performance \times Quality \qquad (1)$$

Table 21 - Description of OEE parameters [73]

OEE Parameter	Description/Formula
Availability (Av)	Reflects the time that the equipment was operating. Improving this parameter allows to reducing preventive stocks created to cover production stoppages.
	$Availability = \frac{Operation\ Time}{Available\ Time}$
Performance (Pf)	Reflects the number of products that were supposed to be produced *versus* the real quantity produced. The implementation of improvements to reduce or eliminate micro stoppages and increasing the operation velocity of the equipment allow an increased production capacity.
	$Performance = \frac{Production\ Time}{Operation\ Time} = \frac{Cycle\ Time \times Quantity\ Producted}{Operation\ Time}$
Quality (Q)	Reflects the percentage of conforming units *versus* the overall production.
	$Quality = \frac{Quantity\ Produced - Reworks - NOK\ Units}{Quantity\ Produced}$

Considering all these metrics, the OEE should be around 85% or even higher. However, other possible factors should be taken into account, as the degree of production automation [74]. This indicator is of high importance to companies in terms of the search for improvement opportunities. However, its main objective is not to provide a performance indicator, but an indicator to know where resources should be spent on improvement in the system. Furthermore, this tool is very effective when combined with Total Productive Maintenance (TPM), since together they allow the elimination of equipment loss (decreasing problems with availability, performance, and quality) and share responsibilities in terms of maintenance and production [75].

2.2.4 A3 Thinking

The A3 methodology consists in a problem-solving model developed by TMC and with the aim of solve communication problems between the different Toyota installations, as the A3 format is the largest size that can fit through a fax machine.

Communication is the key role of this methodology, that aims to support and reach consensus in critical decisions (13th principle of Lean – nemawashi) with visibility of just critical, clear and objective information [76].

There are four different common types of A3 reports (Figure 33), used for many different types of stories presentations, and that follows a natural flow [77]:

1. *Proposal story*: aims to get approval to invest resources in the project;
2. *Problem-solving story*: used as the project progresses;
3. *Status story*: used in key milestones of the project;
4. *Information story*: used to present the results.

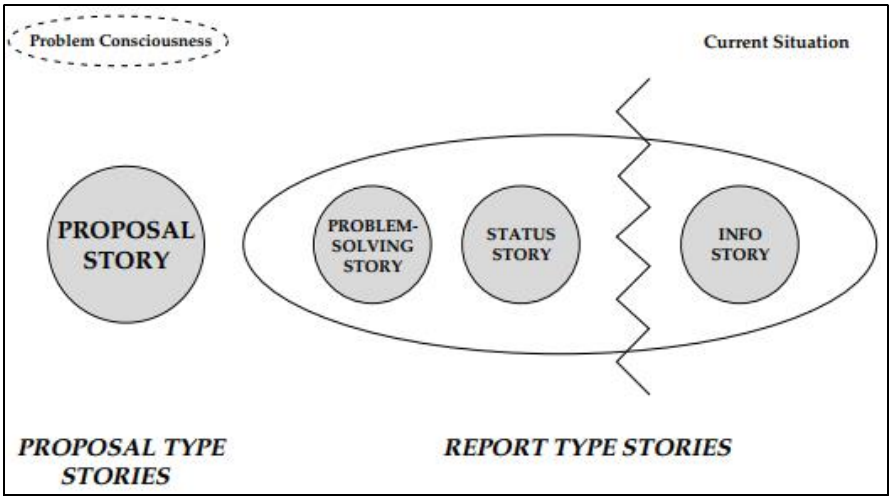


Figure 33 - Four types of A3 stories [77]

2.2.4.1 *Seven Elements of A3 Thinking*

According to Sobek and Smalley [78], the mindset behind the A3 system and the intellectual development of Toyota's workers has seven key elements that are described in Table 22.

Table 22 - Seven elements of A3 Thinking [78]

No.	Element	Description
1	Logical thinking process	Thinking and then act rationally in decision making, through a disciplined execution of PDCA, discerning distinction between "cause" and "effect" and rational use of the limited resources to solve the major problems.
2	Objectivity	Conciliation of multiple viewpoints for the same problem, by framing problems with relevant facts and details.
3	Results and process	Neither one is favored over the other. Both are necessary and critical for effective organizational improvement and personal development.
4	Synthesis, distillation, and visualization	Visualization of key synthesized information in order to communicate the message clearly and efficiently.
5	Alignment	Make decisions incorporating the concerns of workers affected by the solution and determine any broader issues that have not been attended.
6	Coherence within and consistency across	High-level of consistency throughout all the organizational units, speeding up communication and aid in establishing a shared understanding.
7	Systems viewpoint	Understand the problems in an enough broader context that promotes the overall good of the organization. It is not intended to improve individual department if the overall organization performance stays the same.

2.2.4.2 *The A3 Problem-Solving Report Process*

Problem-solving report processes uses different formats depending on the stage of the process and according to what and when information is being presented. It is possible to divide this report process in three different macro stages: *Proposal Stage, Status Reporting* and *Final Reporting*. The evolution of problem-solving report process is described in Figure 34 [77].

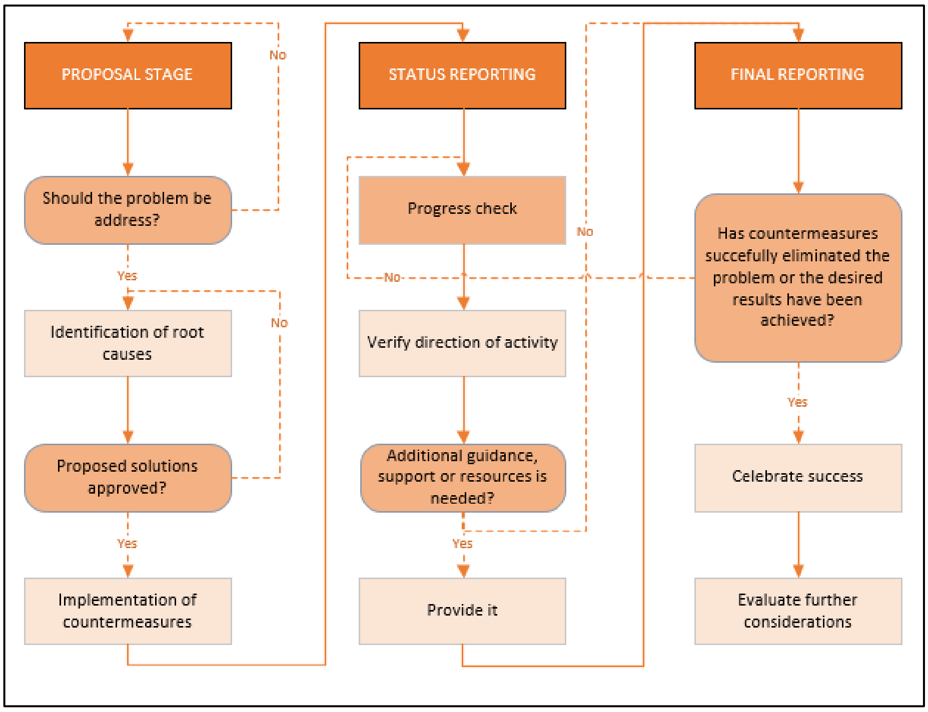


Figure 34 - A3 problem-solving reporting process [77]

2.2.4.3 Outline for an A3

The basic layout and flow of an A3 problem-solving process are represented in Figure 35.

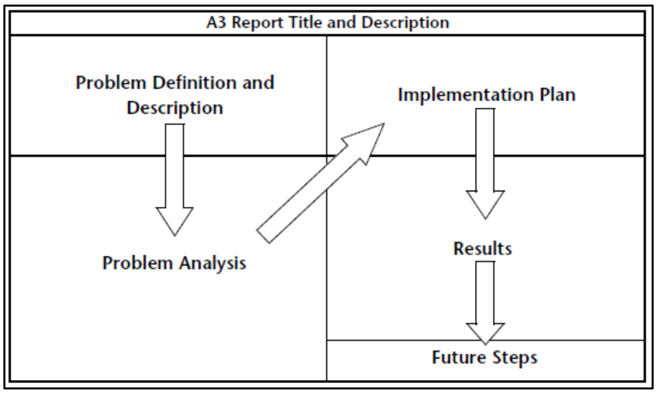


Figure 35 - A3 problem-solving story format and flow [77]

The *Problem Definition and Description* (the problem statement) and the *Problem Analysis* fill the entire left side of the A3 sheet. The analysis is the heart of the problem-solving process, as a thorough and accurate analysis allows solutions to be implemented and achieve effective results. The right side of the A3 is reserved for the *Implementation Plan*, *Results* and *Future Steps*, with *Results* filling the most of it, as the global purpose of the process is to improve results.

The connection between root causes (analysis) and the results must be logical and clear, so there is less need to outline the implementation details [77].

2.2.5 Assembly Line Balancing

A proper assembly line balancing means the highest possible uniform distribution of sequential operations through the different workstations, minimizing the time of empty load. Regardless the studies for assembly lines design are theatrically well elaborated, contemplating the people, materials, and equipment in each workstation, it is common to verify, in practice, a certain lack of balance that needs to be adjusted in order to eliminate waits and bottlenecks. To do so, it is necessary to start a time measurement study of the different operations [79].

2.2.5.1 Time measurement techniques

The study of work basis is a set of analysis tools and techniques used to study the human work, with the aim to develop and standardize methods. It is determined the time spent by a qualified worker, at a normal pace, as well as verified if the worker follows the defined method [80]. Study of work has two techniques: a study of methods and work measurement; that are described in Table 23 as well as the correlation between them [81].

Table 23 - Different techniques for time measurement [81]

Technique	Description	Co-relation
Study of methods	Examination of the current methods for the execution of specific work in order to improve their performance.	Need to quantify the gain time, if new processes are introduced.
Work measurement	Determination of the necessary time to carry out specific tasks, under specific and patronized conditions.	Elimination of unproductive times with the introduction of new methods.

The basic steps involved in the study of work are represented in Figure 36. This measure and determination of the standard time have a key importance for [82]:

- Planning of the organization, using efficiently the available resources and also to measure the production performance in relation to the existent standard;
- Supply data to calculate the standard cost of production and estimate costs of new products;
- Supply data for production structures balancing, define production cadence and realize planning and capacity analysis.

Figure 36 – Basic steps involved in the study of work [82]

There are various methods for the measurement and determination of times, but the most common are comparison, timing and Methods Time Measurement (MTM). The criteria's and consideration for each technique are described in Table 24 [83].

Table 24 - Comparison between different techniques of time measurement [83]

	Comparison	Timing	MTM (Methods Time Measurement)
Type of production	Single	Small and medium series	Big series
Necessary information	Identical projects already made	Information about the operation, product, and method	Detailed information about movements
Precision and accuracy	Low	Good	Elevated

2.2.5.2 Calculated times associated with time measurement techniques

For the determination of the standard time for each operation, there are some corrections and assumptions that need to be done. They are summarized in Table 25 [84].

Table 25 - Different times associated to time measurement techniques

Designation	Description	Formula
Observed Time (OT)	Real-time when an operation is performed., that varies according to the worker and the occasion. Results from the average number of measurements, previously established.	-
Rhythm Factor (RF)	Defines the pace of work. If a worker has a normal rhythm, the rhythm factor is 100%.	-
Normal Time (NT)	Required time for a worker complete the operation, with a normal velocity.	$NT = OT \times \frac{RF}{100}$
Corrections (C)	The complement of time added to the normal time for rest, personal necessities, among others. Standard correction times are applied as these times are of hard measurement.	-
Standard Time (ST)	Necessary time for the realization of a specific operation by a qualified worker, at a normal pace and under a pre-established method and normal conditions of work.	$ST = NT \times \frac{\sum C}{100}$

2.2.5.3 *Takt time and assembly lines balancing*

Takt Time (TT) is used to synchronize production and sales. It is calculated by dividing the total available time of work (in seconds) by the volume of customer demands (in units), for the same period, representing the rhythm that the client is requiring the products. If production runs at a lower speed, customer demands are not satisfied, while if production runs at a higher speed, it led to overproduction that causes accumulation of stock and increases costs for the organization. Takt Time matches the necessary rhythm that each product needs to be produced in order to satisfy customer demands in the established deadlines [85].

One way to represent the balancing of an assembly line is with the help of a bar graph (Figure 37) where the x-axis represents the different workstations and the y-axis represents the time of operation. The line that represents takt time is placed as a reference for the balancing and operations distribution [79].

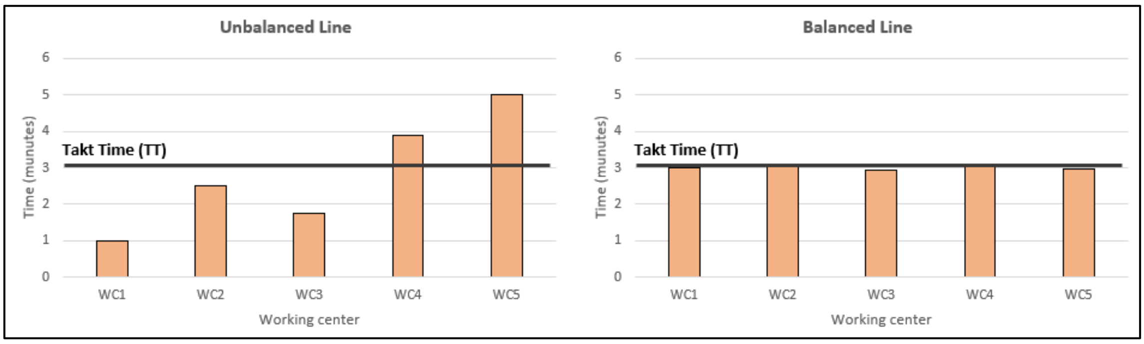


Figure 37 - Assembly line balancing versus Takt Time (Adapted from [79])

In the traditional view, there is a tendency to balance through an equal distribution for the working centers. In this case, the working centers are balanced but they are not fully utilized. In the *Lean* philosophy, balancing is made so workers are utilized near to their maximum of efficiency, with an exception for the last worker that has some availability to assure administrative tasks or substitute another worker, if needed. Balancing is intended for the organization of tasks in working centers and has a high importance in increasing productivity, as it minimizes the stoppages for waiting times [86].

2.3 Six Sigma

"A comprehensive and flexible system for achieving, sustaining and maximizing business success. Six Sigma is uniquely driven by close understanding of customer's needs, disciplined use of facts, data and statistical analysis, and diligent attention to managing, improving, and reinventing business processes." [87].

2.3.1 History of Six Sigma

The process of evolution of Six Sigma approach, from the initial development by Motorola to the current application for all types of industries, is represented in Figure 38 [50, 87, 88].

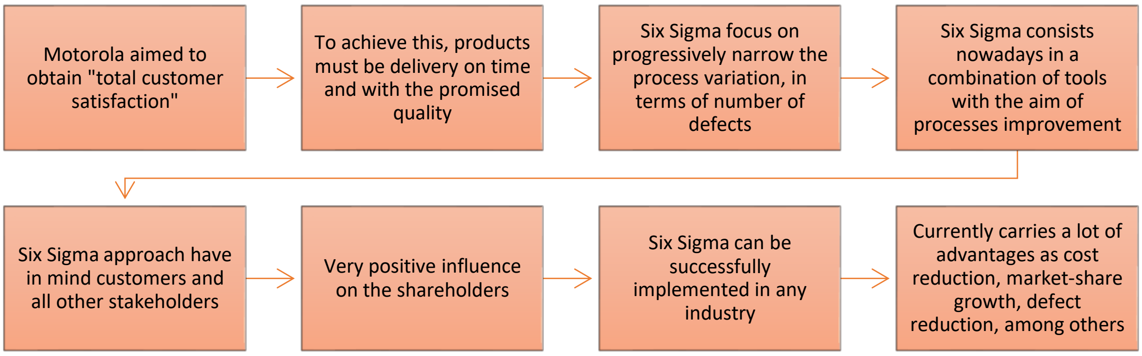


Figure 38 – Evolution of Six Sigma [50, 87, 88]

The name Six Sigma derives from the fact that the quality concept of this approach is established on a standard deviation of the process for the specification range of +/-6. Since standard deviation is commonly designated with the letter sigma it became 6σ. The number of defects on the products is measured in terms of defects per million. The use of this unit of measure is to underline the determination to achieve a zero defect production [50].

General Electrics has described this approach as "*A disciplined methodology of defining, measuring, analyzing, improving, and controlling the quality in every one of the company's products, processes, and transactions – with the ultimate goal of virtually eliminating all defects*" [50].

2.3.2 Six Sigma Methodology

Six Sigma methodology, in terms of improvement cycles, comes originally from TQM, which was one of the first approaches used in management, and focuses on meeting the needs of the customers and in covering improvement on all parts of the organization. In terms of the statistical process control of reducing variability, Six Sigma aims to obtain a statistical performance of having only 3.4 defects per million opportunities (the number of defects in the whole production if there were one million opportunities to do so), thus making the level of variability lower enough to be considered acceptable [50].

Initially, the Six Sigma included only four steps in its implementation: *Measure*, *Analyze*, *Improve* and *Control* (MAIC), but later, General Electric added the fifth phase – *Define* – which originated DMAIC, one of the two main methodologies of Six Sigma [89].

DMAIC consists of an improvement cycle model used to optimize processes [50]. It comprises the five phases mentioned above, and it appeared with the purpose of being applied in the production area of an organization [89]. However, companies do not need only to improve processes, but also to develop them, so Six Sigma englobes also the DMADV approach, whose main purpose is developing processes and products. DMADV consists of five phases: *Define*, *Measure*, *Analyze*, *Design* and *Verify*. DMAIC gives Six Sigma the necessary tools and methods for the improvement of products or processes, whereas the DMADV offers the possibility of developing new products and processes [88].

Both methodologies are represented in Figure 39.

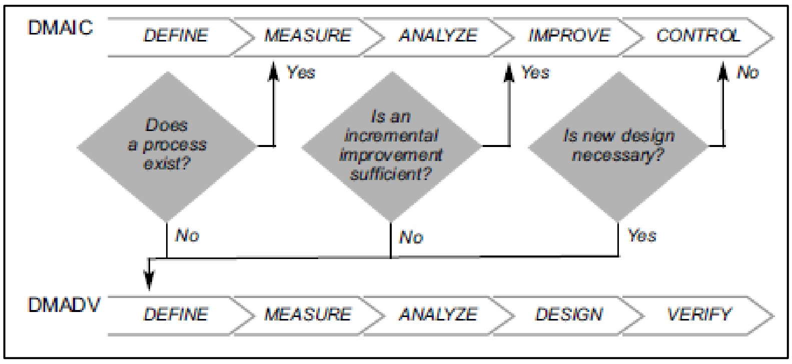


Figure 39 – Methodology of DMAIC and DMADV [88]

2.3.3 Six Sigma metrics

Six Sigma uses a lot of metrics to verify the performance of operations processes, as described in Table 26.

Table 26 - Different metrics of Six Sigma [50]

Metric	Description
Defect	When the product or service fails to meet the customers' demanded quality
Defect unit or item	Unit of product that contains a defect
Defect opportunity	Number of different ways a product can fail to meet the customers' demanded quality
Proportion defective	Percentage of units that have one or more defects
Process yield	Percentage of total units produced by a process that is not defective
Defect per unit (DPU)	Average number of defects per unit
Defects per opportunity (DPO)	Percentage of defects divided by the total number of defect opportunities
Defects per million opportunities (DPMO)	Number of defects in the whole production if there were one million opportunities to do so
Sigma measurement	Derives from the DPMO; It corresponds to the number of standard deviations of the process variability that will fit within the customer specification limits

2.3.4 DMAIC cycle

Since the developed work focused on the process's improvement, it will be described all the steps of the DMAIC cycle. The five of DMAIC stages are described in Table 27.

Table 27 - Description of DMAIC stages [50, 90]

DMAIC stage	Description
Define	Definition of the scope of the project, identifying customer demands, what needs to be done and the requirements of the possible improvement.
Measure	The problem is validated to realize if it is worth solving, using all the information to better understand the problem and to measure the dimension and impact of it.
Analyze	Identification of possibilities on what can be the root of the problem. These possibilities can be checked or not but once the origin of the problem is found the improvement stage can begin.
Improve	Testing and implementation of possible solutions.
Control	Confirmation and maintenance of the implementation.

A flowchart of the DMAIC path is represented in Figure 40.

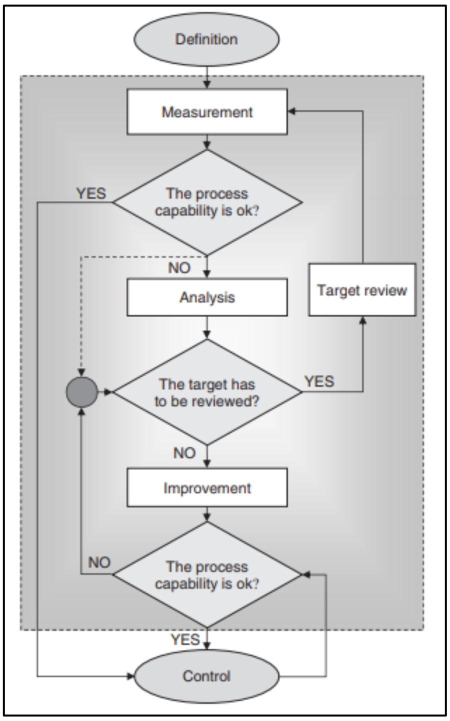


Figure 40 - Flowchart of the DMAIC path [89]

2.3.4.1 Define

The first phase of DMAIC begins by identifying the products or processes whose intervention is needed with more urgency, based on inputs as customer complaints, DPMO, suggestions from workers and so on. This will be the crucial phase in all the process since everything will depend on this first decision.

Once the processes or products that need the improvement are identified, their prioritization is chosen based on several tools like the Pareto diagram or the cause and effect diagram. However, there are a lot of variables that can influence the way these projects are prioritized like the possible benefits that could be generated for the customers, the benefits to the company or even the potential cost savings. The main activities for the identification of products and processes are described in Figure 41.

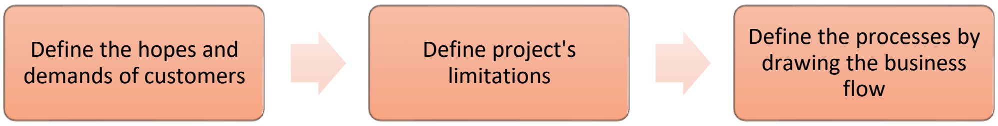


Figure 41 - Steps for identification of products and processes [89]

Finally, to better perform this phase it is essential to include some research on the international competitors to define what are the key product/process features in the industry [89].

2.3.4.2 Measure

This second phase begins with the selection of the "response" variables, that are the characteristics of the chosen product/process, and with the identification of the "input variables", which are the corresponding resources that have an influence on these characteristics. These characteristics are defined as *Critical to Quality* features of the product/process, the ones the client values the most. Subsequently, we need to gather information from all the selected input variables, using tools like sampling techniques, measurement intervals and so on.

Measurements are to provide all the important information needed for decision making in terms of changes in the product/process. Thus, making the measurement of situations where the evaluation of the performance of products/processes is at stake, much more detailed and focused on possible project improvement must be [89].

The main activities in the measure stage are represented in Figure 42.

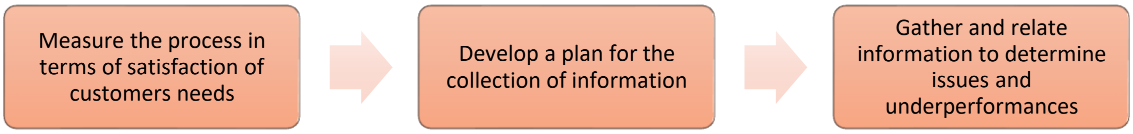


Figure 42 - Main activities in measure stage [89]

2.3.4.3 Analyse

The third phase of the DMAIC Cycle involves the assessment of the previous data gathered in the measurement and definition phases. Using statistical methods, this phase will evaluate the process centering and variation, the stability, the possible tendency of the process/product performance without forgetting to evaluate in terms of DPMO. In this phase, it is normal to perform a gap analysis to identify common factors that determine the best performance.

Like in the define phase we should include some research on the performance of response variables for similar products/processes of our best competitors. This activity would allow having a good basis for the choice of the improvement targets [89].

The main activities in the measure stage are represented in Figure 43.

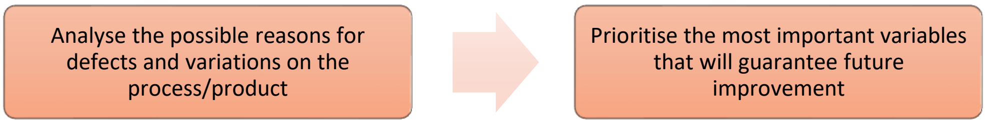


Figure 43 - Main activities on analyze stage [89]

2.3.4.4 Improve

This phase begins with the decision about what are the characteristics of the product or process that require intervention and with whose intervention we can accomplish the target set previously. For this improvement, some tools like 5S, Poka-Yoke, Pull System or Cross training are used to verify the presence of possible causes for variation, and posterior aiming at the elimination and reduction of these same causes [89].

The main activities in improve stage are represented in Figure 44.

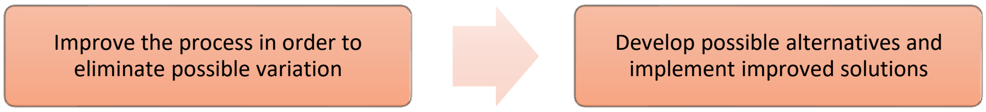


Figure 44 - Main activities on improve stage [89]

2.3.4.5 Control

Finally, the control phase will establish the actual improvement, following the measures adopted in the previous phase. To make this establishment it will use some statistical process control tools like control charts, to monitor the results and after passing the period of adjustment, it will evaluate the process capability to check if the whole path was done correctly.

In this phase is also common to make these improvements the new rule for the procedure and to disseminate the good results throughout the whole organization and also to see how they affected the whole organization, in terms of annual savings, for example [89].

The main activities in the control stage are represented in Figure 45.

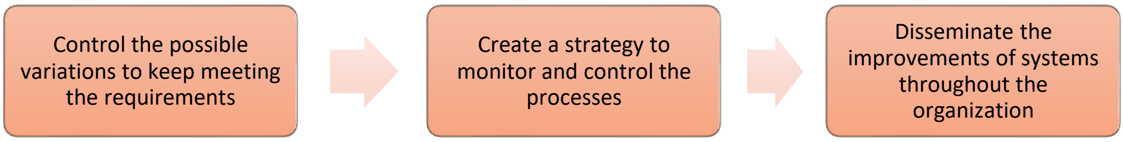


Figure 45 - Main activities on control [89]

CASE STUDY DEVELOPMENT

3 CASE STUDY DEVELOPMENT

3.1 Specific goals of this work

This work was focused on three main goals:

- Improve flows and eliminate/reduce wastes on a specific assembly line with the aim of increasing productivity;
- Reduce the quantity of scrap produced in the most critical module of the company;
- Create and implement an A3 methodology to follow and monitor specific KPIs.

The first goal relates to a productivity improvement plan focused on specific assembly lines with values of productivity per hour (PPH) below the target and forecasted on budget. This inefficiency could compromise the deadline with the client and result in significant costs for the company. In this sense, it was formed by different teams according to the type of inefficiency detected. In this case study, it was approached an assembly line integrated into the *Continuous Improvement* department.

Relatively to the second goal, it was created a specific team to undergo a six-sigma project with the aim to reduce the quantity of scrap produced along the different processes of the comfort systems module. It was verified that the biggest quantity of scrap was produced along the adjustment process and setups, so the key goal of this project was to reach a reduction of about 20% on scrap produced in these circumstances. However, the developed project was intended to achieve other goals that are listed below:

- Standardize method of work on the three shifts;
- Document new lessons learned for future equipment;
- Stabilize the process on the different types of equipment of straightening/cut equipment;
- Knowledge of the different process variables and their interconnection on the chain (from raw material to final product).

Finally, the A3 project aimed to improve the current methodology of controlling and monitoring the most important KPIs for production management.

3.2 Characterization of the host company

3.2.1 The group FICOSA (FICOSA International, S. A.)

FICOSA is a multinational company. In 1949, Josep Maria Pujol and Josep Maria Tarragó created a workshop in Barcelona (Spain), with the name "Pujol I Tarragó", dedicated to the production of mechanical cables. In 1987 the company changed to the name FICOSA International. This company invests mainly in research, development, production, and marketing of components and systems for the automotive sector. It has production centers, engineering centers and commercial offices in 19 countries all over Europe, North and South America and Asia (Figure 46). It is the official supplier and technological partner of a great part of the vehicle producing companies in the world. All of this success is partially due to the fact that FICOSA has developed a successful system that guarantees global quality and high levels of service, the FICOSA Manufacturing System, which allows the company to have the brand image "made by FICOSA ". This system is based on four principles: Just-In-Time, Focus on Quality, Continuous Improvement, and Commitment and Team's High Performance.

Figure 46 - The Global presence of the group FICOSA

3.2.2 *Fico Cables*, Lda.

In Portugal, the company goes by the name of *Fico Cables*, Lda. In 1972, "Pujol I Tarragó", with the aim of covering and serving the global market of the Iberian Peninsula, expanded to Portugal by associating with a Portuguese company called Teledinâmica. Teledinâmica was located in a garage in Vila Nova de Gaia and was managed by Eng. Franco Dias and had only three employees. From 1980 the company began to export to Fiat and other European manufacturers. As a consequence of its expansion, the company moved in 1981 to Maia where later, in 1993, the company changed its name to *Fico Cables*, Lda. The company has grown in turnover, product range, and equipment from that moment on. Nowadays the sales surpass the value of 60 million euros as seen in Figure 47.

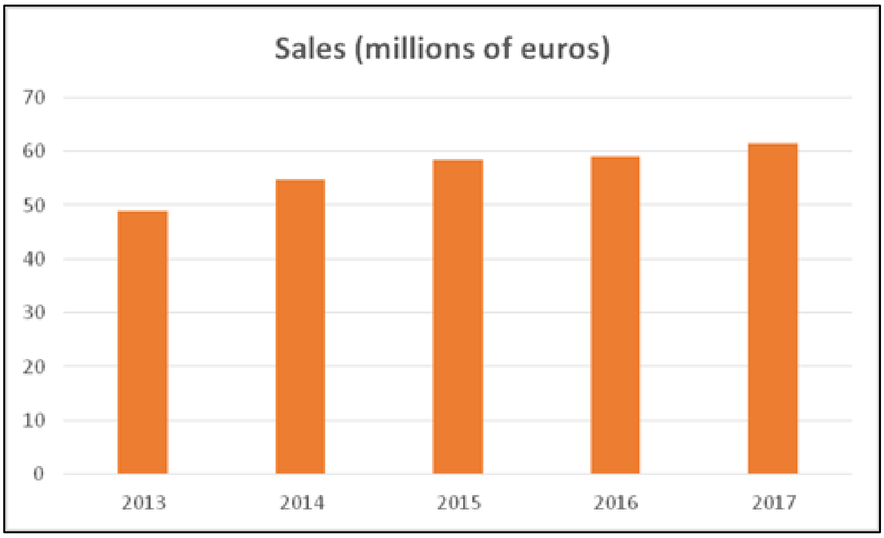


Figure 47 - Sales volumes from 2013 to 2017

At the moment, the company has two business areas, one of which is called Doors and Seating Systems and the other Comfort Systems. It produces cables used in the transmission of movement and comfort systems that are incorporated in the seats of the vehicles. These products are designed to be adapted in different solutions, such as window lift system, handbrake, door opening, seat back adjustment, seat tilt systems, among others. *Fico Cables* provides these types of products for customers who are OEMs and others who are direct manufacturers to OEMs. The main customers are VW, Opel, PSA, Renault, Brose, Johnson Controls, Faurecia, Kiekert and Inteva.

In terms of type of production system, *Fico Cables* follows a *Standardized Production System* based on the TPS and on the principles of Lean Thinking.

3.3 Case study no. 1

This case study is included in a *Productivity Improvement Plan*, developed with the Continuous Improvement department.

3.3.1 Characterization of the problem

One of the main Key Performance Indicators (KPI) of *Fico Cables* is the direct labor deviation (currently denominated on *Fico Cables* as *MOD*). This indicator measures the difference, in terms of a number of people, between the real number of people that were working on a specific assembly line and the theoretical number of people needed for the number of OK units produced. This theoretical number of people is calculated based on the defined output per hour for each working center.

For the calculation of this KPI, it is assumed that each shift works 8 hours, with a break of 15 minutes (total of 7.75 hours). Also, this KPI measures the deviation for an expected OEE contained in the budget instead of an OEE of 100%.

An example of the calculation of this KPI is demonstrated below:

$$MOD = Number\ of\ people\ reported - Theoric\ number\ of\ people \qquad (2)$$

$$MOD = \frac{\sum presence\ hours}{\sum hours\ per\ shift} - \frac{\sum OK\ production \big/ Defined\ output\ per\ hour}{\sum hours\ per\ shift \times OEE\ (budget)}$$

$$MOD = \frac{91\ h}{7.75\ h} - \frac{4000/57}{7.75\ h \times 83\%}$$

$$MOD = 11.7\ people - 10.9\ people = \mathbf{0.8\ people\ of\ inefficiency}$$

The evolution of this KPI, relatively to the global factory, during the previous year of 2017 is represented in Figure 48.

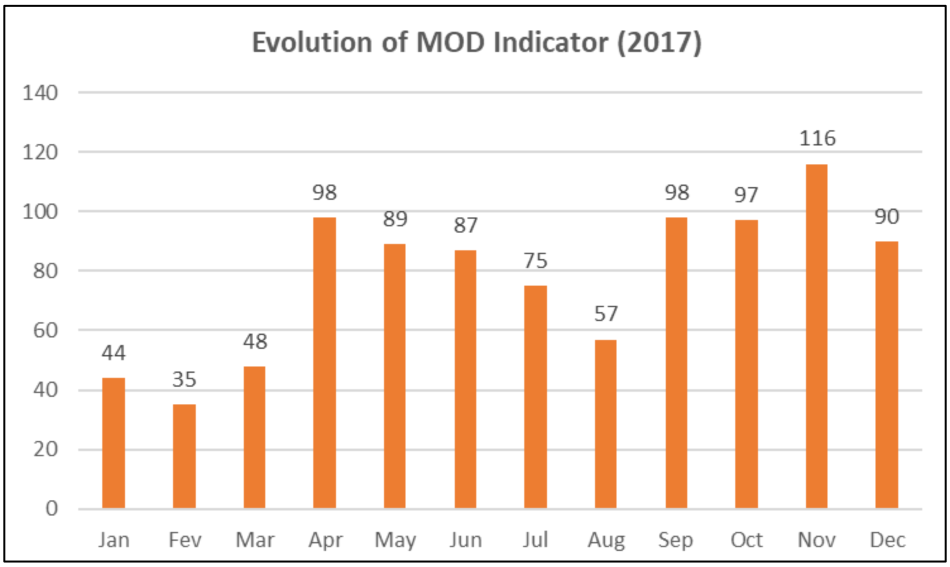


Figure 48 – Evolution of the MOD deviation KPI during the year of 2017

The aim of this *Productivity Improvement Plan* is to reduce this deviation in 33 people until the end of 2018, with the improvement of specific assembly lines each month.

The respective progress of the MOD gain is represented in Figure 49.

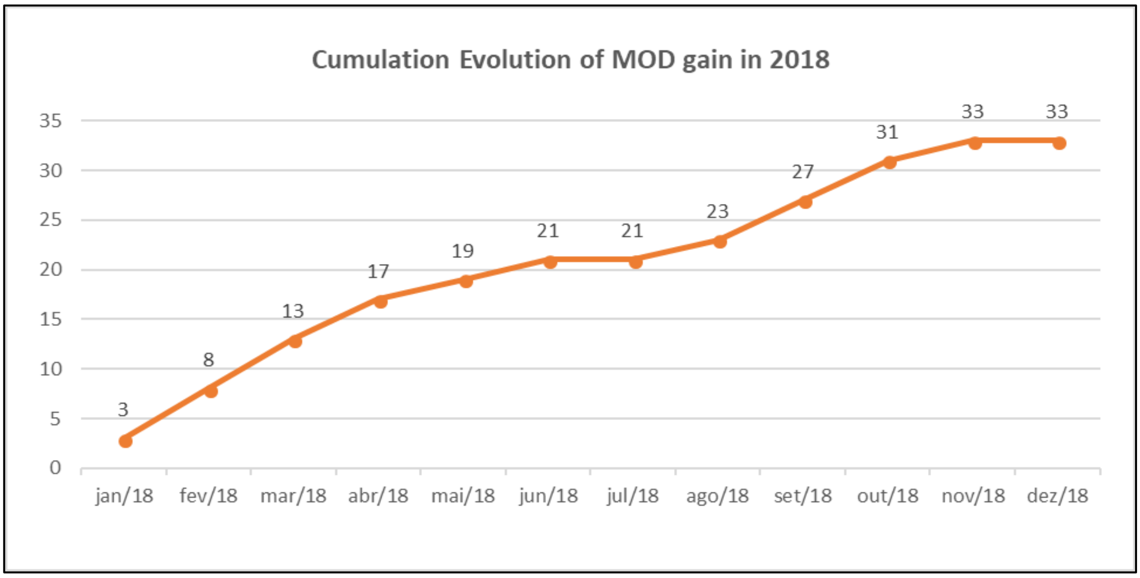


Figure 49 - Cumulative evolution of expected MOD gain in 2018

3.3.2 Requirements to observe

This *Productivity Improvement Plan* was focused on the improvement of the efficiency of different assembly lines. For the development of this project, it was defined four teams, described in Table 28.

Table 28 - Teams defined for the development of *Productivity Improvement Plan*

Team	Type of assembly lines on focus	KPI / Indicator
Continuous Improvement	Assembly lines with a high number of people and with performance problems (but with OEEs that accomplish the goal)	Productivity per hour (PPH)
Maintenance	Assembly lines with availability problems.	% Availability of OEE
Processes	Assembly lines with performance problems and with OEE values out of the target.	Productivity per hour (PPH)
Logistics	Assembly lines with higher number/time of setups.	Time of setups and number of setups

In a more detailed way, the criteria used to define which assembly lines were focused by the Continuous Improvement team was:

- Assembly lines with values of OEE that accomplish the goal, but that works with a big number of people (potential to gain productivity per hour);
- Assembly lines with values of OEE that accomplish the goal, but that has problems on the performance component;
- Assembly lines with major visual potential based on historical knowledge.

Based on the values of March of 2018, the assembly lines with good values of OEE and that works with a high number of people are the following:

- B479 Exterior;
- VW B8 L2;
- JEEP Locks;
- RG3 Interior;
- Transit Exterior;
- KL;
- RG3.

The corresponding values of OEE and the number of people that works on these assembly lines are represented in Figure 50.

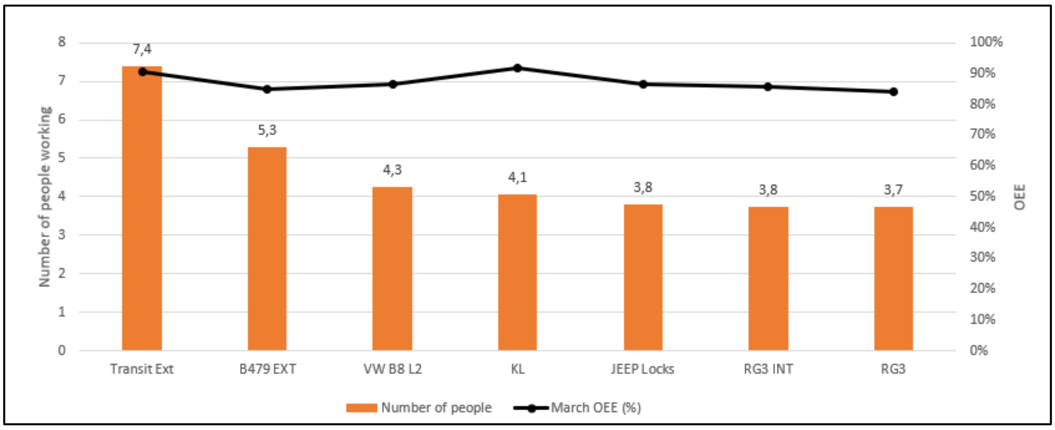


Figure 50 – OEE (%) of March of 2018 and number of people that works on the selected assembly lines

In addition, there was identified assembly lines that have also a high number of people working on them, but that present availability and/or performance problems:

- 'PSA travão';
- Magna 139/225;
- Multi-reference assembly line (assembly line prepared to work and produce several references from different customer projects).

The number of people that work on these assembly lines, as well as the losses by performance and availability (in a number of people), is represented in Figure 51.

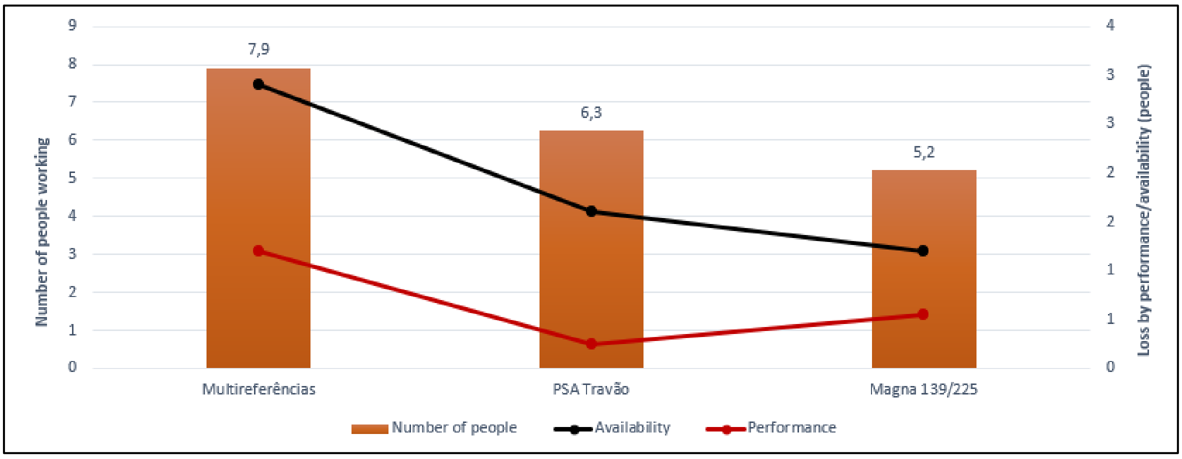


Figure 51 – Loss (in number of people) by performance and availability and number of people that works on the selected assembly lines

In this case study, it will be approached the specific improvement case of *'PSA Travão'*. This assembly line was also the selected to start this project as it represents one of the assembly lines with more people working on it: 5 or 6 people, depending on the reference that is being produced. It could be chosen the Multi-reference assembly line, which presents a higher number of people working on it, but this represents a complex case of a very specific assembly line, created to produce a bigger number of different references and that would not allow a quick gain.

3.3.3 Methodology of implementation

The methodology of implementation applied to this improvement case consists of three different main stages, which are described below.

1. ***Time measurement of different workstations***

In this operation, it was measured the time that the operator consumes, at a normal pace and without the occurrence of special circumstances, in each operation of the different workstations. This measurement led to understand and visualize the global panorama, identify where it was possible to have a potential improvement opportunity and to quantify the production capacity in each workstation before defining and implement improvement actions.

2. ***Compare actual cycle time of each workstation with Takt Time***

After measure the time consumed by each operation in the different workstations, it was compared the respective time with the Takt Time, as it represents the rhythm that each product needs to be produced in order to satisfy the customer demand. Also, the visualization of the line balancing status led to understand if specific workstations were much slower or faster than the others, causing the unnecessary production of intermedium stocks and waiting times between workstations.

3. ***Eliminate wastes and re-organize*** workstations

After quantified and compared the cycle time of each workstation, it was necessary to understand the different assembly line debilities, through the identification of the different wastes and inefficiencies (*Seven Wastes* concept). The identification of these wastes and the implementation of the respective improvement actions allowed then to re-organize the different workstation operations and to globally re-balance the assembly line.

4. ***New time measurement and verify implemented improvements***

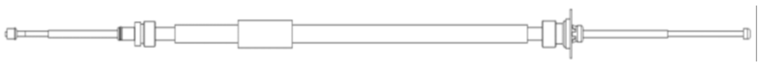
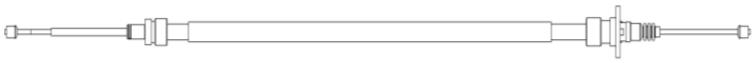
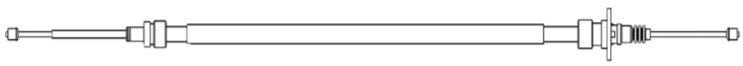
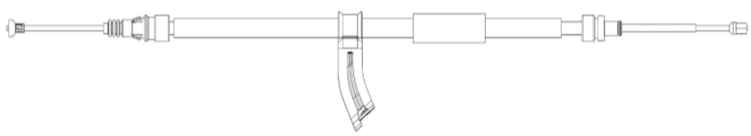
In order to validate the implemented improvement actions previously defined, it is necessary to measure new operation times. By this way, it is possible to understand if the improvements solved the detected inefficiencies and wastes.

3.3.4 The case of the assembly line ‘PSA Travão’

3.3.4.1 Introduction to the product

In the assembly line designated as ‘PSA Travão’, are produced cables for handbrake actuation and for seven different projects of the PSA group. These projects, as well as the respective handbrake cable, are represented in Table 29.

Table 29 - Different handbrake cables produced in the assembly line ‘PSA travão’

Project	***Fico Cables* Reference**	Drawing
M3M4 6 inch	111912036	
M3M4 9 inch	111913039	
A88	111912695	
E3	111912350	
	111913106	
F3	111913106	
	111913107	
K9	111912903	
	111912904	
	111912905	
	111912906	

This type of cable has, with primary function, the role to transmit the necessary force to stop the car or keep it stationary when the handbrake lever is pulled. In the case of the projects produced in the *PSA Travão* assembly line, they are all referred to the secondary cable of the handbrake system.

This system has the handbrake pulling a primary cable, attached to a U-shaped guide that is denominated by *equalizer yoke*. A different cable (denominated by secondary cable) loops around this yoke and runs to the rear wheels on both sides. When the handbrake is pulled on, the primary cable is activated and pulls on the yoke that tensions the secondary cable.

This system is represented in Figure 52.

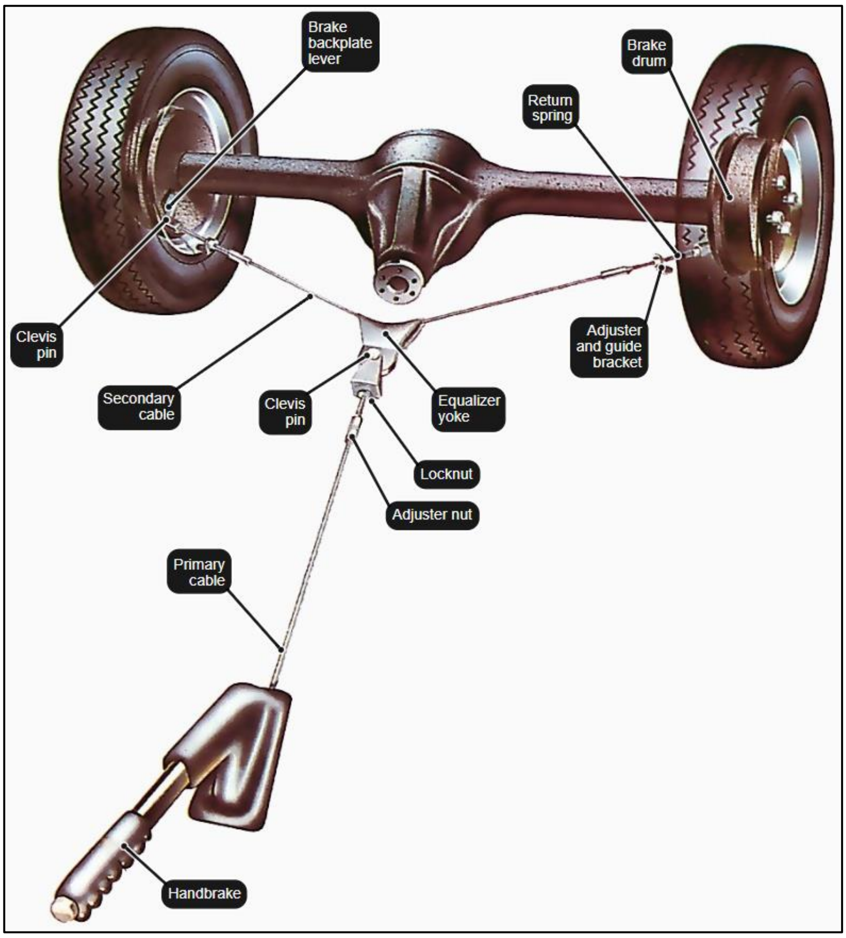


Figure 52 – Representation of a handbrake system [91]

3.3.4.2 Introduction to the 'PSA Travão' assembly line

This assembly line is located in the *F3 assembly lines* submodule. It occupies an area of 62 m² and has five operators distributed by five different workstations (100 A/B, 101, 102, 103 and 104). In some cases, there is a sixth operator in a quality wall and that also assumes the packaging and labeling operations. The assembly line layout as well as the flow of materials in operations (green line), and the components and WIP supply (dashed green line), are presented in Figure 53.

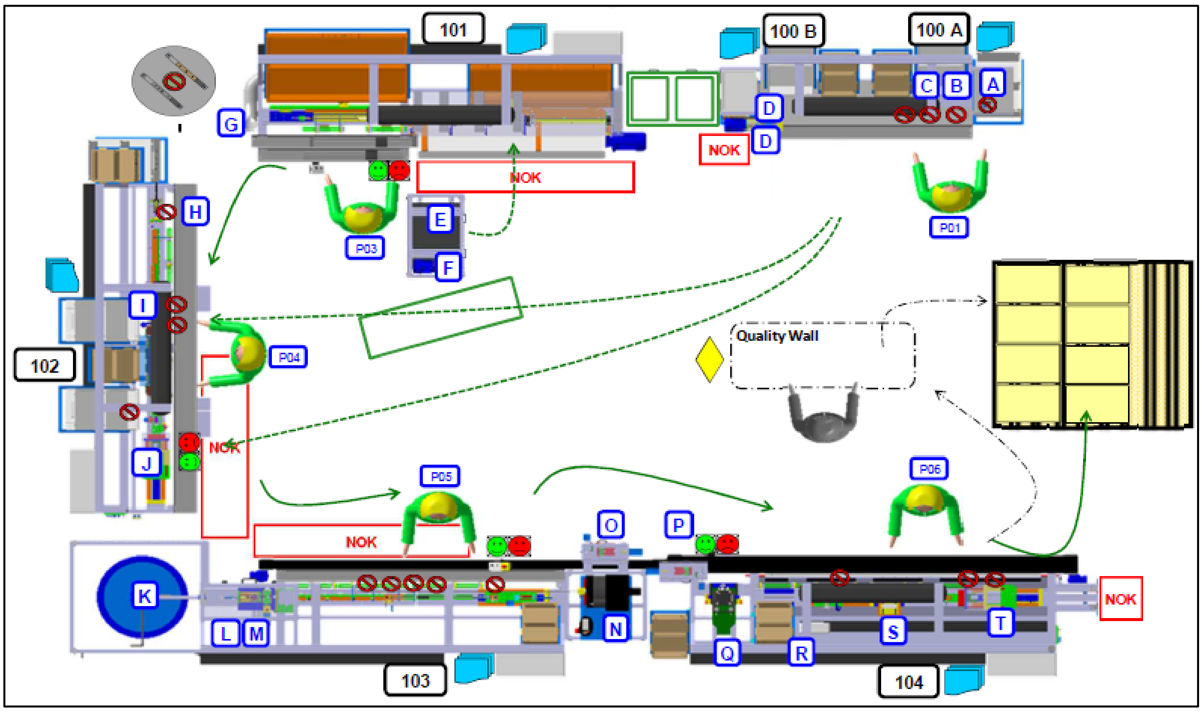


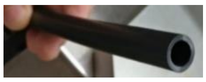
Figure 53 – 'PSA Travão' assembly line layout

A flow chart with the representation of the different operations sequence and the respective workstation where they are performed is represented in *ANNEX 1 – Flow chart of operations of the 'PSA Travão' assembly line.*

3.3.4.3 Components consumed on the assembly line 'PSA Travão'

In the *PSA Travão* assembly line, it is consumed different components in the different working centers. This componentes comes both from the other working centers or they are directly purchased components, as shown in Table 30.

Table 30 – Components supplied to the assembly line 'PSA Travão'

Working station	Component designation	Component
100A	Conduit end fitting	
	External O'ring	
	Smaller inner tube	
	Bigger inner tube	
	Rubber bellow	
100B	Conduit end fitting	
	Sealing	
	Metallic O'ring	
101	Conduit	
	External tube	
	Extra tube	
102	Grease	
103	First cable end fitting	
104	Second cable end fitting	

3.3.4.4 Supply of components on the assembly line 'PSA Travão'

The supply operator places the components boxes on both sides of the assembly line and, from there, each operator supplies their working stations. The components transfer from the storage zones to the respective workstation is made by two different ways, as shown in Figure 54.

- The conduit end fittings, rubber below, O'ring, bigger inner tube, sealing, grease, and the second cable end fitting are consumed from the containers in which they were supplied to the storage zone (supply without decanting);
- The smaller inner tube, the metallic O'ring, the extra tube, the exterior tube, the first cable end fitting and the conduits are transferred to smaller containers, used in the assembly line (supply with decanting).

This supply method distinction relates to the existent conditions in the assembly line, about the space to store the components and the need to easily reach the components during the assembly operations.

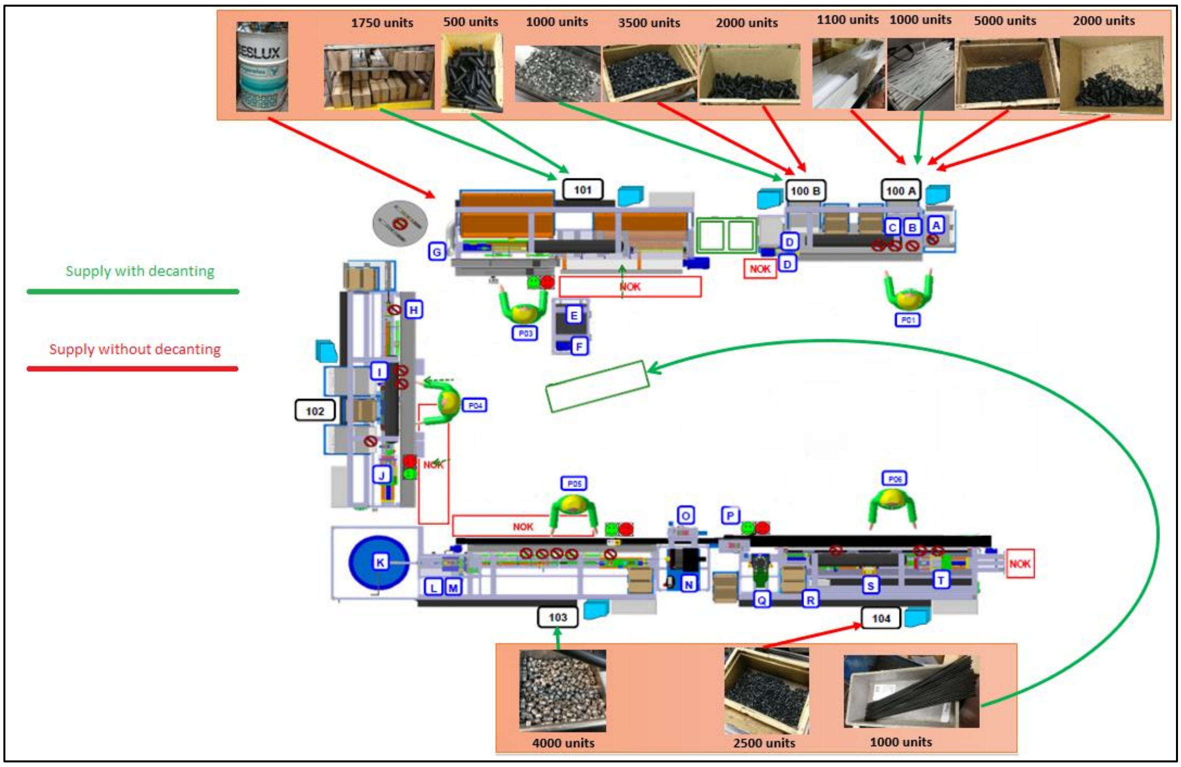


Figure 54 – Components supply process to the assembly line 'PSA Travão'

3.3.4.5 Workstation operations

Workstation 100A/100B

In the diagram in Figure 55, it is highlighted the operations performed in the workstations 100A and 100B.

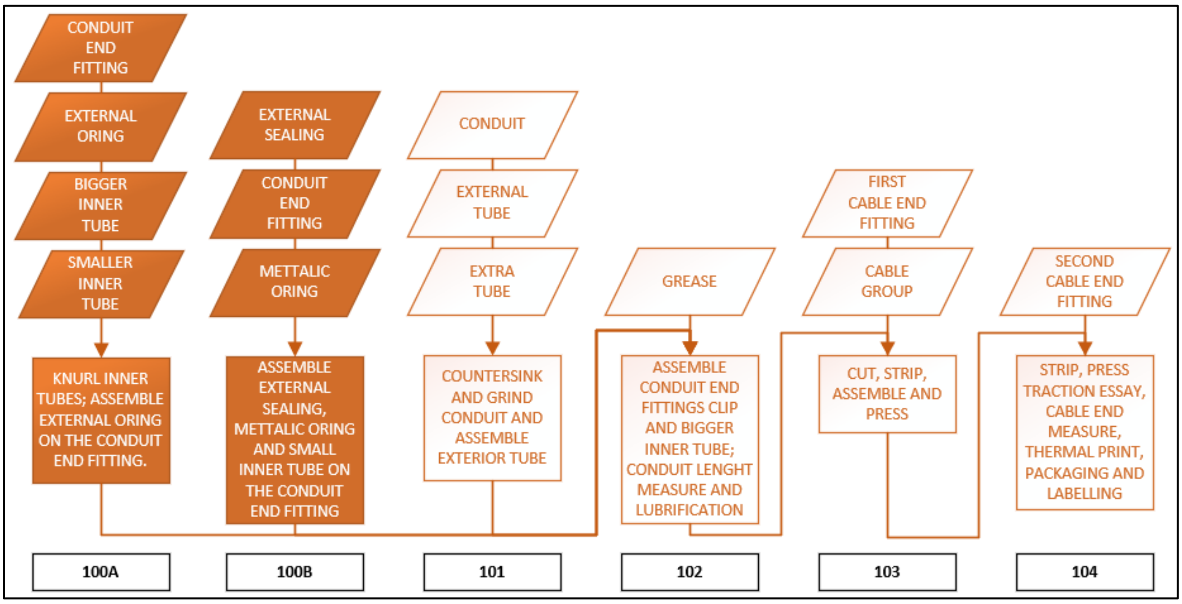


Figure 55 - Diagram with main operations of the workstations 100A and 100B

In the workstation 100A, the operator grabs a smaller and a bigger inner tube, positioning them in the respective knurl machine, and pressing, in order to activate the automatic knurl operation. Then, the operator assembles an O'ring on the conduit end fitting and places the subgroup in a container (Figure 56).

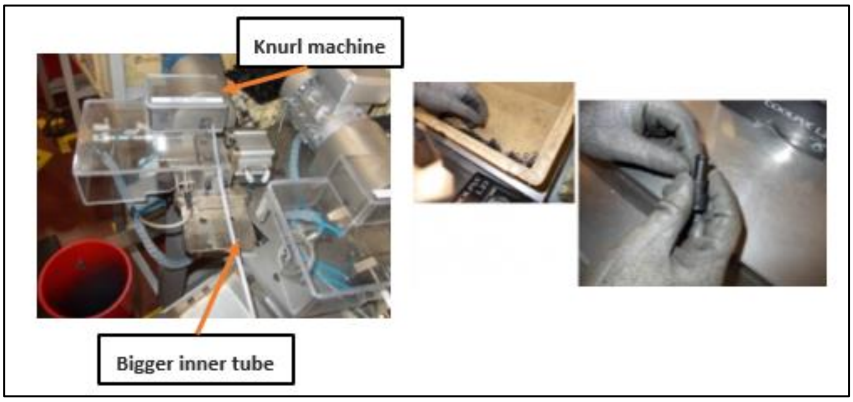


Figure 56 - Knurl inner tubes operation (left) and assembling of O'ring on the conduit end fitting (right)

In the workstation 100B, the operator places a conduit end fitting with a sealing on the dispositive that inserts it with the help of the bimanual pushbutton mechanism. After that, equipment assembles a metallic O'ring on the conduit end fitting. Further, the conduit end fitting is placed on a device that validates the position of the metallic O'ring (Figure 57).

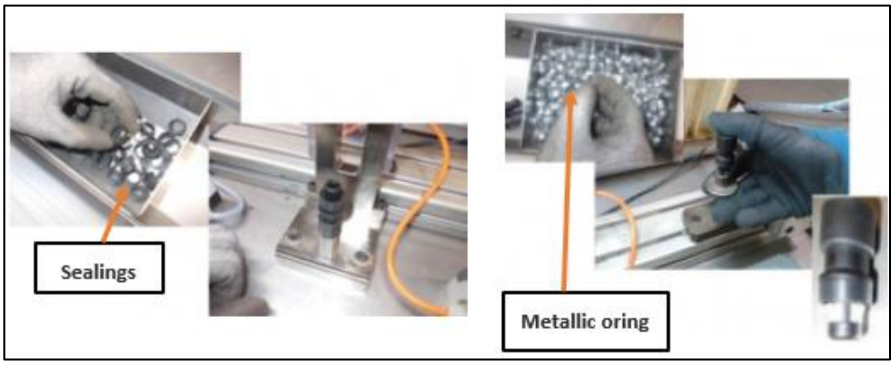


Figure 57 - Introduction of the sealing on the conduit end fitting (left) and assemble of metallic O'ring on the conduit end fitting (right)

Then, a knurled inner tube is assembled on the conduit end fitting and it is after introduced on a dispositive to perform a final validation (Figure 58).

Figure 58 - Assemble of knurled inner tube on the conduit end fitting (left) and final validation of (right)

<u>Workstation 101</u>

In the diagram in Figure 59, it is highlighted the operations completed in the workstation 101.

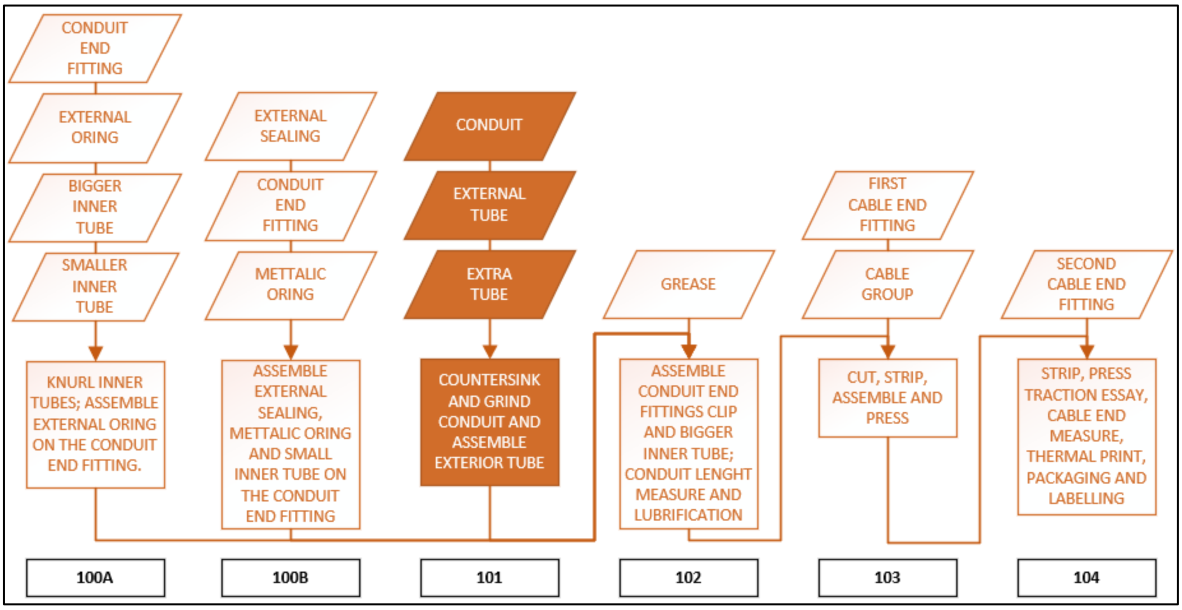


Figure 59 - Diagram with main operations of the workstation 101

In this workstation, the operator countersinks and grinds two conduits on the respective equipment and on both sides. After these operations, both conduits are placed on the feeder of external tube assembling equipment. The operator then grabs an external tube and places it in the position of the jig, triggering both push buttons at the same time (Figure 60).

Figure 60 - Grind and countersink operation (left) and introduction of external tube on the jig (right)

In the last operation, the operator introduces a conduit subgroup and an extra tube, pointing this last into the conduit subgroup. Then, a dispositive assembles both elements (Figure 61).

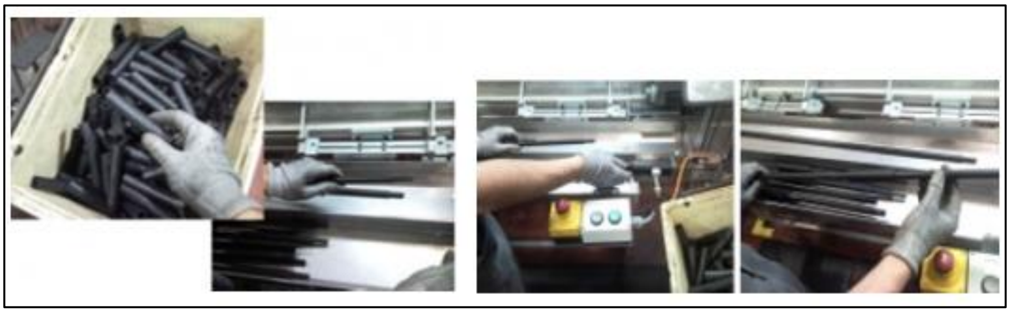


Figure 61 - Operator grabbing the extra tube (left) and insert of conduit group on the dispositive to position the extra tube (right)

Workstation 102

In the diagram in Figure 62, it is highlighted the operations carried out in the workstation 102.

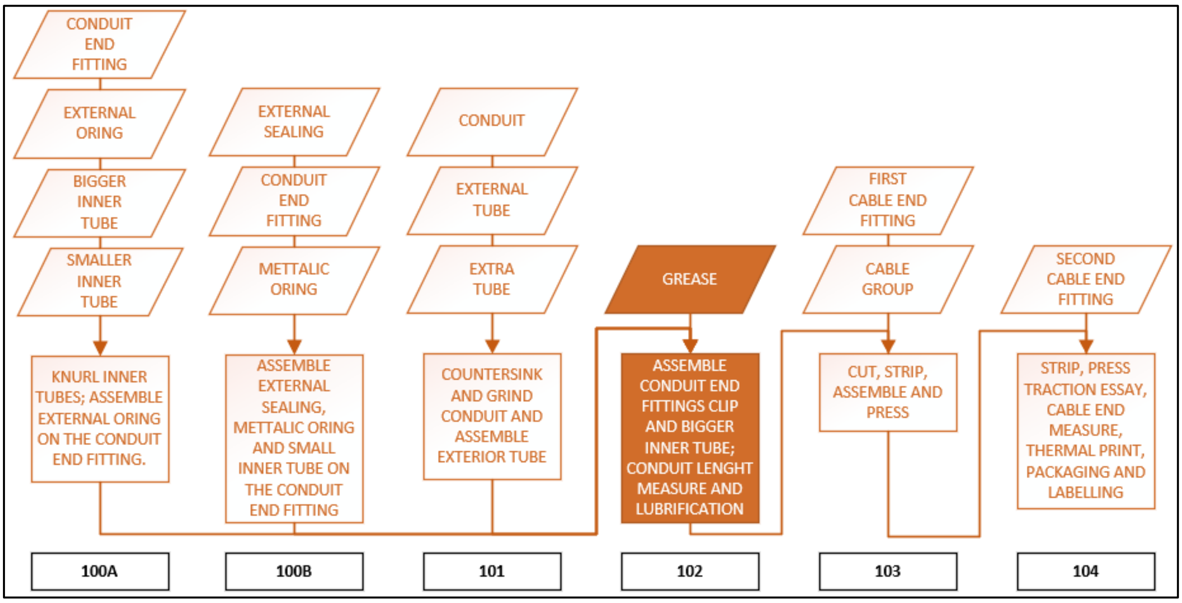


Figure 62 - Diagram with main operations of the workstation 102

Initially, the operator grabs a bigger inner tube (from one to five units at once) and assembles it into the conduit, validating it further on a dispositive. After this operation, the conduit end fitting subgroup is introduced inside the bigger inner tube until the edge of the conduit subgroup (Figure 63).

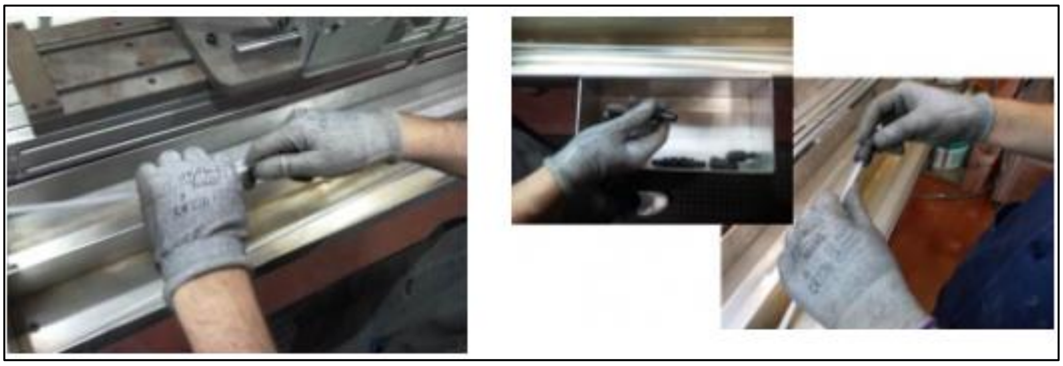


Figure 63 - Assembly of the inner tube on the conduit (left) and insert of the conduit end fitting subgroup into the bigger inner tube (right)

Then, the operator positions the conduit and the conduit end fitting subgroup on the jig, press the pushbutton and starts the knurl test, the assembly of the conduit end fittings clip, measures the length of the conduit and lubricates (Figure 64).

Figure 64 – Assemble of the conduit/conduit end fitting subgroup on the jig (left) and pressing the pushbutton (right)

Workstation 103

In the diagram in Figure 65, it is highlighted the operations performed in the workstation 103.

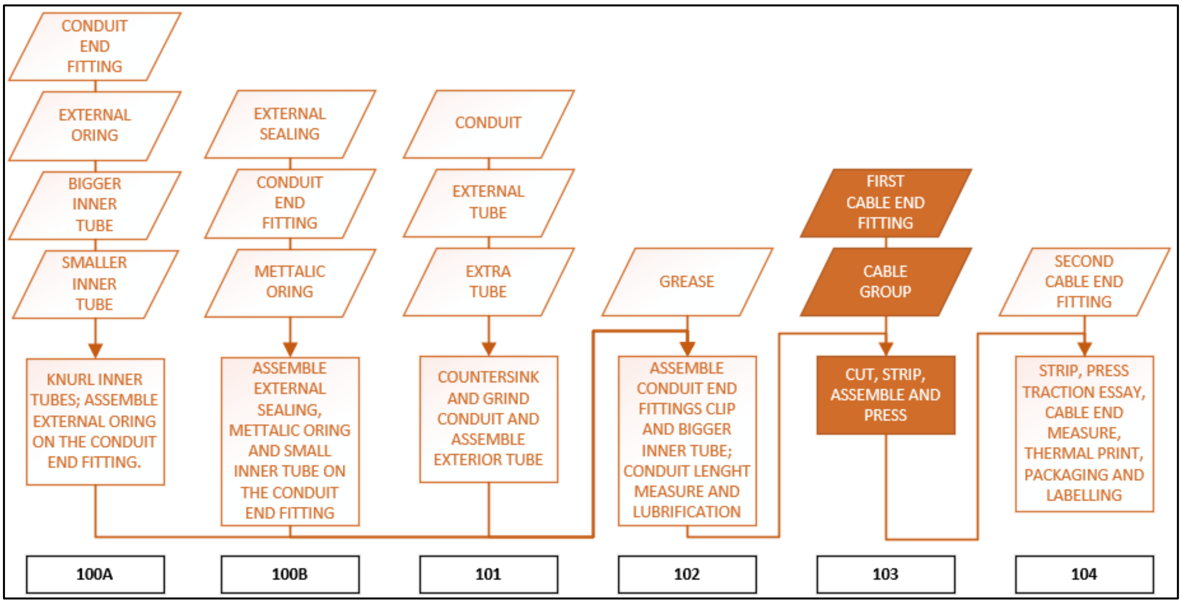


Figure 65 - Diagram with main operations of the workstation 103

In this workstation, the operator starts to grab a conduit subgroup and position it on the jig, where the cable is introduced and is automatically stripped. Then, the operator slightly pulls the cable from the conduit subgroup, inserts the first cable end fitting and introduces the cable and the end fitting on the radial press, extracting it after a press signal (Figure 66).

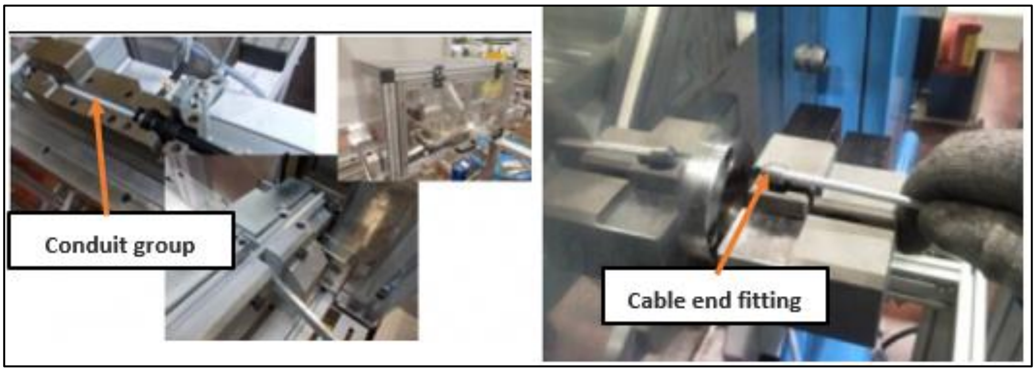


Figure 66 - Introduction of the conduit group on the jig (left) and cable end fitting on the radial press (right)

<u>Workstation 104</u>

In the diagram in Figure 67, it is highlighted the operations performed in the workstation 104.

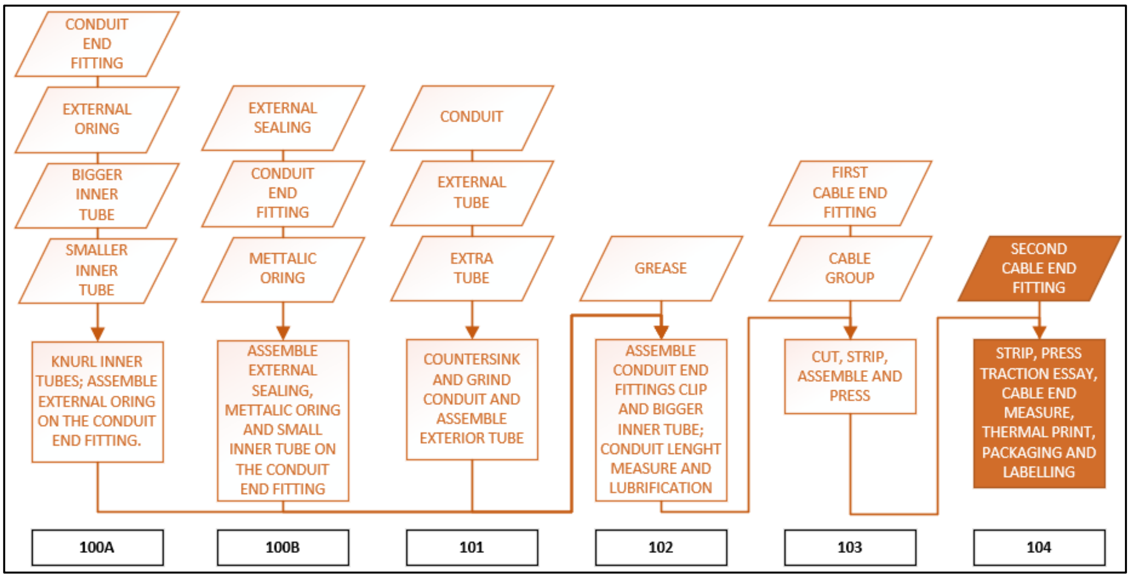


Figure 67 - Diagram with main operations of the workstation 104

Initially, the operator introduces the cable on a dispositive that strips the coating and then inserts the second cable end fitting up to face (Figure 68).

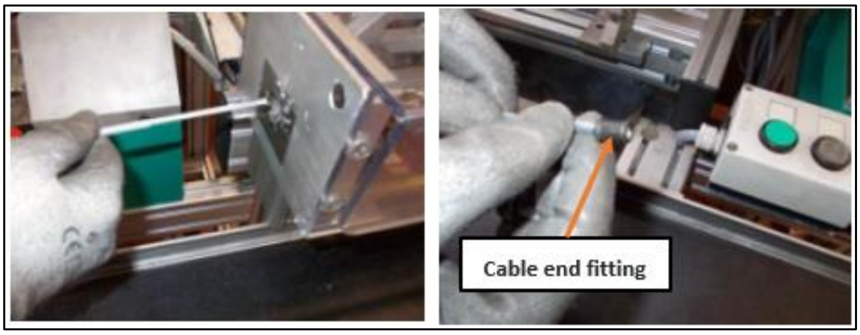


Figure 68 - Operator introducing the cable on a strip dispositive (left) and introducing the cable end fitting (right)

After this process, the operator positions the cable subgroup on the measure jig and on the essay jig and, if everything is OK, it is carried out the thermography test for final product validation. Then, the operator takes the cables from the finished product container (fifteen cables at a time) by grabbing them through the second cable end fitting and packs them according to the respective packaging instruction (Figure 69).

Figure 69 - Operator inserting the cable subgroup on the measurement jig (left) and on the essay jig (right)

3.3.4.6 Time measurement of the different operations and line balancing

It was realized a time measurement study for each operation carried out in the different working stations of the '*PSA Travão'* assembly line. The results are presented in Table 31. As workstations 103 and 104 include operations with very short duration and that could induce measurement error, it was measured the whole time consumed by this set of operations instead of measured in an individual fashion.

Table 31 – Time measurement for the different operations carried out in the different working centers of ‘PSA Travão’ (before)

WS	Necessary quantity to produce	Operating time (sec)	Operation No.	Operation description	Operation time (sec)
100	4260	55800	1	Assemble sealing, metallic O’ring, and smaller inner tube	9.58
100	4260	55800	2	Supply workstation 102 with assembled conduit subgroup	0.28
100	4260	55800	3	Knurl bigger and smaller inner tube	4.28
100	4260	55800	4	Supply workstation 102 with bigger inner tube	0.29
101	4260	55800	1	Countersink and grind two conduits on both sides	4.29
101	4260	55800	2	Assemble exterior tube	6.44
101	4260	55800	3	Supply container with conduits	0.93
101	4260	55800	4	Supply assemble equipment with countersink and ground conduits	0.35
101	4260	55800	5	Supply workstation with exterior tube	0.31
102	4260	55800	1	Assemble bigger inner tube on the conduit	4.93
102	4260	55800	2	Assemble first conduit end fitting on the conduit	2.34
102	4260	55800	3	Validation of the knurled inner tube	1.87
102	4260	55800	4	Assemble second conduit end fitting on the conduit	1.31
102	4260	55800	5	Position cable on the jig and embed cable end fitting	3.45
102	4260	55800	6	Supply conduit end fitting from the container	5.1
102	4260	55800	7	Supply workstation 103	0.22
103	4260	55800	1	Insert cable and embed first conduit end fitting	13.80
104	4260	55800	1	Strip cable insert second cable fitting and embed; Position first cable end fitting, essay, and thermography.	11.27
104	4260	55800	2	Packaging	2.39

The necessary quantity to produce comes from the weekly volumes of 2018, for the projects produced in this assembly line, and according to the number of the days per week that the assembly line works (in the case of this assembly line, it works 5 days per week). Also, the operating time comes from the number of shifts that the assembly line works per day (in the case of this assembly line, if works 3 shifts per day, in average). These parameters allow to calculate the Takt Time, which represents the number of seconds needed to produce a final product, in order to satisfy the customer demand.

The correspondent parameters and the value of the customer Takt Time calculated are presented in Table 32.

In terms of operation time*, Fico Cables* works with shifts of eight hours. Although, for calculation purposes, it is discounted an allowed break of fifteen minutes for a quick meeting at the beginning of the shift and to rest.

Table 32 - Calculation of takt time according to 2018 volumes

Parameter	Value
Weekly volumes (units)	21 300
Number of work days per week	5
Necessary quantity per day (units)	**4 260**
Number of shifts per day	2
Number of hours per shift	7.75
Operation time (seconds)	**55 800**
TAKT TIME (seconds)	**13.10**

There were ten different observations for this time measurement and, in order to reach a correct longest and shortest cycle time, it was rejected observations with erratic values. This means that observations do not include operations with a time value that deviates excessively from the average value measured. Summarizing, the total cycle times that were obtained for the different workstations, as well as the longest cycle time and the corresponding fluctuation are presented in Table 33.

Table 33 – Cycle times for each workstation and corresponding fluctuation to the takt time

	WS 100	WS 101	WS 102	WS 103	WS 104	GLOBAL
Operation No. 1 (sec)	9.58	4.29	4.93	13.80	11.27	-
Operation No. 2 (sec)	0.28	6.44	2.34	-	2.39	-
Operation No. 3 (sec)	4.28	0.93	1.87	-	-	-
Operation No. 4 (sec)	0.29	0.35	1.31	-	-	-
Operation No. 5 (sec)	-	0.31	3.45	-	-	-
Operation No. 6 (sec)	-	-	5.10	-	-	-
Operation No. 7 (sec)	-	-	0.22	-	-	-
Total cycle time (sec)	**14.44**	**12.32**	**19.22**	**13.80**	**13.66**	**73.44**
Longest cycle time (sec)	19.88	13.87	24.83	15.73	16.10	90.41
Takt Time (sec)	**13.10**	**13.10**	**13.10**	**13.10**	**13.10**	**65.50**
Fluctuation (Sec)	5.44	1.55	5.61	1.93	2.44	16.97
Fluctuation ratio	**37.6%**	**12.6%**	**29.2%**	**14.0%**	**17.9%**	**23.1%**

Although it was realized during the time measurement study, it was confirmed by the data that, with exception for the workstation 101 (12.32 sec), all workstations present a cycle time above the takt time (13.10 sec), with the workstation 102 being clearly the bottleneck of the assembly line (19.22 sec) as it requires the biggest cycle time. In this way, these are the workstations that must primarily be improved in terms of equipment and/or flow, in order to satisfy the required demand of the client.

This data allowed to evaluate the corresponding line balance of the different workstations and to visually see the comparison of cycle times relative to the takt time, and how much the cycle time varies (Figure 70).

It is visible by the line balancing graph that the workstation 100, 102, 103 and 104 presents a cycle time above the takt time and it is necessary to explore improvement opportunities and to eliminate all kind of wastes detected in order to comply with takt time required. It is also noticeable that workstations 100 and 102 has high variabilities, that are caused by excessive movements and transports performed by the operators, to deliver subgroups for another workstation or to pick components from a distant rack. Reducing this variability will allow getting a bigger output and to have lower performance losses.

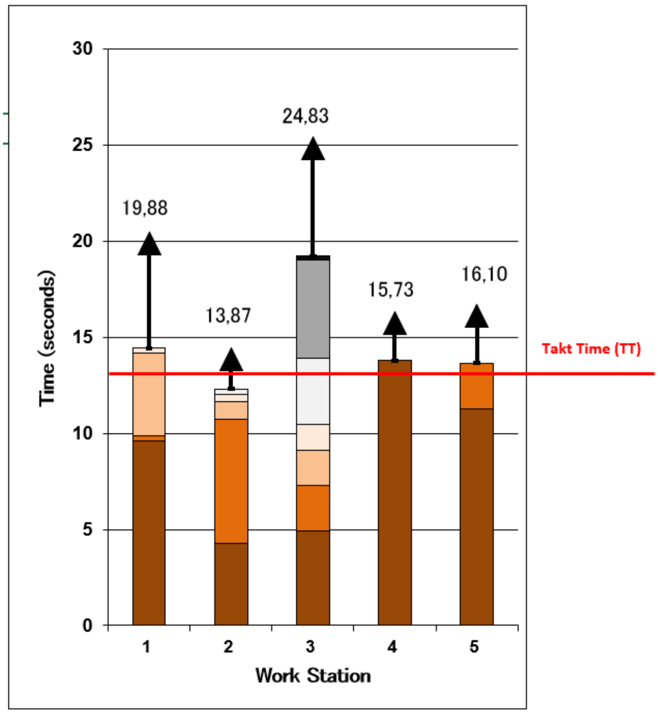


Figure 70 – Line balancing of the different workstation of the assembly line 'PSA Travão' (before)

Ideally, the reduced/eliminated wastes would allow to balance the workstations and to eliminate one of them, but, in this case, there is not enough yield to do that. In a future stage, with a measurement of new cycle times and the elimination of other wastes identified, it could be possible.

In Table 34 it is presented the corresponding line balance efficiency.

Table 34 - Line balance efficiency (before)

	Workstation					
	WS 100	**WS 101**	**WS 102**	**WS 103**	**WS 104**	**GLOBAL**
Line Balancing Efficiency	89.75%	94.05%	53.28%	94.66%	95.73%	**85.49%**

3.3.4.7 Possible improvements identified in the different workstations

In order to eliminate wastes and "gain" cycle time on the different workstations, it was defined as a set of improvement actions which are further summarized.

Workstation 100A/100B

Table 35 – Improvements/wastes identified on the workstation 100A/100B

No.	Problem/Waste observed	Improvement action defined
1	Assembly workstation (100 A/B) and supply workstation (102) are too far from each other. The operator wastes about 14 seconds with this movement.	Remove "add-ins" of the workstation 100A/100B in order to shorten it and could be possible to modify the existent layout, bringing this workstation closer to the workstation 102.
2	Equipment that assembles the metallic O'ring on the conduit end fitting does not complete the assembling operation. Some operators need to assemble it manually, causing the risk of overstretching the metallic O'ring.	Verify and repair the metallic O'ring assembly equipment.
3	Operator needs to successively perform up/down movements to grab the bigger inner tubes.	Relocate and adapt the bigger inner tube stock container.
4	The operators have difficulties in assembling the rubber below on the conduit end fitting due to the lack of lubrication.	Introduce the use of grease for the assembling operation of the rubber bellow on the conduit end fitting.
5	Occupation of the shop floor and workstation side area to store component containers, as there is not enough space on the existent rack. In addition, as a result for the inexistent of identification of each storing space, operators spend an excessive time searching for the needed components.	Optimize the area to store the components that directly supply this workstation and for the subgroups produced on it. Identify each storing space, assuring that each component has just one possible location to be stored.

Workstation 101

Table 36 - Improvements/wastes identified in the workstation 101

No.	Problem/Waste observed	Improvement action defined
6	The operator needs to constantly turn and transport the conduits between the grind/countersink equipment and the exterior tubes assemble equipment.	Relocate grind/countersink equipment.
7	The operator spends excessive time to find the exterior tubes box of the needed reference as this stock area is hardly accessible and lacks organization. This obligates operators to accumulate boxes close to them, occupying the shop floor area.	Organize the exterior tubes stock area.
8	Other components that directly supply this workstation, as small exterior tubes, do not have a defined stock area and occupies the shop floor area.	Define a stock area for the small exterior tube's containers.

Workstation 102

Table 37 - Improvements/wastes identified in the workstation 102

No.	Problem/Waste observed	Improvement action defined
9	The operator frequently needs to rotate 180° in order to collect the bigger inner tubes and, sometimes, it was verified that he/she needs to walk to the workstation 100.	Create a stock zone, next to the operator, to store the knurled bigger inner tubes, allowing to do minimum effort possible to reach them.
10	It is not defined as a stock zone for the smaller inner tubes.	Create and identify a stock zone for the smaller inner tubes.

Workstation 104

Table 38 - Improvements/wastes identified in the workstation 103 and 104

No.	Problem/Waste observed	Improvement action defined
11	It was visible that the operator of the workstation 104 spends excessive time organizing the containers to package the final product.	Define an operator to assist in this packaging operation, assuring that the operator of the workstation 104 spends the minimum time possible.

3.3.4.8 Implementation of the improvement actions defined

Workstation 100A/100B

- ***Improvement action no. 1**: Layout modification - Remove "add-ins" of the workstation 100A/100B and bring it closer to the workstation 102*

A movement waste was identified where the operator needed to transfer the conduit end fittings (after the assembling operations are performed on the workstation 100A/B) to the workstation 102, where it is further assembled with the bigger inner tube and the conduit group. It was measured that the operator takes about 14 seconds to perform this supply operation and that it represents 28 seconds per 100 cables produced.

As a solution for this unnecessary movement, it was defined to re-locate the workstation 100A/B in order to place it closer to the workstation 102. However, to do so, it was verified that the "add-ins" of the workstation 100 needed to be removed as well as adapt the necessary equipment in the main structure.

The ideal layout for this assembly line would be a *Product or Line Layout*, as all the products produced in this assembly are very similar and because it is intended to produce in larger quantities. Also, using a layout model like this would allow having less WIP and movements by materials and operators. For reasons of available shop floor area, it was not possible to adopt this layout.

Using the same layout model, it was designed some modifications in terms of the location of the workstations 100A/B, 101 and 102. These modifications allow having lower distances for direct supply flows.

After evaluating that the solution was suitable, with sufficient shop floor area to do these layout modifications, the maintenance team could perform the structure modifications on the workstation 100A/B, removing the respective “add-ins” on both sides. These complements included, on the left side, both knurl equipment and, on the right side, the validation jig equipment (Figure 71).

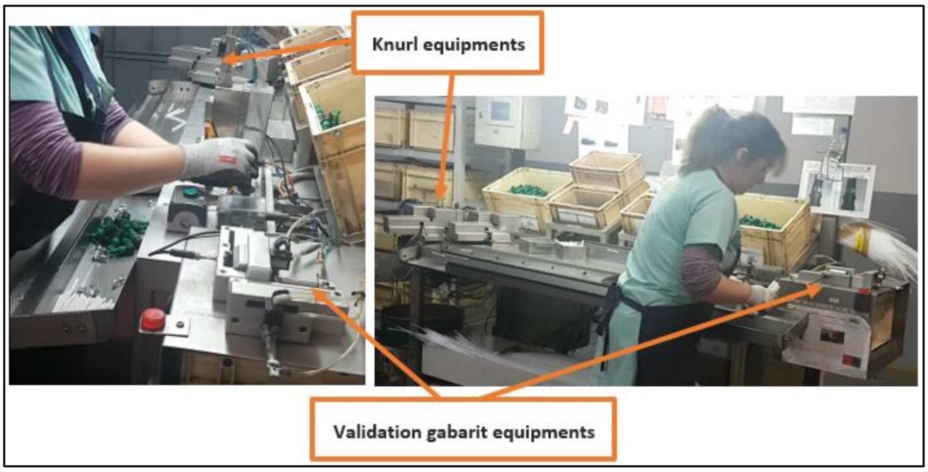


Figure 71 - Workstation with “add-ins” for knurl and jig validation equipment (before)

The final structure of the workstation 100A/100B is visible in Figure 72.

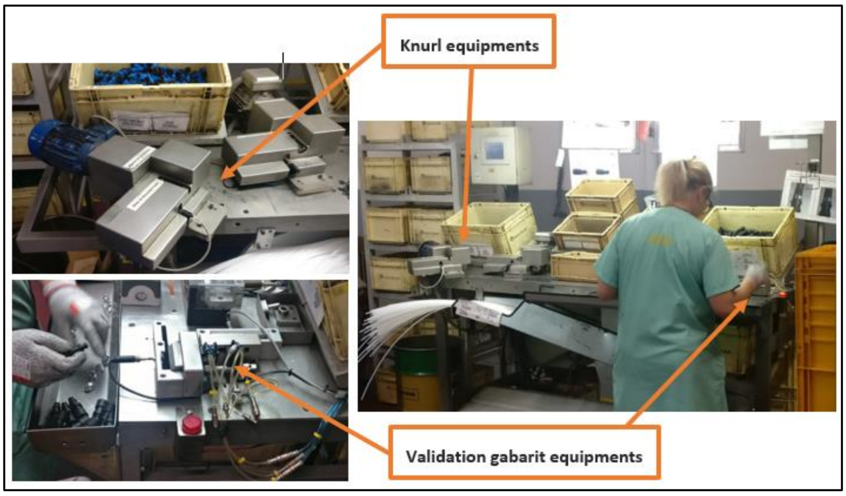


Figure 72 – Removed “add-ins” removed and knurl/jig validation equipment adapted in the main structure (after)

The final layout is represented in Figure 73.

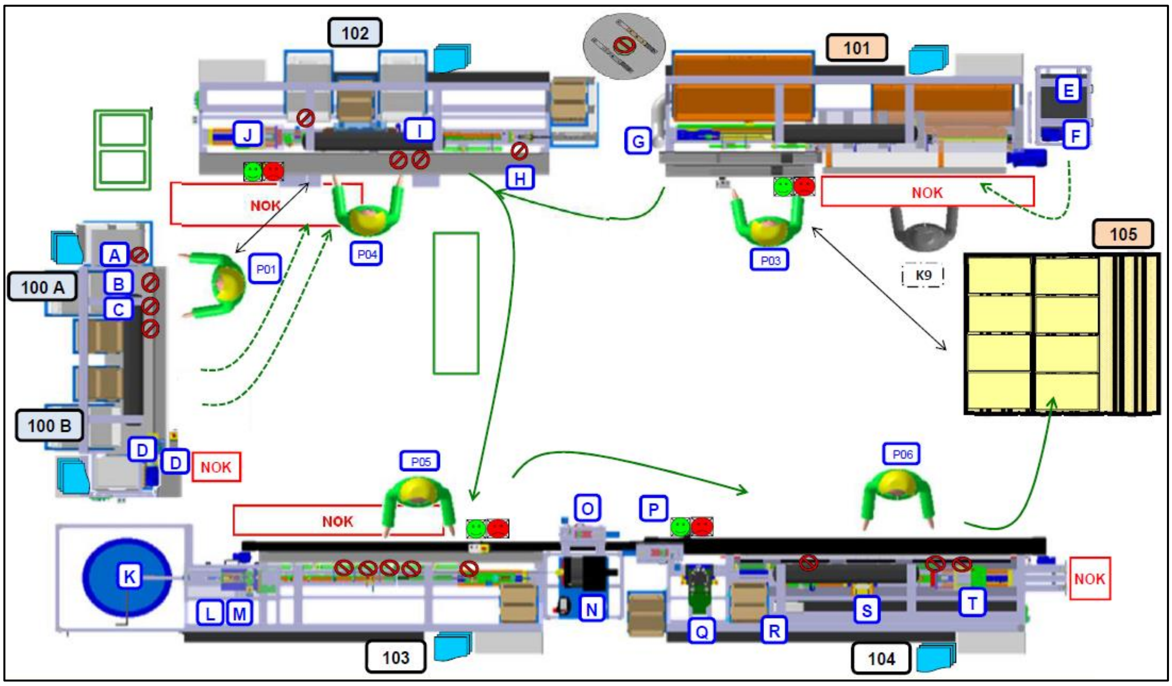


Figure 73 - Final layout of the *PSA Travão* assembly line

- ***Improvement action no. 2**: Verify and repair the metallic O'ring assembly equipment*

Different operators, from different shifts, claimed that the equipment that assembles the metallic O'ring on the conduit end fitting does not always work properly. Sometimes it was verified that the metallic O'ring was not completely assembled or was not assembled at all. This led some operators to assemble it manually, causing sometimes a slack on the assemble, that inclusively was detected by the client and resulted in a complaint. In order to solve this problem, both assemble equipment was fixed by the maintenance team by removing the inherent slack of the equipment and allowing to have a bigger stroke of actuation and then complete the assembling operation (Figure 74).

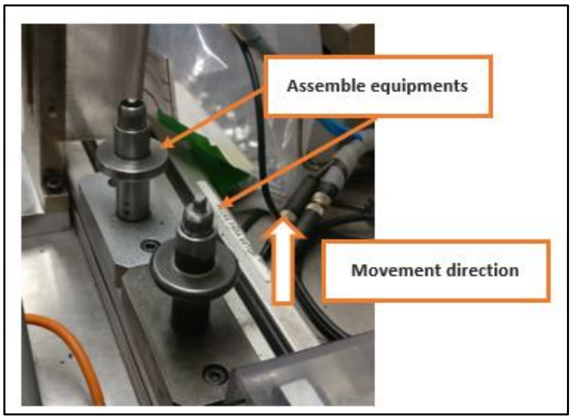


Figure 74 - Metallic o'ring assemble equipment

- ***Improvement action no. 3****: Relocate and adapt the bigger inner tube stock container*

Regarding the location of the bigger inner tube stock container, it was verified that the operator needed to bend down in order to pick the maximum number of bigger inner tubes possible to grab with one hand. For ergonomic questions, this successive up and down movements are not suitable for the operator who gets tired quicker and increases the operations time.

In order to improve this situation, the container was re-located and the "picking zone" of the bigger tubes are just next to the corresponding knurl equipment, leading that the operator no longer needs to perform special movements to grab the material.

The corresponding previous and after the situation is represented in Figure 75.

Figure 75 - Previous and after bigger inner tube container location

Also, it was maximized the capacity of the new bigger inner tube container, in order to could store a complete supply batch and do not have the necessity to supply it so often. As this new container is tilted, in order to allow the "picking" operation next to the knurl equipment, it was added a shaped handle allowing adapt the depth of the stock container according to the size of the bigger inner tube that is being used (Figure 76).

Figure 76 - Bigger inner tube stock container capacity maximized (left) and shape handle to adapt the depth of the container (right)

- ***Improvement action no. 4****: Introduce the use of grease for the assembling operation of the rubber bellow on the conduit end fitting*

For some production references, a rubber bellow is assembled on one of the conduit end fittings. However, the ergonomic conditions for this assemble operation are not favorable as the both surfaces are not lubricated, and the operators spend too much time completing this assembly operation.

In order to solve this problem, it was introduced as a standard and authorized the use of grease for the assemble operation, after evaluating that it does not compromise the quality of the product and that not introduces risk to get customer complaints, facilitating the execution of this operation and allowing to complete it in a shorter time as well as to reduce the fatigue for the operators (Figure 77).

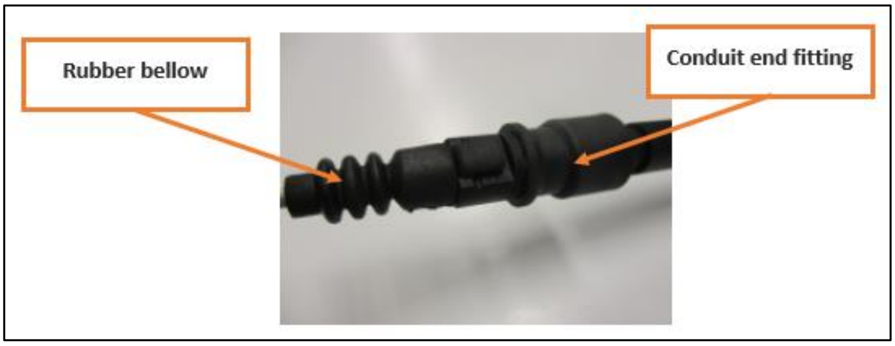


Figure 77 - Rubber bellow and conduit end fitting assembled

- ***Improvement action no. 5****: Organize the stock of the components and conduit end fitting subgroup rack*

Initially, a single rack was in the back of the workstation 100A/B to store different components as conduit end fittings, O'rings, and rubber bellows, that are purchased components and that are directly used in this workstation. The conduit end fitting subgroups, which are also assembled in this workstation, was also stored in the same rack. For logical reasons, there was not enough space to store all these different components/subgroups produced and, for this reason, many boxes and containers were placed over the shop floor and on other zones along the workstation, causing circulation issues and making it difficult for operators to find the necessary material when needed.

The previous situation of this stock organization, as well as some material on the shop floor, is visible in Figure 78.

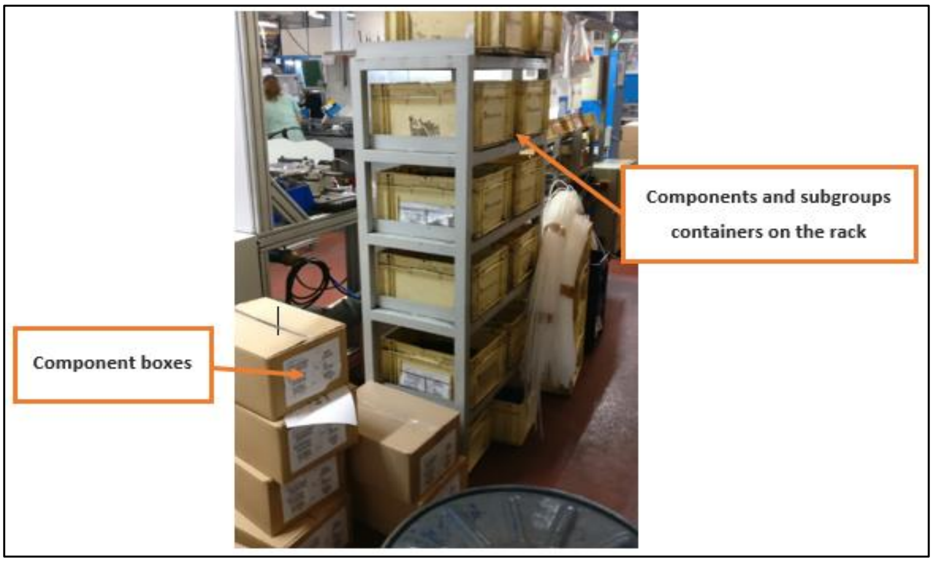


Figure 78 - Stock organization for components and conduit end fitting subgroups of workstation 100A/B (Before)

The existent rack was adopted to store some components that directly supply the workstation 100A/B, including the different conduit end fittings and the rubber bellow. It was defined one store space by each component and all of them were properly identified, preventing to coexist two spaces for the same component. The modified components rack and the corresponding designed layout are visible in Figure 79.

Rubber bellow (11232512 B00)	
Black conduit end fitting (119216539 A00)	Black conduit end fitting (119214922 A00)
Black conduit end fitting (119214923 A00)	Black conduit end fitting (119215315 A00)
Black conduit end fitting K9 (11235397 B00)	Blue conduit end fitting (119214563 B01)
Green conduit end fitting (119215351 B01)	Green conduit end fitting (119215316 B01)
Brown conduit end fitting (119216496 A00)	Light grey conduit end fitting (119216497 A00)

Figure 79 – New workstation 100A/B components rack and corresponding layout (After)

It was necessary to place on the backside of the workstation 100A/B a new and bigger rack in order to allow the storage of the different all the conduit end fitting subgroups, with a specific and exclusive store space for each subgroup, preventing operators to place the containers/boxes on different storage spaces. After identifying the different conduit end fitting subgroups produced for all the production references of the assembly line, it was possible to project the rack layout as visible in Figure 80.

Black conduit end fitting (119214922) + Oring (111912036/39)	**Black conduit end fitting (119214923A01) + Sealing + Mettalic oring (11316747B) + Small inner tube (11630345A01) (111912036)**
Blue conduit end fitting (119214563B01) + Rubber below (111913106)	**Conduit end fitting preto (119216539A00) + Vedante + Clamp (11316747B) + Tubo interior peq. (11636527A00) (111912039)**
Green conduit end fitting (119215351A01) + Oring (111913107)	**Black conduit end fitting (119215315A00) + Metallic oring (11316740A01) + Rubber below (111913106)**
Conduit end fitting azul (119214563B01) + Oring (111912695)	**Green conduit end fitting (119215316A00) + Sealing + Mettalic oring (11316747B) + Tsmall inner tube (11636837A00) (111913107)**
Black conduit end fitting (11235397B00) + Rubber below (111912903/904/905/906)	**Black conduit end fitting (119215315A00) + Clamp (11316740A01) + Rubber below (111912695)**
Blue conduit end fitting (119214563B01) + Oring (111912903)	**Green conduit end fitting (119215351A01) + Oring (111912904)**
Brown conduit end fitting(119216496A00) + Oring (111912905)	**Liight grey conduit end fitting (119216497A00) + Oring (111912906)**

Figure 80 - Layout of the new conduit end fitting subgroups on the workstation 100A/B (After)

The different storage spaces of the conduit end fitting subgroup rack are properly identified, assuring that exists one space for each subgroup and that a subgroup just has one possible division to be stored. The labeling of the different storage spaces (Figure 81) was made through the help of a visual standard, helping the operator to easily and quickly find the subgroup need by the color of the conduit end fitting.

Figure 81 – Conduit end fitting subgroups rack and visual standard used (After)

The space below the workstation 100A/B, that is used to store the sealing and both metallic clamps used on this assembly line was also organized, with the removal of boxes that do not contain one of these two materials. Each store space was specifically labeled with both references of the metallic O'ring and the reference of the sealing (Figure 82).

Figure 82 – Store space under the workstation 100A/B (before and after)

Workstation 101

- ***Improvement action no. 6**: Relocate grind/countersink equipment*

As it was noticeable during the observation of the assembly line, the operator of this workstation needs constantly rotate and to transport the conduits from the grind/countersink equipment to the assemble equipment. The operator moves normally around 15 conduits, which weighs about 3 kg and repeats this transport every 5 minutes. This transport gradually tires the operator, affecting the work pace.

The previous location of this equipment, as well as the movement that the operator needed to perform (red arrow), is shown in Figure 83.

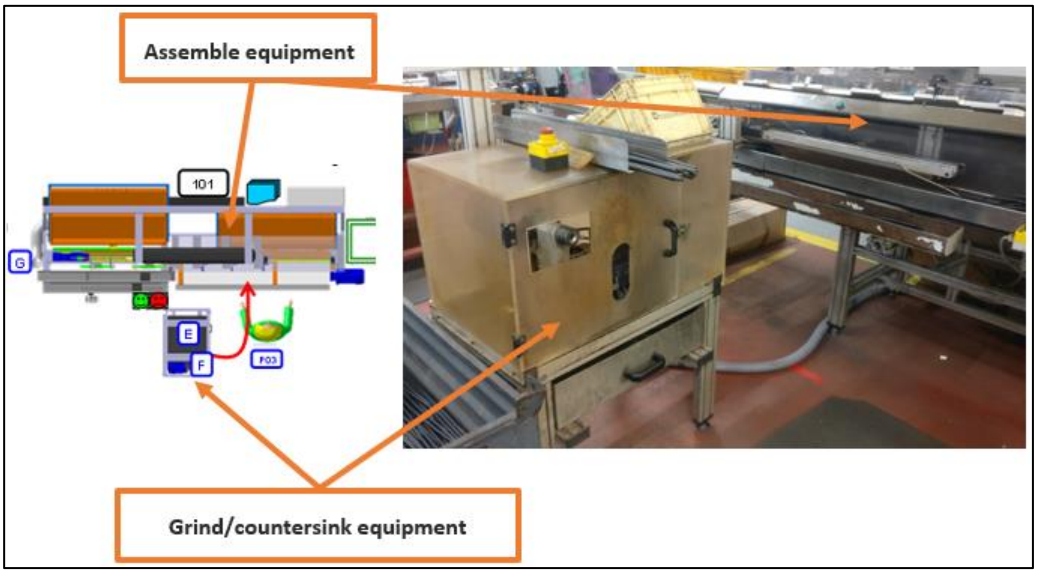


Figure 83 - Location of the grind/countersink equipment (before)

Along with the layout modification of the workstation assembly line, the grind/countersink equipment was placed on the right side of the workstation and, the operator, after finishing the grind and countersink operation, could place the conduit on a gutter of the assembled equipment. As the conduits are long enough to occupy the length of the gutter, the operator could drop them by one side and grab them by the other, minimizing the effort. This way, when underdoing the assembling operation, the operator just needs to grab the conduits one by one and no longer needs to perform the repetitive and frequently effort of transporting a big quantity of conduits. This layout modification is represented in Figure 84.

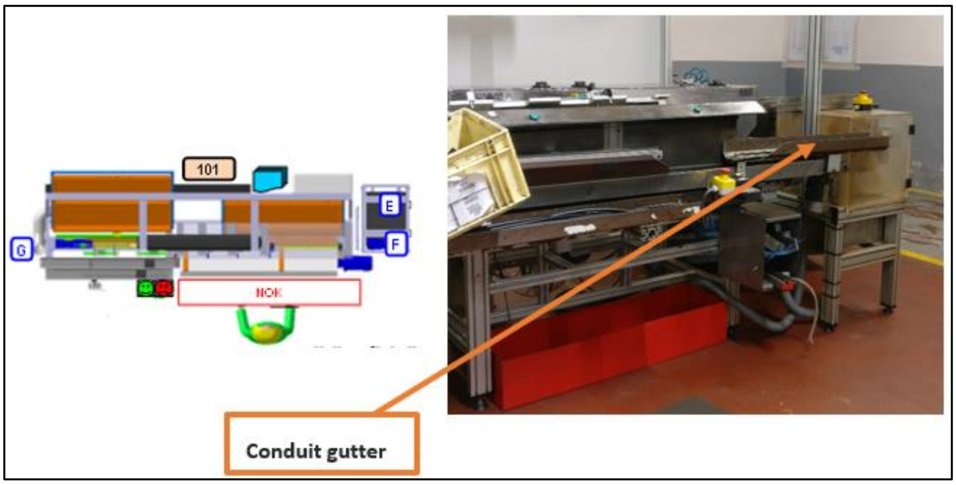


Figure 84 - Location of the grind/countersink equipment and conduit gutter (after)

- ***Improvement action no. 7**: Organize big exterior tubes stock area*

Because there was no defined stock area for this component and given the fact that the exterior tubes box just lasts for a maximum of 2 hours, operators started to accumulate a big quantity of boxes under the workstation and that sometimes reaches the circulation corridor behind the workstation. This situation difficult the access to the area under the workstation, for some setup interventions, limit sometimes the circulation on the zones next to equipment and difficult cleaning operations. Also, some of this area will be necessary for a future improvement opportunity that will be further described. This previous scenario is represented in Figure 85.

Figure 85 – Accumulation of exterior tube boxes under the workstation (before)

The other area where these boxes were store is behind the workstation 104. This area was completely disorganized, as is visible in the Figure 86, with no spaces defined for each reference, boxes stored in poor conditions, which could damage the components, and boxes of obsolete items.

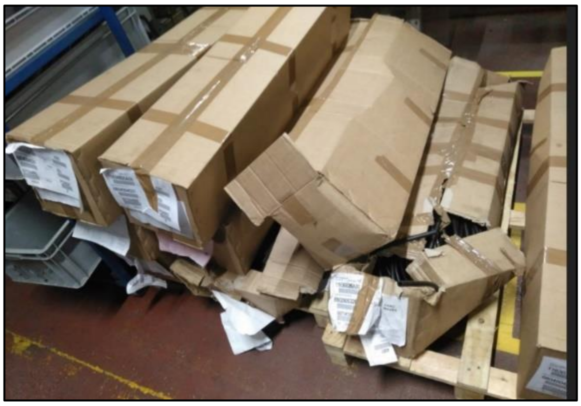


Figure 86 – Big exterior tubes stock zone (before)

In order to maximize the utilization of this stock area and to keep it organized, it was defined the minimum and maximum stocks allowed in this zone. The minimum stock quantity was defined in order to be possible to supply the assembly line supply for a half shift period (4 hours). On the other hand, the maximum stock quantity was established for an entire shift period (eight hours).

In order to organize the stock area zone, it was also necessary to know the different big exterior tubes that are used to produce the different final product. This information is summarized in Table 39.

Table 39 - Big exterior tubes reference according to the final product reference

Final product reference	Exterior tube reference
36 and 39	11630346
695	11634132
106	11636836
107	11636835
903, 904, 905, 906 (K9 project)	11635403

Based on the measured time values presented before, it was possible to calculate the equivalent number of boxes for this minimum and maximum stock periods. It was measured that this assembly line has a cycle time of about 19.22 seconds. In one hour, this represents 187 cables produced. For the K9 project references, as the cable has different significant characteristics relative to the other references (and also a different cycle time), it was used the value of production cadence per hour estimated in the budgeting: 150 cables.

Knowing that every box has 200 exterior tubes, the corresponding number of boxes could be calculated through the following formulas:

$$Number\ of\ boxes = Quantity\ produced\ per\ hour \times \frac{Number\ of\ stock\ hours}{Quantity\ per\ box} \qquad (3)$$

The corresponding calculations for minimum and maximum stocks are summarized in Table 40.

Table 40 - Calculation of the number of big exterior tube boxes associated with the minimum and maximum stock

Final product reference	Big exterior tube reference	Quantity by box	Quantity produced per hour	Min. stock hours	Max. stock hours	Min. stock boxes	Max. stock boxes
36	11630346	200	187	4	8	3.7 ≈ 4	7.5 ≈ 8
39		200					
695	11634132	200					
106	11636836	200					
107	11636835	200					
903	11635403	200	150	4	8	3	6
904		200					
905		200					
906		200					

With the calculation of the equivalent number of boxes relative to the minimum and maximum stock, it was possible to define a storage layout which is represented in Figure 87.

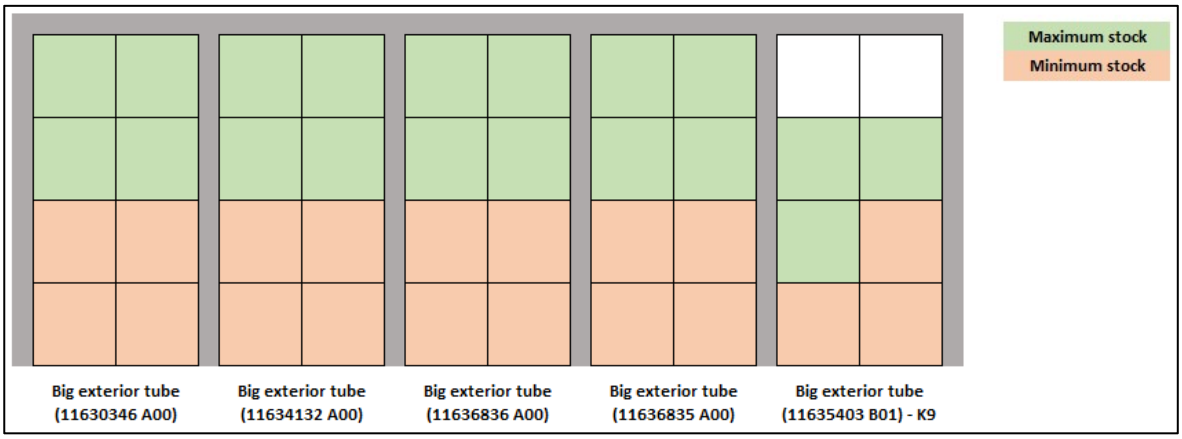


Figure 87 – Big exterior tubes stock zone layout

The implemented structure (Figure 87) has a wire that is setting the height of the maximum stock. Also, a visual standard, as represented on the layout above, was added in order to prevent exceeding the maximum stock or not having the minimum stock defined.

This reorganization of this stock zone allows now the operator to quickly find the needed reference and to have a better view of the available stock and if it is or not necessary to require logistics for material (Figure 88).

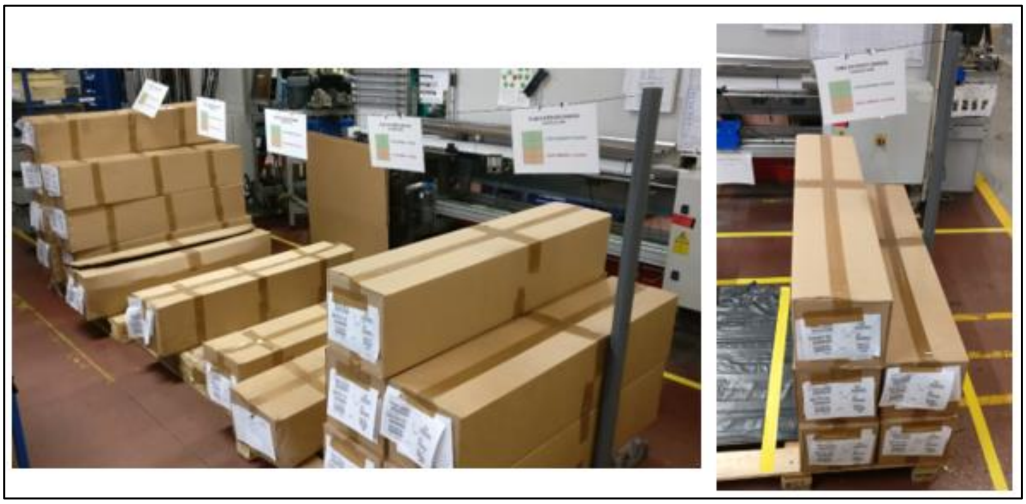


Figure 88 -Big exterior tubes stock zone (after)

- ***Improvement action no. 8**: Define a stock area for the small exterior tubes containers*

There was not a defined stock zone for the small exterior tubes containers, being frequently stored in the backward of the workstation 104 or next to the operator. For this component, it was made the same study as for the big exterior tubes. However, unlike the big exterior tube, this small exterior tube is just used in some of the references that are represented in Table 41.

Table 41 – Small exterior tubes reference according to the final product reference

Final product reference	Small exterior tube reference
36 and 39	11630692
903, 904, 905, 906 (K9 project)	11637030

Following the same conditions as quantity produced per hour and minimum and maximum stock hours, the calculation of the number of boxes needed for each small exterior tube is summarized in Table 42.

Table 42 - Calculation of the number of small exterior tube boxes associated with the minimum and maximum stock

Final product reference	Small exterior tube reference	Quantity by box	Quantity produced per hour	Min. stock hours	Max. stock hours	Min. stock boxes	Max. stock boxes
36	11630692	450	187	4	8	1.87 ≈ 2	3.74 ≈ 4
39		450					
903	11637030	450	150	4	8	1.5 ≈ 2	3
904		450					
905		450					
906		450					

With the equivalent number of stock boxes for each component reference and for the minimum and maximum levels, it was possible to build a layout as represented in Figure 89.

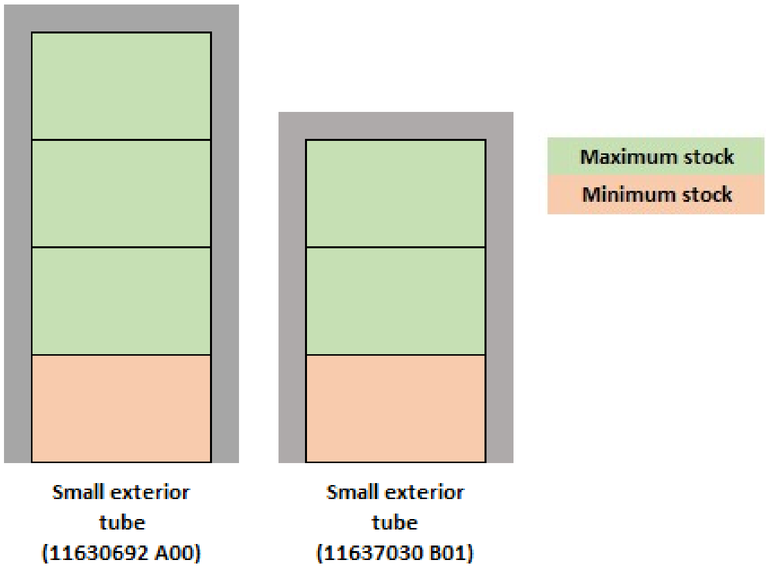


Figure 89 - Small exterior tubes stock zone layout

The consequent implementation of this layout is represented in Figure 90.

Figure 90 – Small exterior tubes stock zone (after)

It was also a visual standard (Figure 91) with the aim to allow to easily control, in a visual way, the stock quantity and if it is necessary to require more material or if there is material in excess.

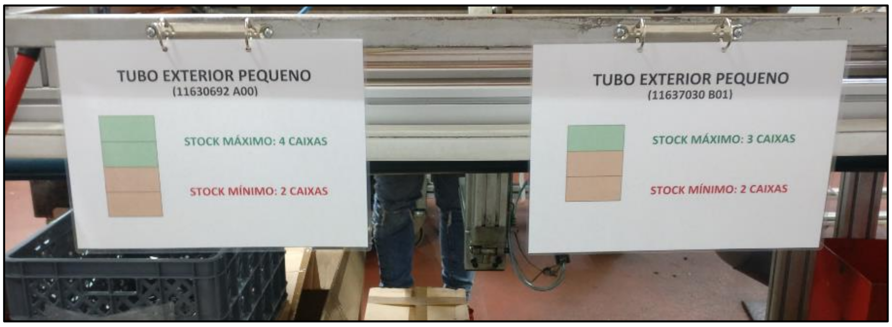


Figure 91 - Visual standard for the small exterior tubes stock zone

Workstation 102

- ***Improvement action no. 9**: Create a stock zone, next to the operator, to store the knurled bigger inner tubes*

It was visible that the operator on the workstation 102 frequently needs to rotate 180° in order to pick the knurled bigger inner tubes that came from the workstation 100A/B, as represented in Figure 92.

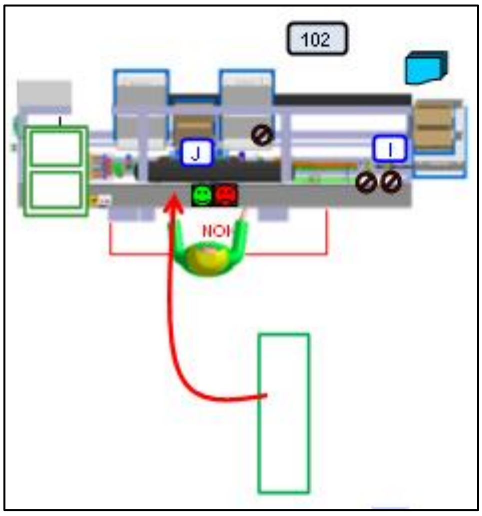


Figure 92 - Description of the movement that the operator needs to perform to pick the knurled big inner tube

As this workstation represents the bottleneck of the assembly line, it is vital to remove all the unnecessary movements performed. The designed solution was to place next to the operator, on both sides of the assembly equipment, a nozzle. This way, the operator does not need to leave the workplace to pick the knurled big inner tubes and, depending on the side of the machine that the operator is working, it is possible to immediately perform the assembly of the bigger inner tubes on the conduits. The application of the nozzle, as well as the location on the workstation, is represented in Figure 93.

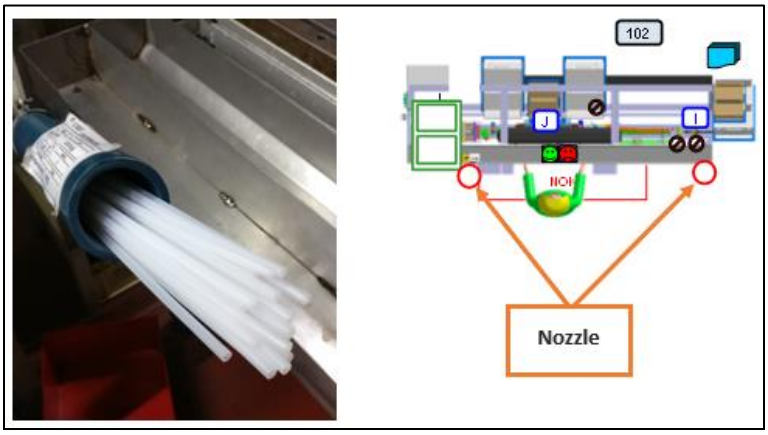


Figure 93 - Nozzle application for big inner tube and location on workstation 102

- ***<u>Improvement action no. 10</u>**<u>: Create and identify a stock zone for the smaller inner tubes.</u>*

This component commonly used to be stored in the backward of the workstation 104 or next to the operator. However, with this zone almost full with the re-arrangement of the bigger exterior tubes, there was the necessity to relocate them and to properly identify them. Again, the same minimum and maximum studies were made, for the same presupposes of 4 hours for minimum and 8 hours for maximum.

This component is just used in the reference 36, 39 and 107, with the following references summarized in Table 43.

Table 43 - Small interior tubes reference according to the final product reference

Final product reference	Small exterior tube reference
36	11630345
39	11636527
903, 904, 905, 906 (K9 project)	11636837

With the same presupposes, as quantity produced per hour and minimum and maximum stock hours, the calculation of the number of boxes needed for each smaller interior tube are summarized in Table 44.

Table 44 - Calculation of the number of smaller interior tube boxes associated with the minimum and maximum stock

Final product reference	Small exterior tube reference	Quantity produced per hour	Min. stock hours	Max. stock hours	Min. stock boxes	Max. stock boxes
36	11630345	187	4	8	0.7 ≈ 1	1.5 ≈ 2
39	11636527	187	4	8	0.7 ≈ 1	1.5 ≈ 2
903, 904, 905 and 906	11636837	150	4	8	0.6 ≈ 1	1.2 ≈ 2

With the equivalent number of stock boxes for each component reference and for the minimum and maximum levels, it was possible to build a layout as represented in Figure 94.

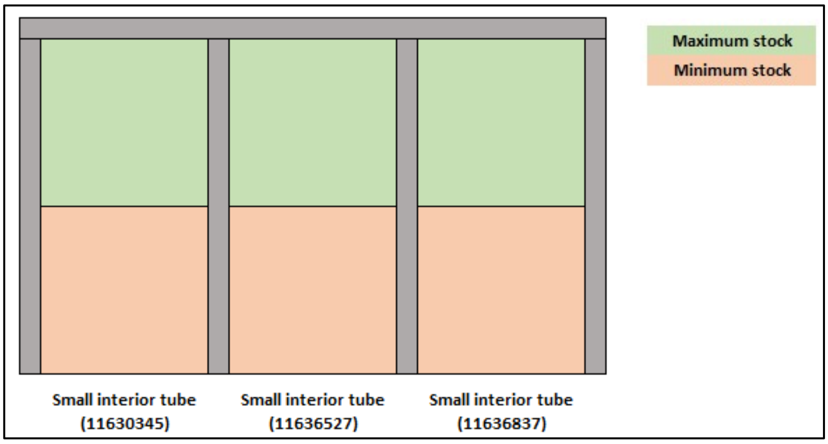


Figure 94 - Small interior tubes stock zone layout

Figure 95 represents the created stock layout for the smaller inner tube component with the corresponding visual help added.

Figure 95 - Small inner tubes stock zone and corresponding visual help added (after)

Workstation 104

- ***Improvement action no. 11:*** *Define an operator to assist in this packaging operation*

In the last workstation of the assembly line, the operator must necessarily open the drawer when a series of a certain quantity of finished cables are produced (it depends from reference to reference, and it can be 12, 15 or 17 cables produced). Then the operator needs to grab the finished cables and place them into the packaging box, closes it and paste the packing label.

As the operator spends too much time in these operations and the cycle time of the corresponding workstation is above the takt time, it was defined that the operator from the workstation 101 (the one with the largest margin in terms of cycle time, 12.32 seconds) started to help with the packaging process. The short distance that separates both workstations to the packaging box was another key factor for this decision.

It was defined that the operator on the workstation 104 opens the drawer and packs the finished cables (green arrow) into the packaging box and the operator from the workstation 101 completes the packaging process, with the closing and the labeling operations (red arrow) (Figure 96).

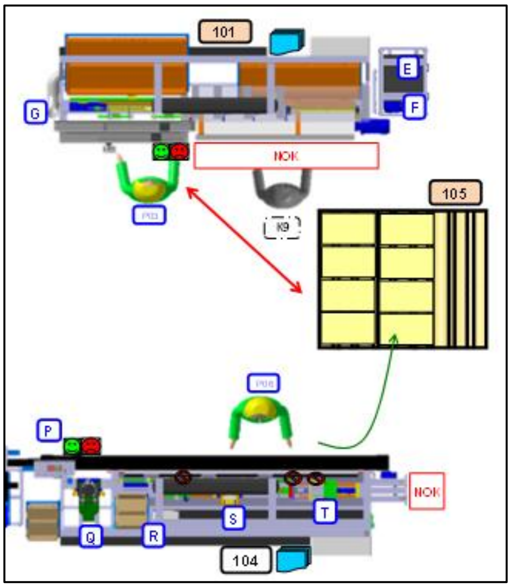


Figure 96 – Co-operation of operators from workstations 101 and 104 for the packaging operation

3.3.4.9 Setups

In terms of setups, it was also identified some improvement opportunities that could be done regarding the organization of tools storage and respective displacement. These improvement opportunities were identified through the observation of different setups, carried out by different adjustment operators. It was visible some difficulties and excessive time wasted finding the necessary tools to perform the setup.

Main setup tools cabinet

For the main setup tools cabinet, located on the back of the workstation 104, it was visible that the adjustment operator spent too much time identifying the necessary tools. This was caused because the cabinet has illogical compartments for each setup tools and that, even so, were not respected. The initial compartment division was based on the reference, but the problem is that there are different types of tools that could be used in different references. The previous division did not allow to have an adequate organization because it created incongruences. If a tool for the reference 106 could also be used for the reference 695, it is not possible to place them in two compartments. However, in another type of tool, it is exclusive to the reference 106, which increased the necessity to divide the cabinet by the type of tool.

The initial compartment division is represented in Figure 97.

Figure 97 – Previous organization of the main setup tools cabinet

With the support of the different adjustment operators, it was made a division by the type of tool and according to the references that could be applicable. The different types of tools are represented in Figure 98.

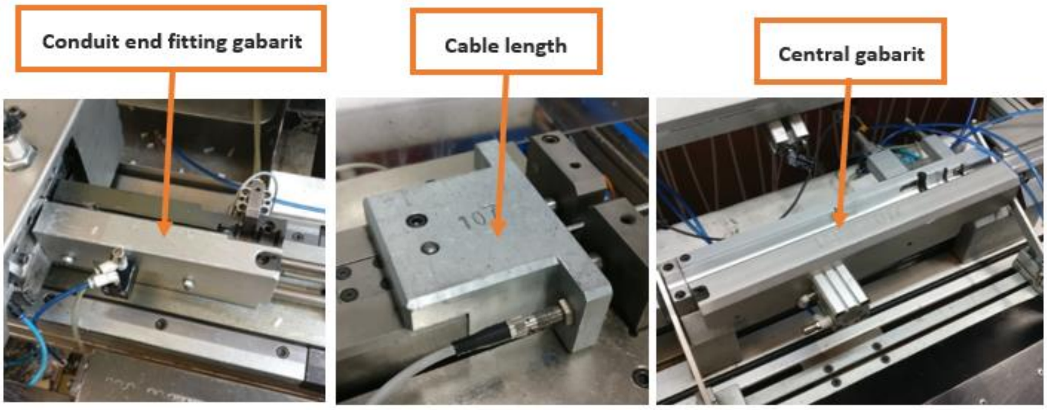


Figure 98 - Main setup tools

The corresponding division by the type of setup tool and the corresponding references that could be used for each one is represented in Figure 99.

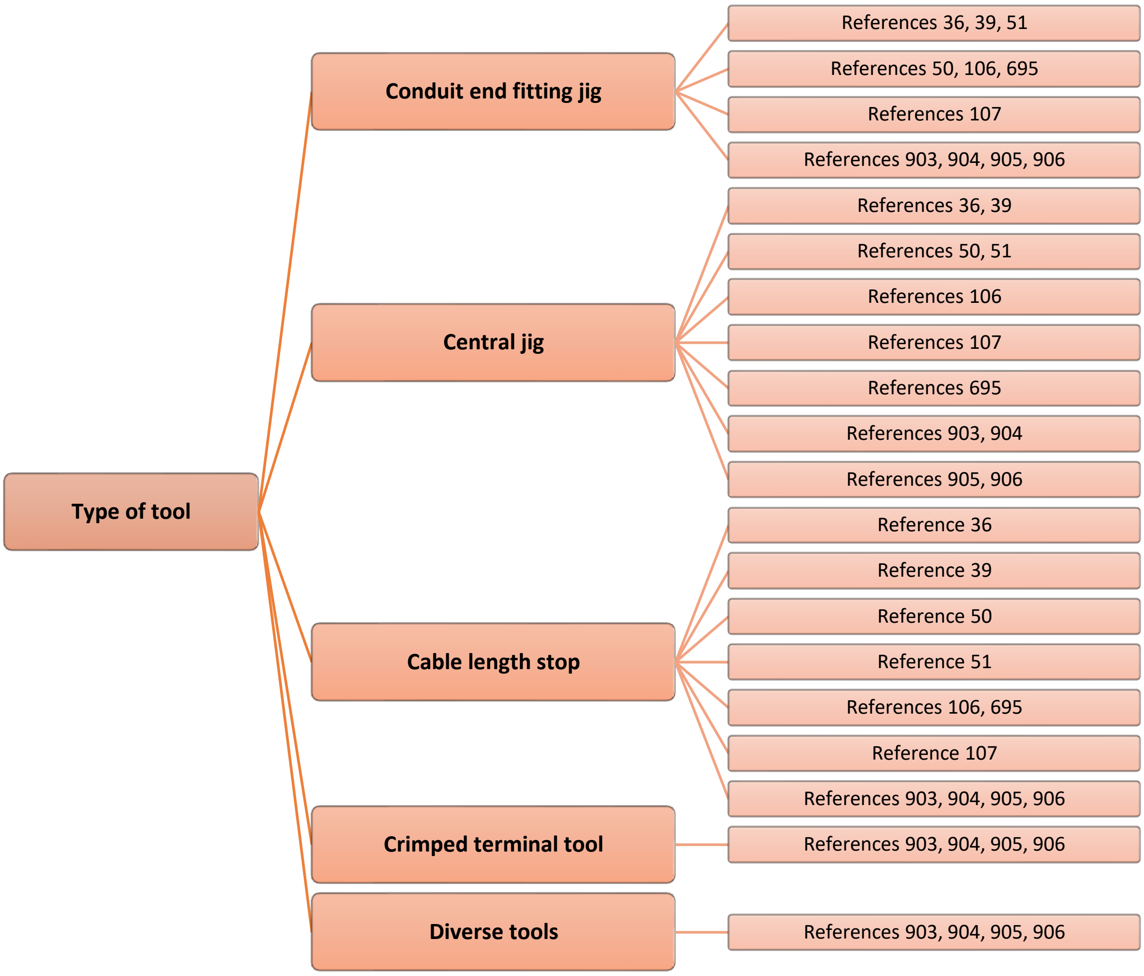


Figure 99 – Division by the type of setup tools and the references that could be used for each one

With this study done it was possible to carry out the necessary changes to the layout of the setup tools cabinet, which is represented in Figure 100.

In addition to the layout modification changes, it was also considered the ergonomic factor related to the weight of the different setup tools and the effort that the adjustment operator needs to perform to remove the tools from the cabinet.

Regarding the ergonomic principles, the heavier tools (for example, the central jig) was placed on the central shelves, allowing the operator to have the less prejudicial effort possible On the other hand, the lighter ones were placed on the lower shelves where the higher effort is made. Finally, the intermedium ones were placed on the upper shelves of the cabinet.

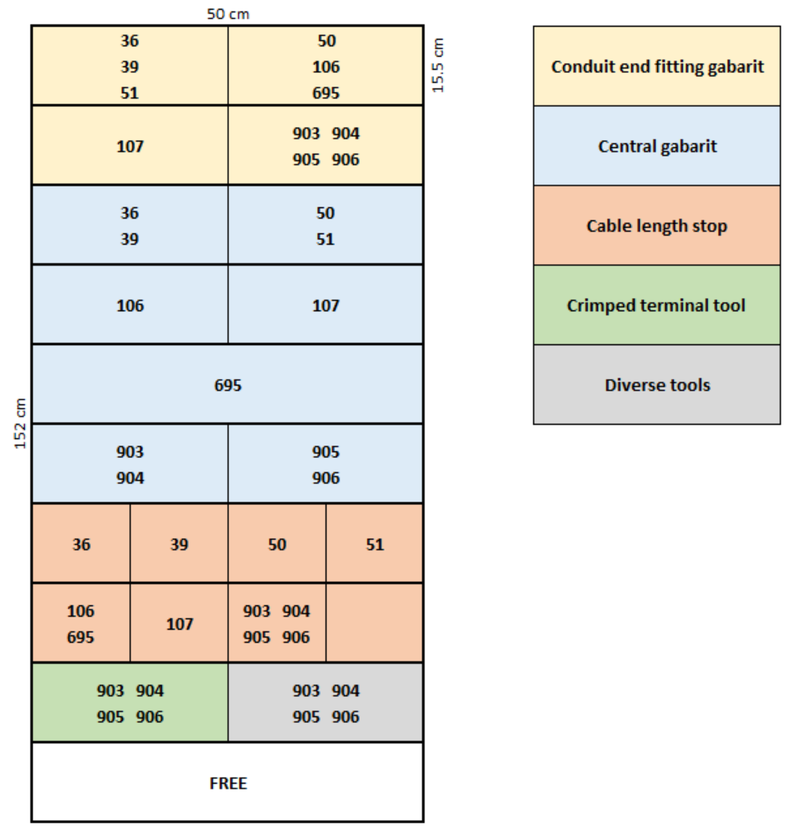


Figure 100 – Redesigned layout for the main setup tools cabinet

In Figure 101 it is shown the implementation of the improvements to the main setup tools cabinet.

Figure 101 - Redesigned organization of the main setup tools cabinet

Setup tools storage on workstations 101, 102 and 104

Included on some of the workstations of this assembly line, there are dedicated places where the setup tools dedicated to the corresponding workstation are stored. It was visible that all of them lacks for identification, allowing the adjustment operator to store the setup tool in every place and making it difficult the search for the necessary tools. In Figure 102, it is represented the previous status of these setup tools storage.

Figure 102 – Setup tools storage of workstations 101, 102 and 104 (before)

For each setup tools storage, it was defined each space in order to assure that every tool has on storage place and that each storage place just belongs to one tool. The result after the organization is represented in Figure 103.

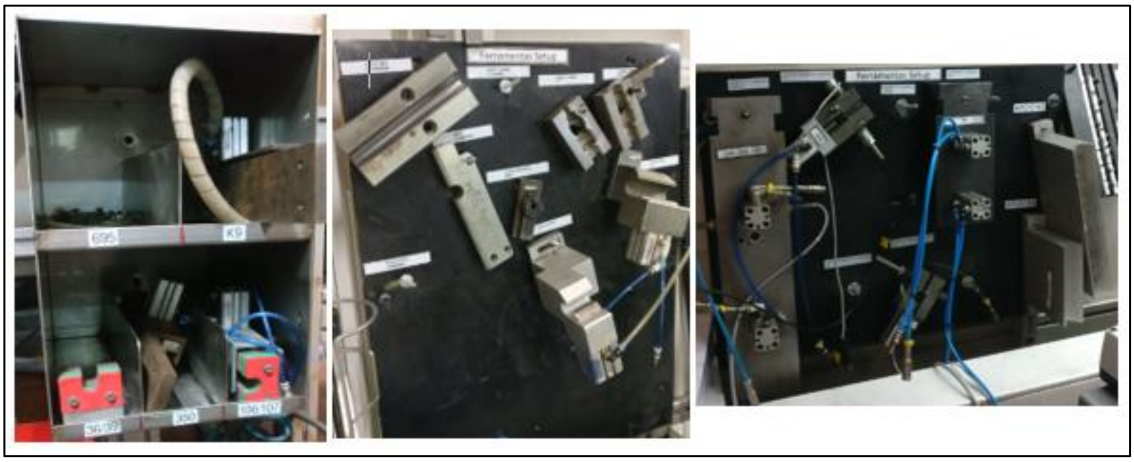


Figure 103 - Setup tools storage of workstations 101, 102 and 104 (after)

Thermography tools

The thermography operation on the workstation 104 is used to stamp the reference of the final product, as well as the corporative logo and the date of production. The possible different combinations of dates lead to a high number of pieces that should be organized and by order, the letters were placed all together, as well as the entire production references. The respective reorganization is represented in Figure 104.

Figure 104 – Organization of the thermography pieces storage (before vs. after)

3.3.5 Critical analysis of results

3.3.5.1 Time measurements and line balance efficiency

After the implementation of the defined improvement actions, it was possible to undergo a new time measurement process in order to get the new scenario of the assembly line and to quickly visualize the effect of the implemented improvements.

The measured times for each workstation and operation performed on it are summarized in Table 45.

Table 45 - Time measurement for the different operations performed in the different working centers of 'PSA Travão' (after)

WS	Necessary quantity to produce	Operating time (sec)	Operation No.	Operation description	Old Operation time (sec)	New Operation time (sec)
100	4260	55800	1	Assemble sealing, metallic O'ring, and smaller inner tube	9.58	**8.49**
100	4260	55800	2	Supply workstation 102 with assembled conduit subgroup	0.28	**0.11**
100	4260	55800	3	Knurl bigger and smaller inner tube	4.28	**3.74**
100	4260	55800	4	Supply workstation 102 with bigger inner tube	0.29	**0.09**
101	4260	55800	1	Countersink and grind two conduits on both sides	4.29	**4.19**
101	4260	55800	2	Assemble exterior tube	6.44	**7.27**
101	4260	55800	3	Supply container with conduits	0.93	**0.28**
101	4260	55800	4	Supply workstation with exterior tube	0.35	**0.13**
101	4260	55800	5	Packing labelling	0.31	**0.44**
102	4260	55800	1	Assemble bigger inner tube on the conduit	4.93	**3.57**
102	4260	55800	2	Assemble first conduit end fitting on the conduit	2.34	**2.03**
102	4260	55800	3	Validation of the knurled inner tube	1.87	**1.62**
102	4260	55800	4	Assemble second conduit end fitting on the conduit	1.31	**1.14**
102	4260	55800	5	Position cable on the jig and embed cable end fitting	3.45	**2.99**
102	4260	55800	6	Supply conduit end fitting from the container	5.10	**4.42**
102	4260	55800	7	Supply workstation 103	0.22	**0.19**
103	4260	55800	1	Insert cable and embed first conduit end fitting	13.80	**12.93**
104	4260	55800	1	Strip cable insert second cable fitting and embed; Position first cable end fitting, essay, and thermography.	11.27	**10.59**
104	4260	55800	2	Packaging	2.39	**1.87**

Summarizing, the individual cycle times and longest cycle times for the different workstation, as well as the corresponding fluctuations calculated, in seconds and in ratio percentage, are represented in Table 46.

Table 46 - Cycle times for each workstation and corresponding fluctuation to the takt time (after)

	WS 100	WS 101	WS 102	WS 103	WS 104	GLOBAL
Operation No. 1 (sec)	8.49	4.19	3.57	12.93	10.59	-
Operation No. 2 (sec)	0.11	7.27	2.03	-	1.87	-
Operation No. 3 (sec)	3.74	0.28	1.62	-	-	-
Operation No. 4 (sec)	0.09	0.13	1.14	-	-	-
Operation No. 5 (sec)	-	0.44	2.99	-	-	-
Operation No. 6 (sec)	-	-	4.42	-	-	-
Operation No. 7 (sec)	-	-	0.19	-	-	-
Total cycle time (sec)	**12.43**	**12.31**	**15.96**	**12.93**	**12.46**	**66.09**
Longest cycle time (sec)	13.71	13.55	17.20	13.67	13.94	72.07
Takt Time (sec)	**13.10**	**13.10**	**13.10**	**13.10**	**13.10**	**65.50**
Fluctuation (Sec)	1.28	1.25	1.24	0.74	1.48	5.98
Fluctuation ratio	**10.3%**	**10.1%**	**7.8%**	**5.7%**	**11.9%**	**9.05%**

Comparing the before and after scenarios (Table 47) it is possible to visualize that the cycle time values of every workstation dropped, and the corresponding fluctuation ratios followed the same tendency. These values are the result of the implemented improvements, focused on eliminating/reducing all kind of wastes and with a big focus in movement and transportation wastes. These movements and transportations were the main responsible for the big variations detected before implement the improvement actions.

Table 47 – Cycle times and fluctuation comparison (before vs. after)

	WS 100	WS 101	WS 102	WS 103	WS 104	GLOBAL
Total cycle time (sec) BEFORE	**14.44**	**12.32**	**19.22**	**13.80**	**13.66**	**73.44**
Longest cycle time (sec) BEFORE	19.88	13.87	24.83	15.73	16.10	90.41
Total cycle time (sec) AFTER	**12.43**	**12.31**	**15.96**	**12.93**	**12.46**	**66.09**
Longest cycle time (sec) AFTER	13.71	13.55	17.20	13.67	13.94	72.07
Fluctuation (Sec) BEFORE	5.44	1.55	5.61	1.93	2.44	16.97
Fluctuation ratio BEFORE	**37.6%**	**12.6%**	**29.2%**	**14.0%**	**17.9%**	**23.1%**
Fluctuation (Sec) AFTER	1.28	1.25	1.24	0.74	1.48	5.98
Fluctuation ratio AFTER	**10.3%**	**10.1%**	**7.8%**	**5.7%**	**11.9%**	**9.05%**

In Figure 105, it is represented the line balancing after implemented the improvement actions.

With the exception for the workstation 103, that continues to be the bottleneck of this assembly line, all other workstations have now cycle times lower than the takt time, being able to respond to the client demand.

In terms of balancing, it is possible to verify that the different workstations are move leveled between them, allowing have a more controlled and continuum production rhythm, reducing the levels of intermedium stock. However, it is fundamental to improve the cycle time of the workstation 103 to values below takt time so that the whole production line can respond to the client's needs.

Nevertheless, due to the fact of already having explored and discussed various improvement actions, we concluded it will be necessary to have technological improvements in this workstation to be able to reduce this much the cycle time. One of the possible improvement actions will be presented in the next chapter.

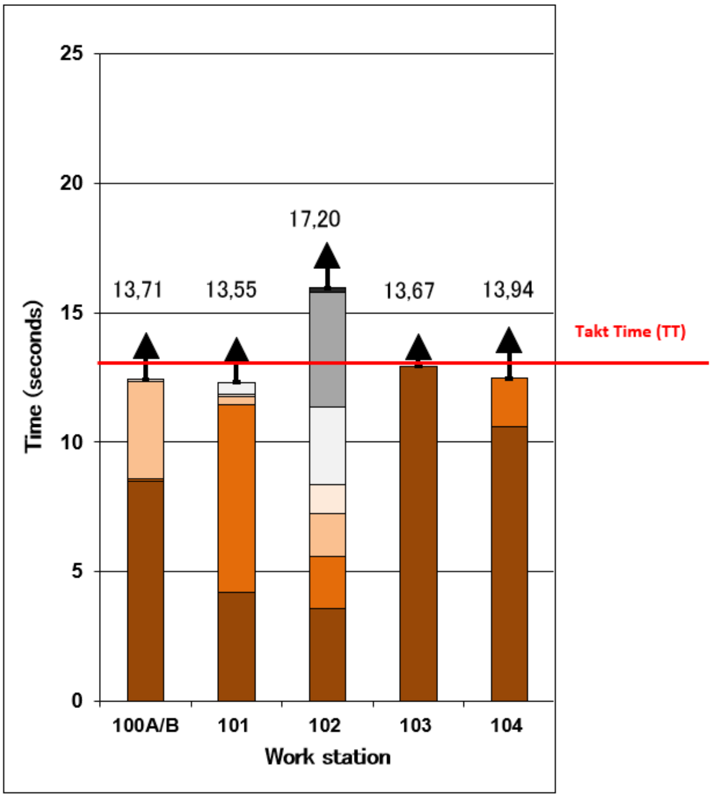


Figure 105 - Line balancing of the different workstation of the assembly line 'PSA Travão'

In Table 48, as represented, the line balancing after implementation of the defined improvement actions has a value of 93.10% comparatively to the previous scenario, before the implementation of the improvement actions, we can verify there was a rise of 7.61 pp.

The workstation 102 has a lower line balance efficiency (74.13%), since it is clearly the assembly line's bottleneck, comparatively to the other workstations that have a much higher line balance efficiency (all around 98%) as they are almost perfectly balanced between them.

Table 48 - Line balance efficiency (after)

	Workstation					
	WS 100	**WS 101**	**WS 102**	**WS 103**	**WS 104**	**GLOBAL**
Line Balancing Efficiency	98.03%	97.05%	74.13%	98.03%	98.26%	**93.10%**

3.3.5.2 OEE

In Figure 106, is represented the evolution of the OEE of the assembly line of 'PSA Travão' during the three most important stages to measure the efficiency of an assembly line in an improvement process: the period before, during and after implementation of the improvements.

In this particular case, the OEE is also one of the most adequate indicators since as previously referred this assembly has problems in terms of performance and availability.

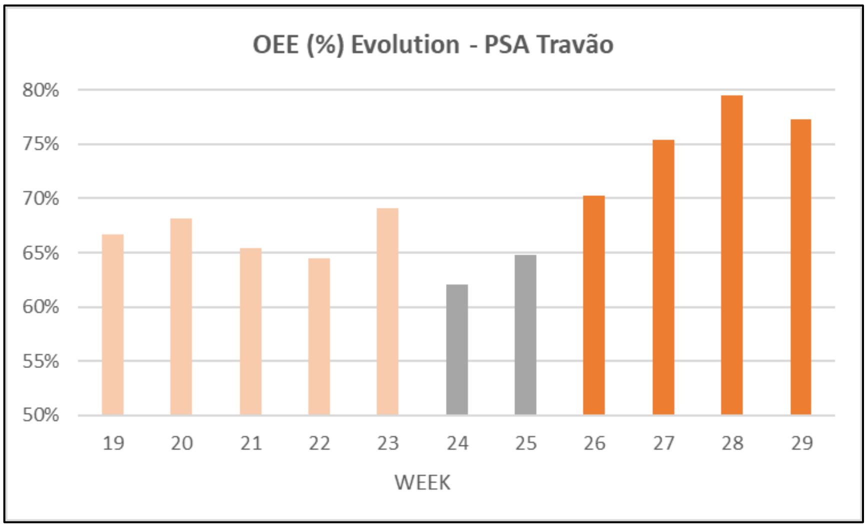


Figure 106 – OEE Evolution of *PSA Travão* assembly line

The first five weeks represented in this graph correspond to a period previous to the line intervention. During these weeks the average OEE value was 66.8%.

The two following weeks (week 24 and week 25) correspond to the period of implementation of the planned improvements. On week 24 occurred the different layout modifications which is a sensitive modification that took some time for the operators to adapt themselves and their way of working.

From week 26 and beyond, with all the improvement actions implemented there is a clear positive tendency on the OEE value, which shows and demonstrates the positive result of the improvement work.

However, during these first weeks, it became crucial to closely follow how the assembly line was working with the aim of rapidly solve any trouble or clarify the different operators for any doubt on the work methods.

3.3.5.3 Production per hour – PPH

As previously referred to the introduction of this case study, this project is included in a Productivity Improvement Plan of the Continuous Improvement department. Moreover, one of the main indicators for evaluation of the improvements developed throughout the project is the PPH indicator (production per hour).

In Table 49, is represented the obtained increase of PPH on this assembly line with this improvement project.

Table 49 – Production per hour (before vs. after)

	Before	After
Cycle time (sec)	19.22	15.96
Production per hour – PPH (units)	187	225

With the decrease of the cycle time from 19.22 seconds to 15.96 seconds, it was possible to increase the PPH to 225 units. This value represents the hour to hour production capacity of the assembly line.

3.3.5.4 5S Audit

The 5S audits is one of the main tools used for the organization of a workplace and posterior maintenance of this organization in order to improve the efficiency of the overall process. In this case, it will be implemented on the assembly line in general but also bearing in mind the specifications of each workstation. Due to reasons of confidentiality, it will not be possible to mention all the points related to the 5S parameters implemented but only to make a brief description about them.

1. *Seiri* (Sort)

It consists of making the distinction between what is really necessary and what is not in order to perform the different operations of the different workstations of the assembly line. It helps to make sure everything will be in the right place and in the right conditions, prompt to be used when necessary

.

2. *Seiton* (Set)

It is related to the importance of keeping everything storage properly in each workstation in a way everyone can have access to the right item for a certain procedure at the right time, easily. Everything needs to have a place and to be in its place.

3. *Seiso* (Sweep)

It consists of keeping the different workstations, the setups cabinets, the racks and the different support tables and all the different equipments as clean as possible in terms of any type of waste, dirt, oil or dust.

4. *Seiketsu* (Standardize)

It focuses on making sure the procedures for the previous 3S are known and that everyone knows what their role is in this implementation. The information provided in terms of routines, tasks, schedules, and plans of action should be updated, clearly defined and available for every workstation of the assembly line.

5. *Shitsuke* (Sustain)

It consists of implementing certain tools to maintain the established standards over the long term in terms of levels of stock, of monitoring and maintenance of the equipment, etc. It is important to make sure everything is going as expected by auditing regularly the assembly line and by showing these results to all the workers.

After the first 5S audit it was created for every non-conforming item a plan of improvement actions specifying what the problem was and what corrective action should be implemented with its respective deadline.

Table 50 - 5S audit (before vs. after)

5S	Before	After
Seiri (Sort)	1/5	4/5
Seiton (Set)	1/5	5/5
Seiso (Sweep)	0/5	5/5
Seiketsu (Standardize)	2/5	5/5
Shitsuke (Sustain)	2/5	4/5
Final Score	**28.10%**	**92.20%**

Through the improvement, measures implemented it was possible to build a standard for the 4th S (standardize) which allowed to keep the improvements made in terms of the 5S as shown in the *ANNEX 2 – Standard 4S developed for 'PSA Travão' assembly line*.

3.3.6 Future improvements

3.3.6.1 Description of the improvement

As it was shown before, the bottleneck of the assembly line was the workstation 102 with a corresponding cycle time of 15.96 seconds, for a takt time of 13.10 seconds. In order to reduce the cycle time to a lower value than the takt time, which will allow responding effectively and on time to the customers' demand there was a need for a more profound technical modification in the workstation.

From the different operations, one of the longest that is executed inf this workstation is the assembling of the big inner tube on the conduit, that takes to the operator a measured operation time of 3.57 seconds.

The proposed modification would be to go from a manual assembly operation to an automatic assembling of the big inner tube on the conduit, which would transfer the cut operation to this workstation.

The basic steps of this process are described in Figure 107.

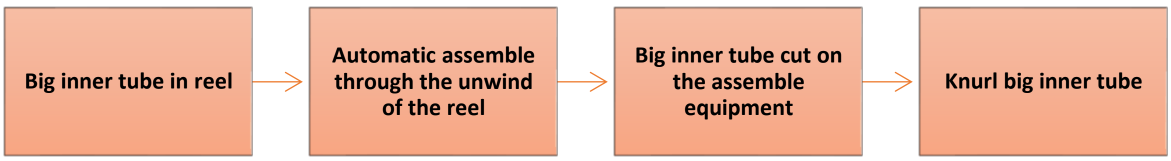


Figure 107 – Process steps for the automatic assemble of the big inner tube on the conduit

3.3.6.2 Future line balance efficiency

As projected by the processes department team, with the implementation of this modification and also without the big inner tube knurl operation on the workstation 100A/B, the total cycle time in this workstation would reduce of about 1 second.

On the workstation 102, that will receive the automatic assembling equipment, the corresponding operation time for the manual assembling of the big inner tube on the conduit could be eliminated as the new time will be considerate a machine time, and the operator does not need to wait for the assembling to be concluded as he could perform the next operation – assemble conduit end fittings.

This way, the new cycle times for each operation and corresponding fluctuation to the takt time are summarized in Table 51.

Table 51 -Cycle times for each workstation and corresponding fluctuation to the takt time (future)

	WS 100	WS 101	WS 102	WS 103	WS 104	GLOBAL
Operation No. 1 (sec)	8.49	4.19	2.03	12.93	10.59	-
Operation No. 2 (sec)	0.11	7.27	1.62	-	1.87	-
Operation No. 3 (sec)	2.74	0.28	1.14	-	-	-
Operation No. 4 (sec)	0.09	0.13	2.99	-	-	-
Operation No. 5 (sec)	-	0.44	4.42	-	-	-
Operation No. 6 (sec)	-	-	0.19	-	-	-
Total cycle time (sec)	**11.43**	**12.31**	**15.96**	**12.93**	**12.46**	**61.51**
Longest cycle time (sec)	12.71	13.55	13.63	13.67	13.94	67.50
Takt Time (sec)	**13.10**	**13.10**	**13.10**	**13.10**	**13.10**	**65.50**
Fluctuation (Sec)	1.28	1.25	1.24	0.74	1.48	5.98
Fluctuation ratio	**11.2%**	**10.1%**	**10.0%**	**5.7%**	**11.9%**	**9.73%**

A comparison of the cycle time, longest cycle time and fluctuation between the before, after and future stages are summarized in Table 52.

Table 52 – Cycle times and fluctuation comparison (before vs. after vs. future)

	WS 100	WS 101	WS 102	WS 103	WS 104	GLOBAL
Total cycle time (sec) BEFORE	**14.44**	**12.32**	**19.22**	**13.80**	**13.66**	**73.44**
Longest cycle time (sec) BEFORE	19.88	13.87	24.83	15.73	16.10	90.41
Total cycle time (sec) AFTER	**12.43**	**12.31**	**15.96**	**12.93**	**12.46**	**66.09**
Longest cycle time (sec) AFTER	13.71	13.55	17.20	13.67	13.94	72.07
Total cycle time (sec) FUTURE	**11.43**	**12.31**	**12.39**	**12.93**	**12.46**	**61.51**
Longest cycle time (sec) FUTURE	12.71	13.55	13.63	13.67	13.94	67.50
Fluctuation (Sec) BEFORE	5.44	1.55	5.61	1.93	2.44	16.97
Fluctuation ratio BEFORE	**37.6%**	**12.6%**	**29.2%**	**14.0%**	**17.9%**	**23.1%**
Fluctuation (Sec) AFTER	1.28	1.25	1.24	0.74	1.48	5.98
Fluctuation ratio AFTER	**10.3%**	**10.1%**	**7.8%**	**5.7%**	**11.9%**	**9.05%**
Fluctuation (Sec) FUTURE	1.28	1.25	1.24	0.74	1.48	5.98
Fluctuation ratio FUTURE	**11.2%**	**10.1%**	**10.0%**	**5.7%**	**11.9%**	**9.73%**

In Figure 105, it is represented the line balancing expected to achieve with the automatic assembling of the big inner tube. Now it is possible to visualize an assembly line well leveled, with all the workstation having cycle times under the takt time and being able to respond to the client demand. It is also expected that the bottleneck would change from the workstation 102 to 103. The workstation 100A/B has a little lower operation time comparing to the other workstation (of about 1 second). However, as it only produces subgroups it could produce for Kanban purposes.

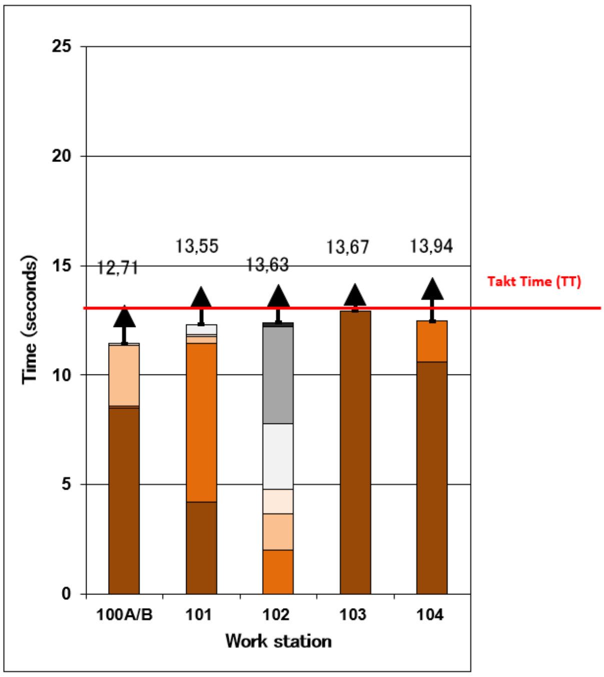


Figure 108 - Line balancing of the different workstation of the assembly line PSA Travão

In Table 53 it is summarized the expected evolution of the PPH value. With the implementation of this improvement, it is expected that the PPH of this assembly line keeps improving for a value of 278 cables produced per hour.

Table 53 - Evolution of cycle time and PPH

	Before	After	Future
Cycle time (sec)	19.22	15.96	12.93
PPH (units/hour)	187	225	278

3.3.6.3 Process mapping

In order to evaluate whether this option compensates the investment, it is necessary to know every element and constraint along the value stream associated with the big inner tube used on this assembly line. It was decided the best option was to use the tool Value Stream Mapping (VSM).

Spaghetti diagrams

Through the usage of a tool called *Spaghetti Diagram,* it is possible to visualize the path of the big inner tube on the factory from the components' warehouse to the final product assemble operation on '*PSA Travão*'.

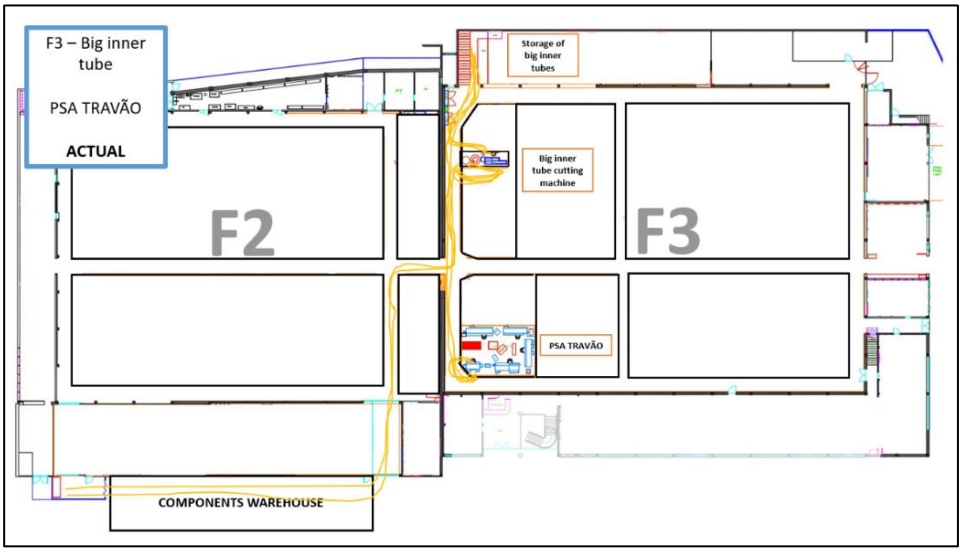


Figure 109 - Spaghetti diagram of the big inner tube for 'PSA Travão' (before)

In Figure 109, it is possible to visualize the flow of the big inner tube. This component is directly purchased from a supplier arriving at a component warehouse. From there a supply operator takes the big inner tube to the cutting equipment located on the F3 module. With the big inner tube already cut a supply operator moves it to a cut big inner tube storage section where it stays until it receives a requirement order to supply PSA and is moved by a supply operator.

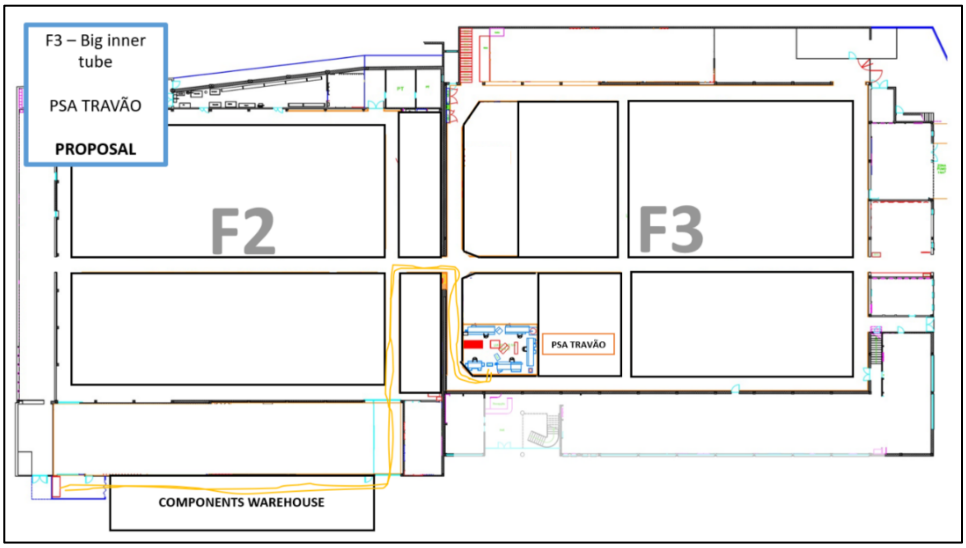


Figure 110 – Proposal for the spaghetti diagram of the big inner tube for 'PSA Travão'

On the proposal model (Figure 110), the big inner tube would come directly to the assembly line moved by a supply operator. This model allows fewer movements and transportations.

Actual Situation

- *Stock*

First, it was necessary to quantify the amount of stock of the big inner tube across the value stream. On a specific day by following the whole flow, from the components warehouse to the assembly line, we were able to quantify the following amount of stock.

Table 54 - Amount of stock through big inner tube flow

Location	Quantity (meters)
Components warehouse	28000
Cutting equipment	4000
Cut big inner tube storage section	26676
Assembly line	180
TOTAL	**58856**

As the material on the cut big inner tube storage section and on the assembly line is already cut it is necessary to translate the quantity in meters to the number of cuts. As it can be seen in Table 55, for a total quantity of PSA cables produced of 207639 that corresponds to a total of 370538,6 meters it is possible to determine that the cut length has an average of 1.8 meters.

Table 55 - Quantity of PSA cables produced for a period of 90 days

Final Product Ref.	Cut Ref.	Cut length (m)	No. PSA cables produced	Total length (m)
111912036P01D01	11630349B00	1,72	29190	50206,8
111912036R01D01	11630349B00	1,72	120	206,4
111913039P01A03	11636528A00	1,756	7035	12353,5
111913106P01A00	11636832A00	1,845	11240	20737,8
111913106R01A00	11636832A00	1,845	15	27,7
111913107P01A00	11636831A00	1,654	33324	55117,9
111912695M01A01	11634129A00	1,826	118000	215468,0
111912695M03A01	11634129A00	1,826	400	730,4
111912695R01A01	11634129A00	1,826	4005	7313,1
111912903P01D03	11635401A00	2,124	36	76,5
111912904P01D03	11635401A00	2,124	72	152,9
111912905P01C02	11636604A00	1,939	512	992,8
111912905P01D03	11636604A00	1,939	1656	3211,0
111912906P01C02	11636604A00	1,939	477	924,9
111912906P01D03	11636604A00	1,939	1557	3019,0
			207639	**370538,6**

Knowing the average cut length is 1.8 meters it is possible to convert the total amount of stock on the cut big inner tube storage section and in the assembly line to the number of cuts.

Table 56 - Conversion from meters to number of cuts for the cut big inner tube stock

Location	Quantity (meters)	No. of cuts
Cut big inner tube storage section	26676	14820
Assembly line	180	100

- *Days of stock*

With the total quantity of stock in the appropriate units, it is possible to convert it to the days of stock as summarized in Table 57.

Table 57 - Days of stock calculation

Location	Quantity (m)	Quantity (m) for 90 days	No. of cuts	No. of cuts for 90 days	Days of stock
Components warehouse	28000	370536	-	-	6.81
Cutting equipment	4000	370536	-	-	0.97
Cut big inner tube storage section	-	-	14820	207639	6.42
Assembly line	-	-	100	207639	0.04

- *Days of stock cost*

Knowing the area occupied by each stock location and with an established cost rate per square meter, it is possible to calculate the cost of each day of stock. The stock cost associated with the total number of stock days is 8.95 €.

Table 58 - Days of stock cost calculation

Location	Occupied area (m²)	Cost/m²/day	Days of stock	Days of stock cost (€)
Components warehouse	3	0.19	6.81	3.88
Cutting equipment	1	0.19	0.97	0.18
Cut big inner tube storage section	4	0.19	6.42	4.88
Assembly line	1	0.19	0.04	0.01
TOTAL	**9**	**-**	**14.24**	**8.19**

- *Retained value of stock*

In Table 59, it is presented the value the company is losing due to the fact that there is an excess of stock storage and from finished products unpaid for. The total cost for the retained value of the stock is 819 euros.

Table 59 - Calculation of the retained value of stock

Location	Quantity (m)	Raw material cost (€/m)	No. of cuts	Process cost (€/cut)	Retained value of the stock (€)
Components warehouse	28000	0.013	-	-	364
Cutting equipment	4000	0.013	-	-	52
Cut big inner tube storage section	-	-	14820	0.027	400
Assembly line	-	-	100	0.027	3
TOTAL	**32000**	**-**	**14920**	**-**	**819**

- *Supply operator*

As there are three supply operators responsible for supplying 'PSA Travão' assembly line (one per shift) and knowing that it takes, in average, about 20 minutes to supply the cut machine from the components warehouse, it represents one hour per day. Bearing this in mind, it is possible to calculate a cost for the supply operator.

Table 60 - Data for calculation of supply operator costs

Description	Value
Number of worked hours/month	173.33 h
Number of the saved hours/day	1 h
Supply operator monthly wage	1200 €

Based on the data presented in Table 60 it is possible to calculate a cost per month regarding the supply operator as presented below:

$$Cost\ per\ month = Cost\ per\ day \times 21\ days \quad (4)$$

$$Cost\ per\ month = {}^{1200€}/_{173.33h} \times 21\ days = 145.38€$$

- *Cut equipment*

Since this cut equipment produces exclusively for 'PSA Travão' assembly line it is possible to calculate the associated cost.

Table 61 - Cut equipment costs

Description	Value
Number of cuts/ 90 days	207000
Number of cuts/months	69000
Cadence of cuts (no. of cuts/ hour)	1000
Number of hours/month	69 h
Cost/ hour/ cut	4.02 €
Cost/ month	277.38 €

Future Situation

Knowing that the big inner tube supplier has a delivery lead time of 2 days and, a stock of 10000 meters is sufficient as the daily consume is under 5000 meters per day (based on the PSA 90-day production of around 370000 meters).

Table 62 - Future daily stock cost calculation

Description	Value
Stock quantity (m)	10000
Cost/m²/day	0.19 €
Stock area (m²)	2
Stock days	2
Day stock cost	0.76 €

- *Retained value of stock*

With the 10000 meters of stock define above, divided by the components warehouse and reels on the assembly line, it is possible to calculate a retained value of the stock, represented in Table 63.

Table 63 - Calculation of the retained value of the stock (future)

Location	Quantity (m)	Raw material cost (€/m)	Retained value of the stock (€)
Components warehouse + Assembly line	10000	0.013	130

3.3.6.4 Actual VSM

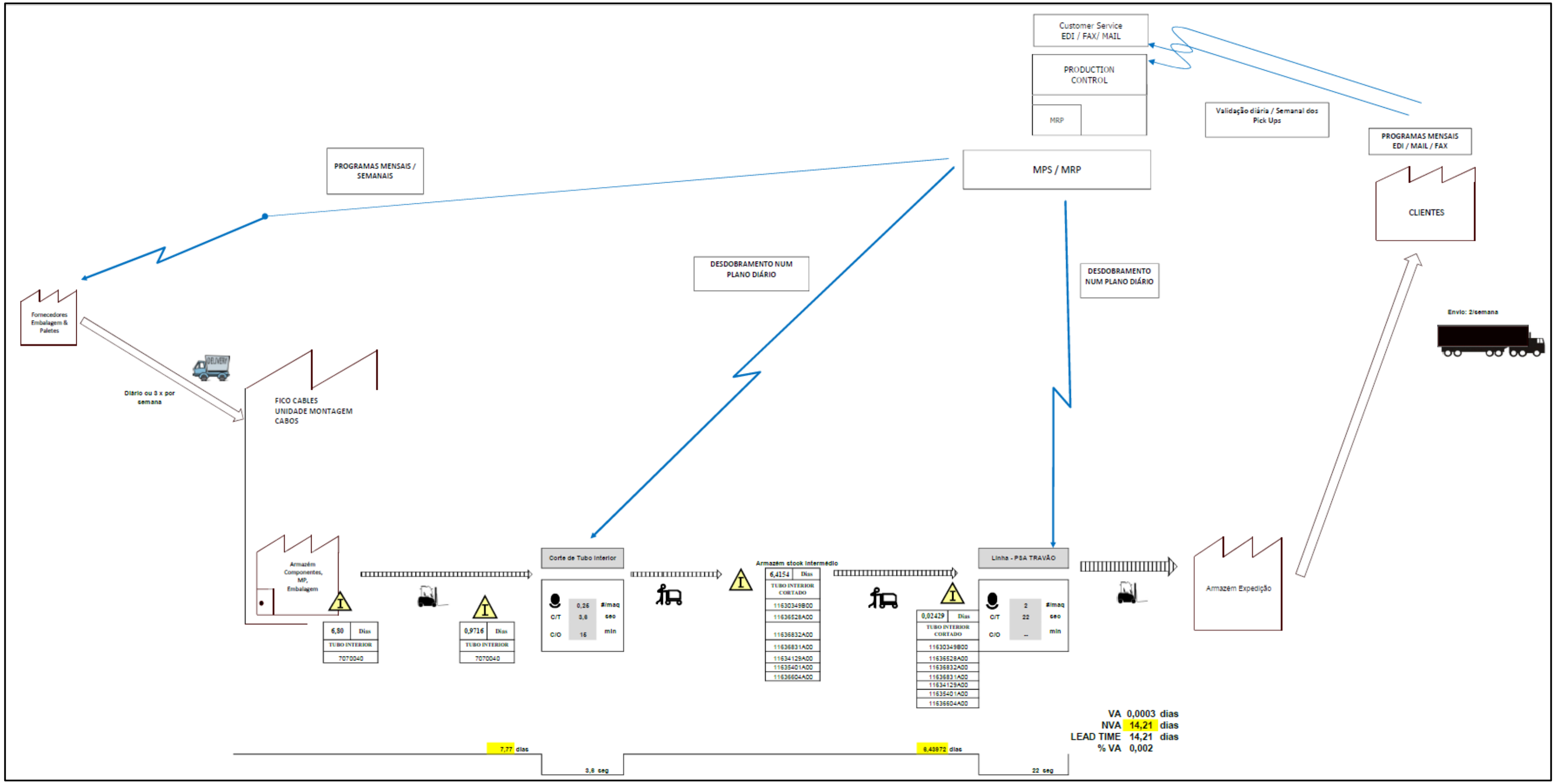


Figure 111 - Actual VSM for the big inner tube (*PSA Travão*)

3.3.6.5 Future VSM

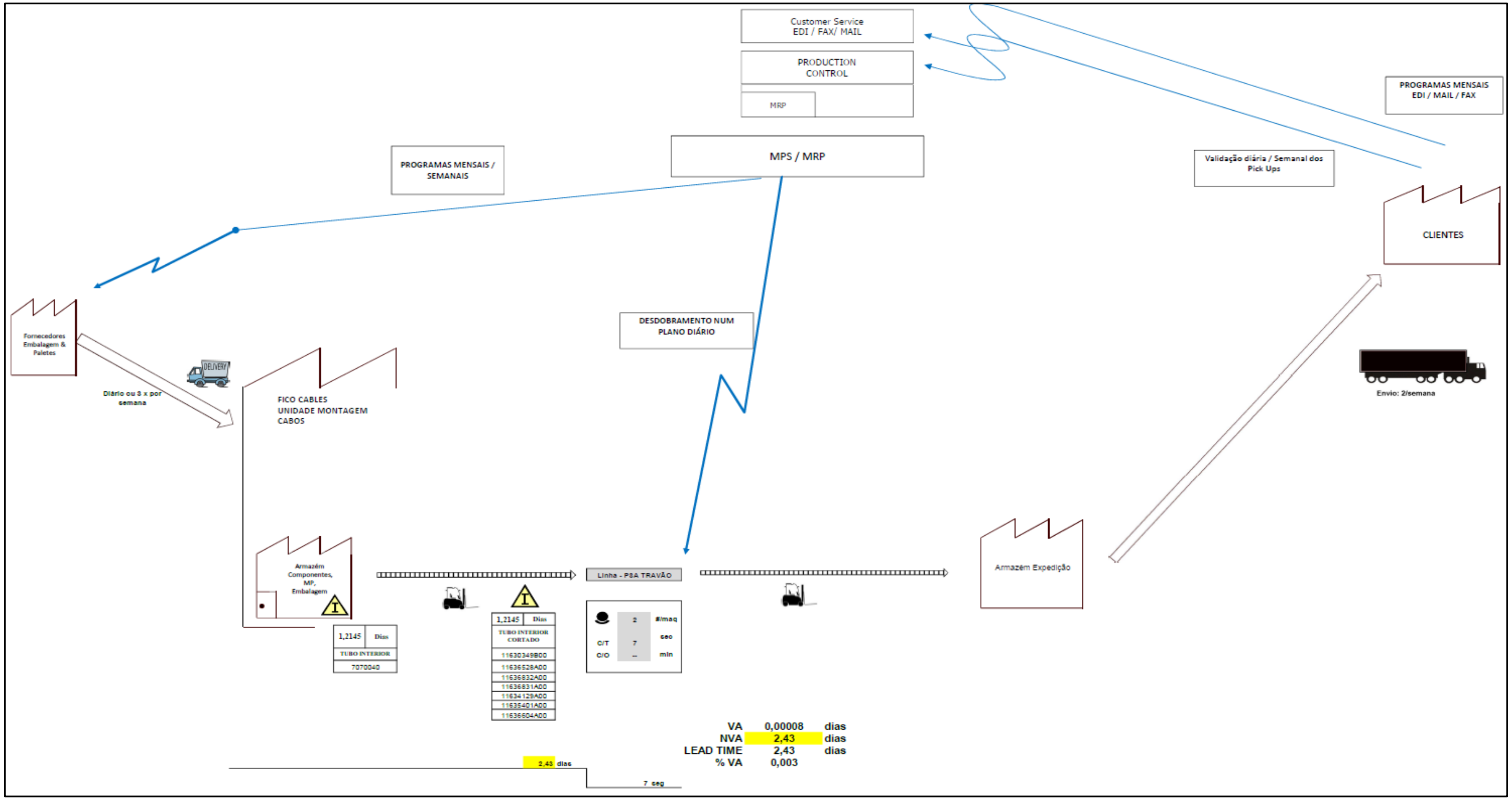


Figure 112 - Future VSM for the big inner tube (*PSA Travão*)

3.3.6.6 Savings

With the implementation of this improvement opportunity, there will be different savings that could be achieved and that will be further resumed.

In terms of the retained value of stock cost, there is a fixed saving, summarized in Table 64.

Table 64 - Retained value of stock saving

Description	Value
Retained value of the stock (actual)	819 €
Retained value of the stock (future)	0.19 €
Saving	689 €

Monthly (21 days), there are savings regarding the days of stock cost, the cut equipment and also the supply operator. These savings are concise in Table 65.

Table 65 - Summary of expected savings with the implementation of the improvement opportunity

Description	Value
Days of stock cost (actual)	8.95 €
Days of stock cost (future)	0.76 €
Days of stock daily saving	8.19 €
Days of stock monthly saving	171.93 €
Cut equipment monthly saving	278.38 €
Supply operator monthly saving	145.38 €
TOTAL month	594.70 €
TOTAL year	7136 €

In every investment, it is always crucial to face the possible savings obtained from the investment to be realized. Knowing that, monthly, it will be saved about 595 €, and for a total investment of 3387 €, it is expected a payback of about 5.7 months.

3.4 Case study no. 2

3.4.1 Characterization of the problem

The problem discussed in this case study had its origin on the evaluation of one of the main issues of the factory: *Scrap*. This issue reflects the quality problems of a certain process/ equipment and can be evaluated under different perspectives: number of non-conforming units, the cost associated with non-conforming units, low equipment/ technology efficiencies (OEE). In this particular case, it was necessary to evaluate data from 2017 to understand which technologies or sub-modules were contributing the most to the deviation found on these KPIs.

After identifying the main scrap source, it became necessary to learn and understand the whole process to identify the possible causes of the quantity of scrap produced. This is one of the most common problems not only in the automotive industry but in all types of industries and it has become one of the most important things to control in order to be able to be to reach today's customers' requirements: to have the best, a fast as possible and at the lowest price.

3.4.2 Selection of ideas

In order to be able to reduce the impact of these quality problems in the most affected sub-module/ technology, we considered two possible types of problem-solving tools: PDCA Cycle and Six Sigma methodology. To support the decision on what improvement methodology to be used both were analyzed through a SWOT Analysis. The SWOT Analysis for the PDCA Cycle is in Figure 113.

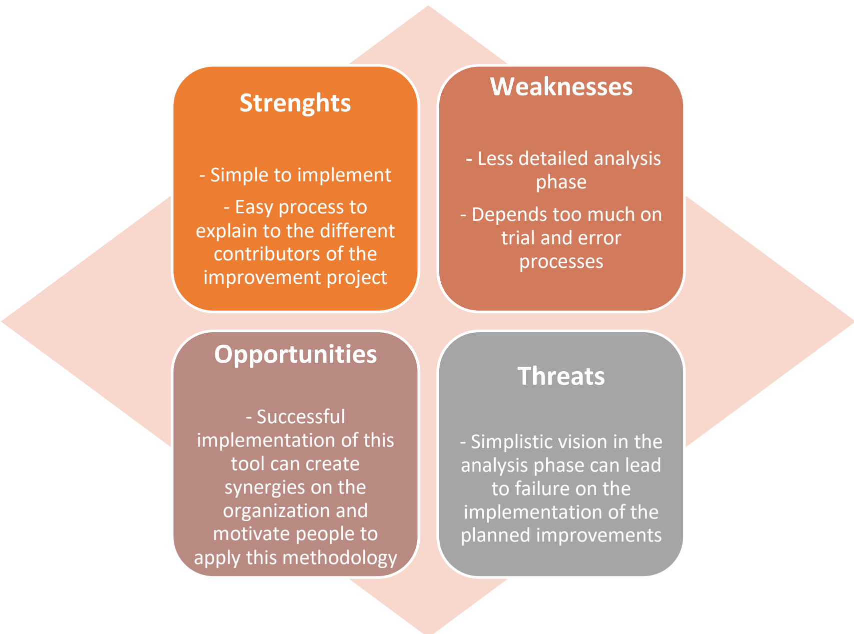


Figure 113 – SWOT analysis regarding the PDCA cycle use

The SWOT Analysis regarding the utilization of the Six Sigma methodology is represented in Figure 114.

Being the excessive quantity of scrap a complex problem, with known and unknown variables responsible for its existence, it is necessary to understand all these variables and how they relate with each other, affecting the problem in question. This necessity led to a need for a deeper analysis phase that would allow defining the adequate improvement actions to eliminate or drastically reduce this problem.

This way we chose to follow the Six Sigma methodology since it was adequate for more complex problems with more associated variables and where there is not a known solution for such a problem as it was the case.

A PDCA methodology would be more adequate for a simpler problem with known and controlled variables for which normally we already know the possible solution and where we just want to follow its implementation and posterior result.

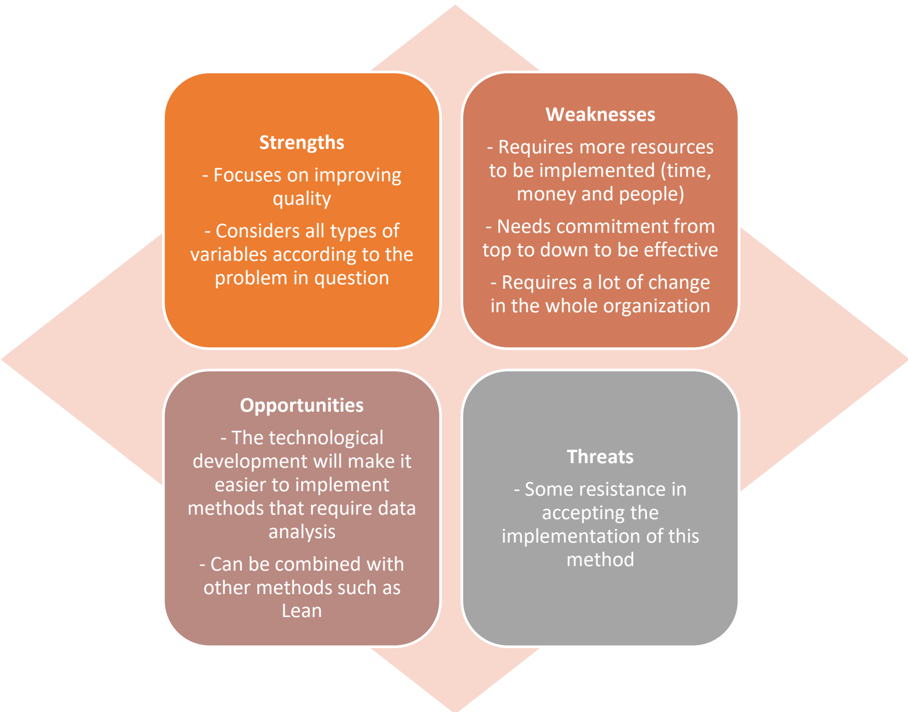


Figure 114 - SWOT analysis of the Six Sigma use

3.4.3 Methodology of implementation

The present study case addresses the application of the Six Sigma methodology with the aim of reducing the number of wires scrapped in the company Fico Cables. The practical development of this project, integrated into the department of Continuous Improvement, was based on the DMAIC approach. Thus, this chapter is composed of the detailed description of the stages of this cycle, applied to the improvement project.

The different DMAIC stages, as well as the main steps involved in each stage, are represented in

Figure 115.

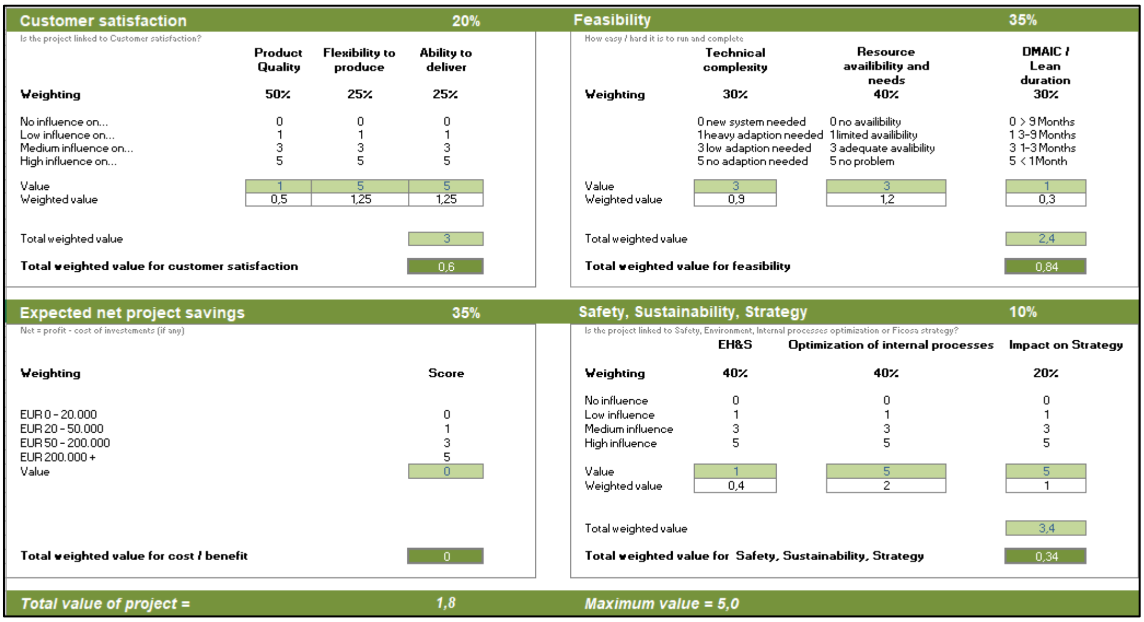
Figure 115 - DMAIC stages and steps of the developed project

3.4.3.1 Pre-Check stage

3.4.3.1.1 Positive evaluation of the opportunity

In order to evaluate the importance of the project for the organization as a whole and the different aspects are taken into consideration in order to undergo this improvement project, it was used a prioritization tool called *Prioritization Ranking Matrix* (Figure 116). This tool evaluates the key aspects of the project as:

- Customer satisfaction;
- Feasibility:
- Expected net project savings;
- Safety, sustainability, and strategy.



Customer satisfaction — 20%

Is the project linked to Customer satisfaction?

	Product Quality	Flexibility to produce	Ability to deliver
Weighting	**50%**	**25%**	**25%**
No influence on...	0	0	0
Low influence on...	1	1	1
Medium influence on...	3	3	3
High influence on...	5	5	5
Value	1	5	5
Weighted value	0,5	1,25	1,25
Total weighted value			3
Total weighted value for customer satisfaction			0,6

Feasibility — 35%

How easy / hard it is to run and complete

	Technical complexity	Resource availibility and needs	DMAIC / Lean duration
Weighting	**30%**	**40%**	**30%**
	0 new system needed	0 no availibility	0 > 9 Months
	1 heavy adaption needed	1 limited availibility	1 3-9 Months
	3 low adaption needed	3 adequate availibility	3 1-3 Months
	5 no adaption needed	5 no problem	5 < 1 Month
Value	3	3	1
Weighted value	0,9	1,2	0,3
Total weighted value			2,4
Total weighted value for feasibility			0,84

Expected net project savings — 35%

Net = profit - cost of investements (if any)

Weighting	**Score**
EUR 0 - 20.000	0
EUR 20 - 50.000	1
EUR 50 - 200.000	3
EUR 200.000 +	5
Value	0
Total weighted value for cost / benefit	0

Safety, Sustainability, Strategy — 10%

Is the project linked to Safety, Environment, Internal processes optimization or Ficosa strategy?

	EH&S	Optimization of internal processes	Impact on Strategy
Weighting	**40%**	**40%**	**20%**
No influence	0	0	0
Low influence	1	1	1
Medium influence	3	3	3
High influence	5	5	5
Value	1	5	5
Weighted value	0,4	2	1
Total weighted value			3,4
Total weighted value for Safety, Sustainability, Strategy			0,34

Total value of project = 1,8 ***Maximum value = 5,0***

Figure 116 – Prioritization Ranking Matrix for the developed project

The development of this project was also important because:

- Allowed to understand the variables associated, and how they interconnect, for the production of scrap, on one of the key modules of *Fico Cables*;
- There was a necessity to reduce costs associated with one of the scrap tops.

3.4.3.1.2 Linkage to corporative values and businesses of FICOSA

It was also important to, before proceeding with the project, identify which corporative values were represented and related to it (Figure 117).

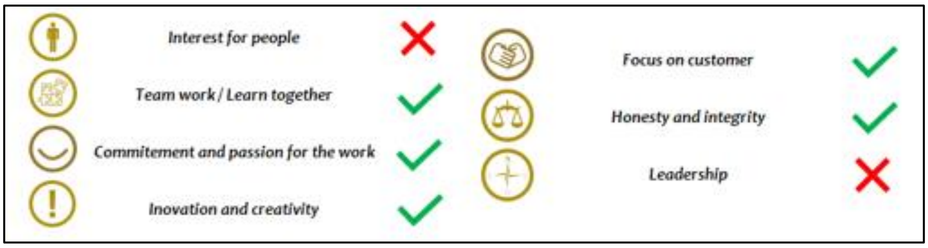


Figure 117 - Identification of the corporative values that were related to the project

3.4.3.2 Define stage

In this initial stage of the DMAIC cycle, a complete definition of the project was made. In this sense, it was necessary to identify the problem (and where it was located in the factory), the goals and objectives to be achieved, and the benefits inherent to the realization of this improvement project. The different team members, their roles and responsibilities along the project was also defined. A process mapping was carried out in order to understand, in more detail, the different operations and activities under analysis and the respective stakeholders (particularly internal and external suppliers and customers).

3.4.3.2.1 Define the project

Once the project was approved, it was necessary to create a document that summarizes the different elements of the project, with the statement of the scope, goals and the different participants and their level of authority on the project. The designed document is called *Project Charter* and it is presented in Figure 118.

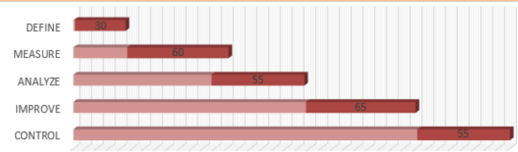
Business Case Background story behind: process, product, customer
The overall value of scrap increased significantly in the months of October and November of 2017, with the respective BSC indicator being out of target (Scrap Over Consumption Nov 2017=5.0%; Target=2.6%). One of the scrap tops is located on F4 module, in the wire bending area. This is one of the key processes, that is growing and saturated, of the company.

Problem Statement Problem description - remember NOT to put any potential solutions here!
Value of scrap above target (target: 2.6%; result in Nov 2017: 5.0%). 34% (69 511€) of the top 20 of overall scrap (202 244€) refers to the scrap of 7 references of wire used on the wire bending area of F4 module. The total of the process of wire bending by technology Tecnogial represents 41% of the scrap on the wire bending area, where in 2017, the scrap and adjusts of this process (Dorca + Tecnogial) represented 91000€.

Goal Statement CTQs	 Target value
Kg sucata	Reduce 17 000€ of scrap on wire straightned by Dorca and bending by Tecnogial

Benefits If possible discuss expected benefits with your CI team.	
- Reduction of 20% of the scrap made by setups and adjustments. - Standardization of the work method on the 3 shifts. - Learning lessons for future equipments - Stabilization of the bending process Dorca/Tecnogial/Heat treatment/Injection - Knowledge of the process variables and their interconnection in the chain (from raw material to final product)	
Expected savings [EUR]	17 360,00 €

Timeline
Phase — Scheduled phases



Team members Role	 Name
Project Leader	S.Loureiro, M.Gaspar
Process Champion	C.Pereira
Team	R.Dias, G.Ferreira, F.Higino, R.Ribeiro, J.Pereira
Experts on Demand	C.Riquito, P.Amaral

Figure 118 – Document for definition of the project (*Project Charter*)

In order to better define the quality indicator of the project as well as quantify the goals, it was created a Critical to Quality Tree (CTQ), that allows translating customer needs into specific and measurable performance indicators. This tool is represented in Figure 119.

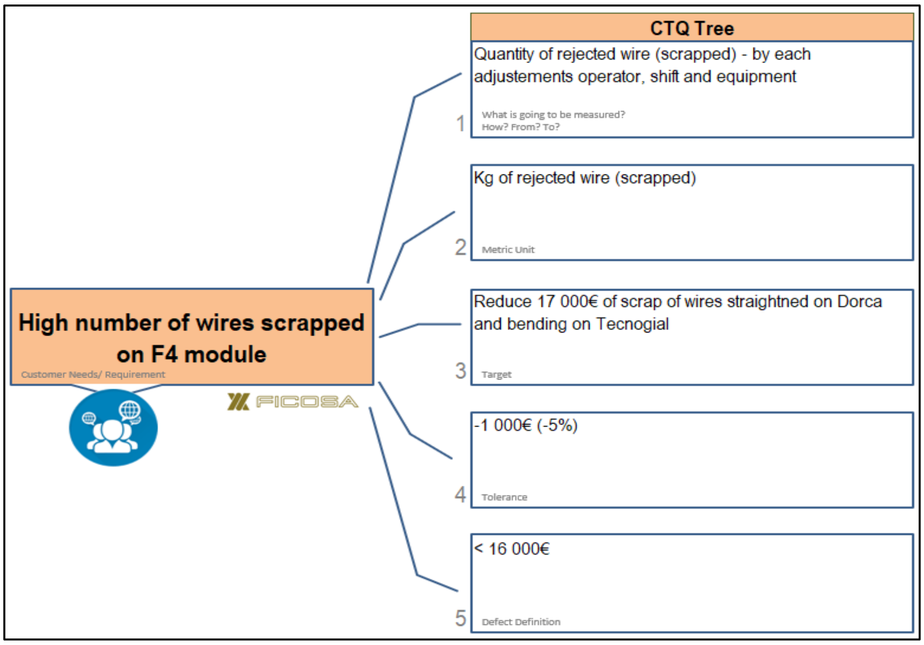


Figure 119 - CTQ Tree related to the quality parameter of the project

3.4.3.2.2 Introduction to the product

As a component manufacturer for the automotive industry, *Fico Cables* is a 2nd tier supplier. In the case of the comfort product systems, *Fico Cables* supply to 1st tier suppliers, as Brose, Faurecia or Johnson Controls, which in turn supply OEMs as BMW or Mercedes (Figure 120).

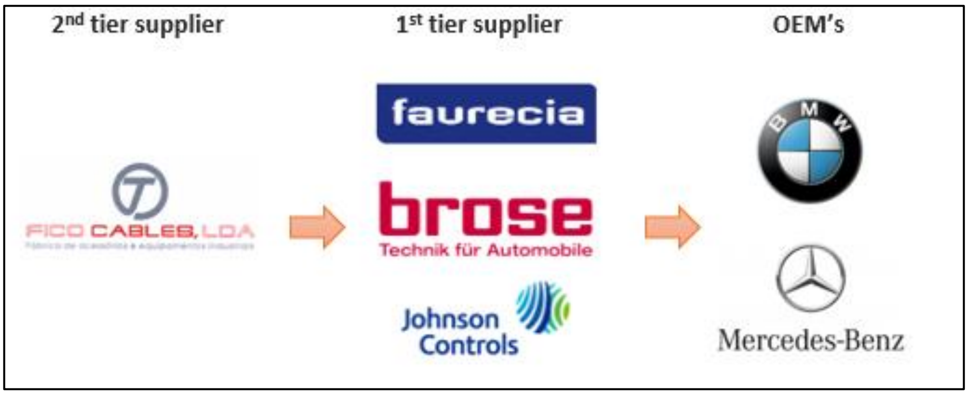


Figure 120 - Position of *Fico Cables* in the supply chain of OEMs

The product manufactured in the process discussed in this work is part of the automobile seat. It basically consists in a structure responsible for the comfort offered in the seats for their users. These structures are subdivided in terms of assembly location on the seat:

- *Cushions* – Flexible structures responsible for the comfort and support of the seat and that are located in the interior of the bottom padding of car seats (Figure 121).

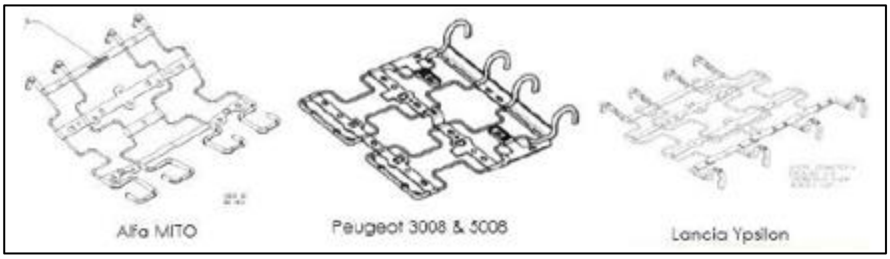


Figure 121 - Example of *cushions* used by different automobile manufacturers

- *Suspension Mat* (SM): Flexible structures responsible for the comfort and support of the lower back zone of the seat (Figure 122).

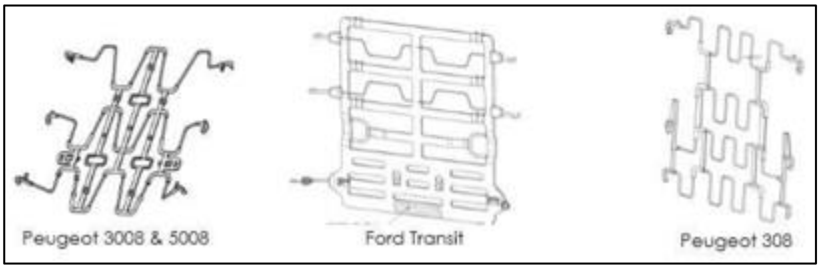


Figure 122 – Example of *suspension mats* used by different automobile manufacturers

In Figure 123, it is represented the structure of an automotive seat and the location of the cushions and SM comfort systems assembled.

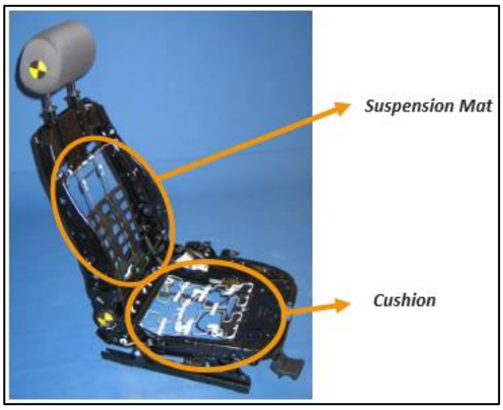


Figure 123 – Automotive seat structure and location of SM and cushion comfort systems

Cushions and Suspension Mats are suspension structures constituted by bent wires that are posteriorly over-injected of plastic. However, there are also produced other seat comfort system products that has the same purpose, but different morphologies, that are represented in Figure 124.

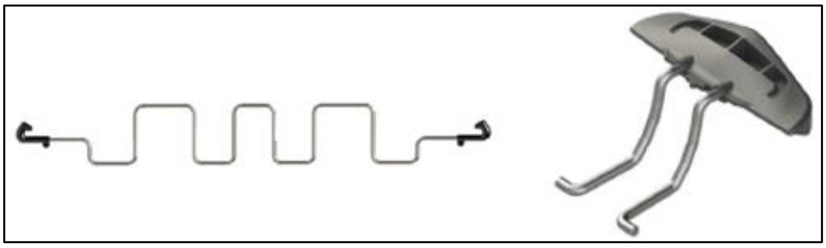


Figure 124 - Other comfort system products produced: M3M4 SM (left) and IBK lateral support (right)

The project *M3M4* is considered an SM, but with the particularity of the bent and over-injected wires does not have connections between them. In Figure 125, it is demonstrated how this component is applied in an automotive seat structure.

Figure 125 - Assembly of the project M3M4 SM on an automotive seat structure

The lateral support (Figure 126) has the purpose of supports and regulates the lateral saliences that exist in some automotive seats. In the Figure 125 it is represented the application of this type of component in an automotive seat structure.

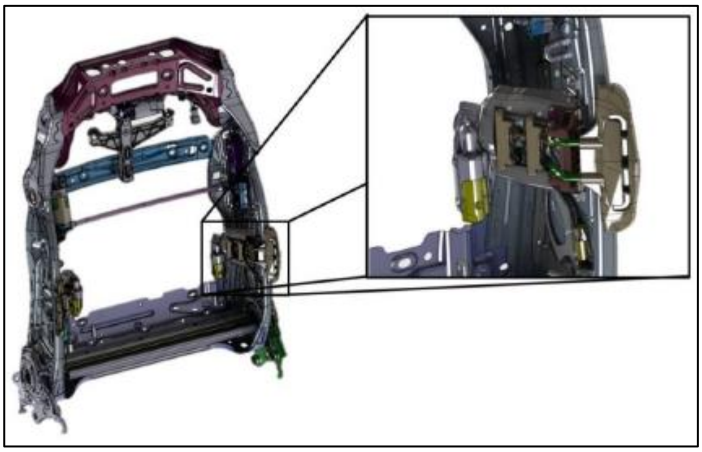


Figure 126 - Assembly of the project IBK lateral support on an automotive seat structure

3.4.3.2.3 Introduction to the manufacturing process

The manufacturing process of comfort system products varies according to the project that is being produced. The different projects can only be produced in certain machines, that has their own features. Thus, the manufacturing process follows the path 1, 2 or 3, according to the type of machines that can produce them. These manufacturing process variations are summarized in Figure 127.

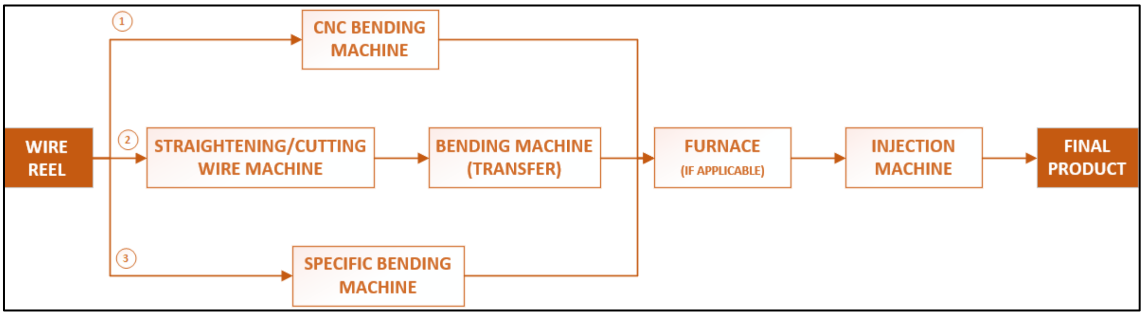


Figure 127 – Different variations of the manufacturing process of comfort system products

Stage 1 – Wire reel

The wire that feeds the different types of straightening, cutting, and bending machines is stored in reels (Figure 128).

Figure 128 – Wire reel

The different wires that are used to produce the different comfort system products vary in diameter (from 1.8 mm to 4.0 mm), in the coating type (galvanized or phosphated) and according to the class (SM, SH or SL).

These reels need to be placed on an unwinder support through the use of a mobile bridge (Figure 129), transported to the different machines and then placed on the unwinder, allowing to feed the corresponding bending or cutting/straightening machine.

Figure 129 – New wire reel (left) and wire reel being moved to an unwinder support through a mobile bridge (middle) and wire reel mounted on the unwinder support (right)

Stage 2 - Wire straightening, cutting and bending process (*CNC bending machines*)

The different types of CNC bending machines in the F4 module are:

- *Latour* (two machines);
- *Robomaq* (six machines);
- *Inovmaq* (one machine);
- *Waffios* (two machines).

The output of these machines varies between 600 to 1000 pieces per hour, depending on the complexity of the wire. Also, these machines are classified as the most flexible as they could produce the majority of projects. Although these machines have different characteristics, the manufacturing sequence of the process is similar, and it is represented in Figure 130.

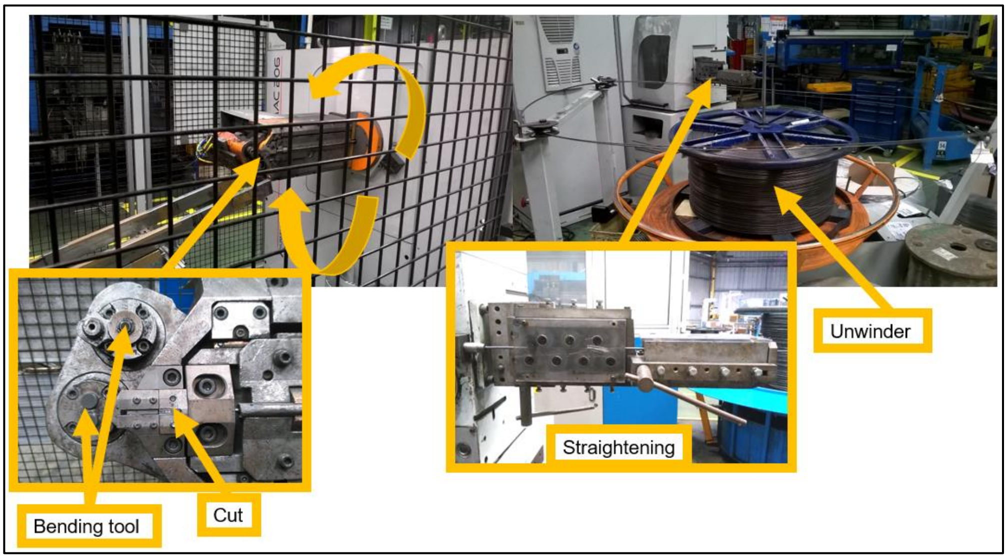


Figure 130 – Wire straightening, bending and cutting process on a CNC bending machine

Initially, the rotary movement of the wire reel unwinder, guides the wire through a set of pulleys, directing it to the feeding entrance of the machine (Figure 131).

Figure 131 - Unwinder pully (left) and wire entrance in the CNC bending machine (right)

Then, after entering the machine, the wire is then pulled through the movement of a set of traction wheels, allowing it to pass over several rollers, which straighten the wire. The position of the traction wheels is adjusted according to the diameter of the wire, as well as the adjustment of the straightening rollers allows for greater or smaller traction (Figure 132).

Figure 132 - Straightening rollers (above) and traction wheels (below)

In the next step, the straighten wire is bent by the rotation and translation movement of one or more bending tools. In *Robomaq* machines, there are two bending heads while in *Inovmaq*, *Latour* and *Waffios* machines there is only one bending head. The existence of two bending heads allows work in two stages, with both heads performing different bends at the same time. This feature leads to a shorter cycle time.

As these machines have Computer Numerical Control (CNC) technology, all the parameters could be pre-programmed. These parameters include lengths, angles, plan inclinations and radius. In Figure 133 we could see the computer screen of an Inovmaq machine and the different parameters that could be adjusted for each bend.

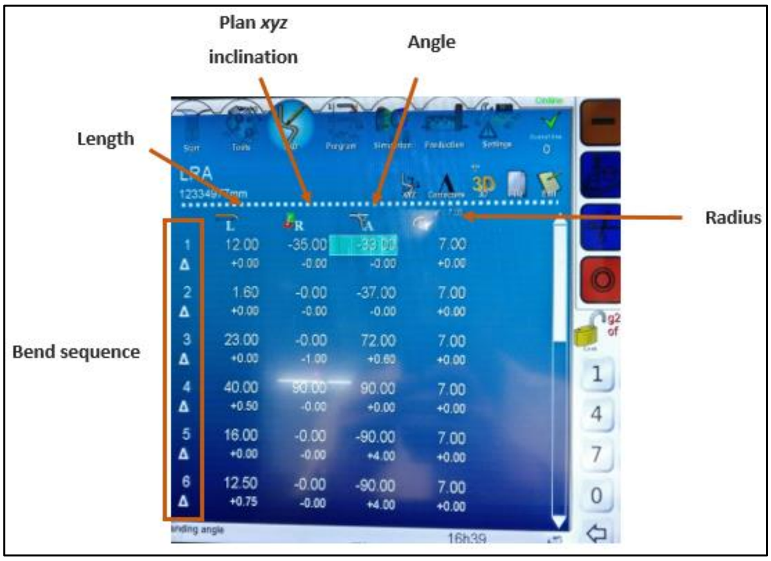


Figure 133 – Inovmaq bending parameters configuration

Also, as the material of the different wires has different elasticities and elastic returns behaviors, compensations could also be pre-programmed in order to compensate for this effect, as is shown in Figure 134.

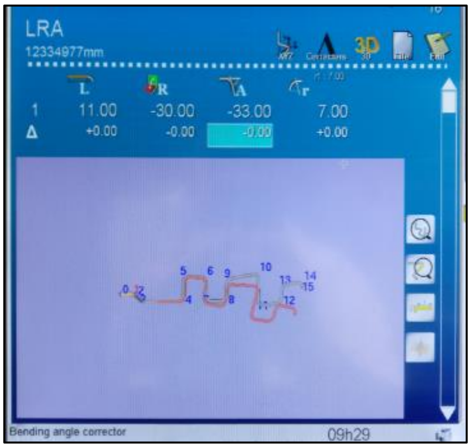


Figure 134 – Elastic return behavior compensation

After the bend sequence is done, the wire is cut by the action of a blade. Both blade and counter blade must have a similar diameter of the wire that is being cut (Figure 135).

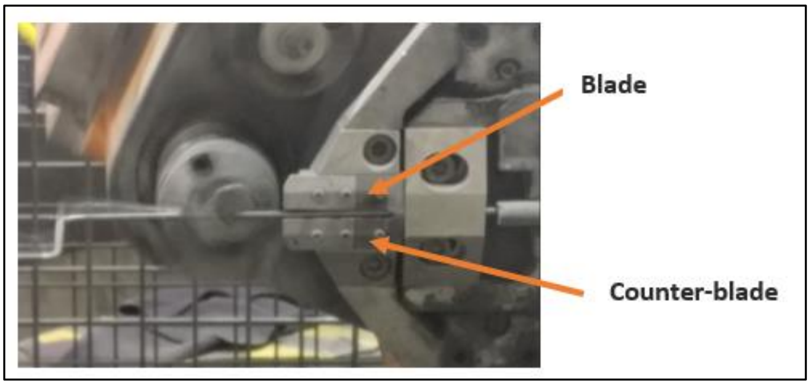


Figure 135 - Blade and counter-blade mechanism

Finally, after the wire is cut, it falls for an extraction guide. The operator periodically removes the wires of the guide, preventing it from being completely occupied, and packs them into containers (Figure 136).

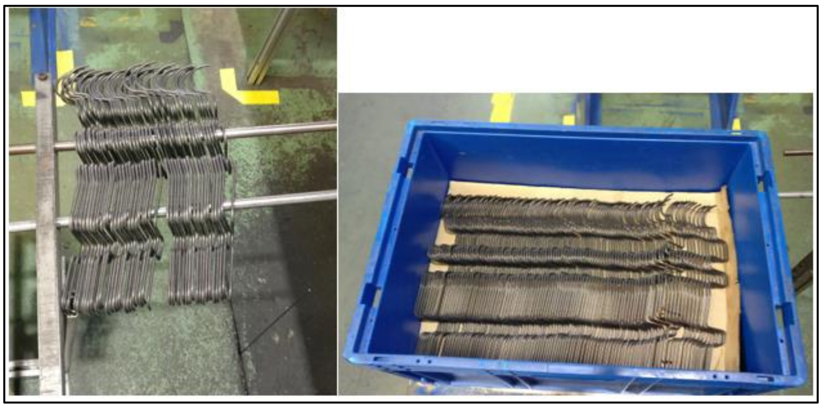


Figure 136 - Wire cut on the extraction guide (left) and wire placed in containers (right)

Stage 2 - Wire straightening, cutting and bending process (*Specific/dedicated bending machines*)

The different types of specific bending machines in the F4 module are:

- *Inovmaq* (two machines);
- *MPRO* (one machine).

These machines have also CNC technology for the bending operations, but they are dedicated to specific projects. However, they have a bigger output cadence. The sequence of operations, as well as their location on the machine, is represented in Figure 137.

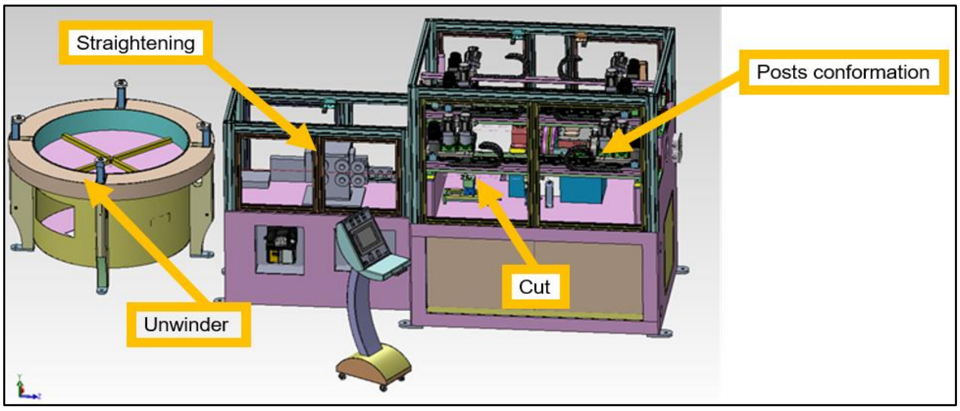


Figure 137 - Wire straightening, bending and cutting process on a specific/dedicated bending machines

The wire feeding operation, from the unwinder and by the movement of traction wheels, as well as the straightening operation, performed by the set of different straightening rollers, is similar to the other CNC bending machines. However, these machines cut the wire before the deformation operations. The wire is cut by an identical blade and counter-blade mechanism, and the cut length is adjusted with the support of an adjustment ruler.

These machines are also called "transfers" because of the bending mechanism. The wire cut sequentially rotates through a rotary servomotor called "bending head" that performs four different conformations (bends) in each stage of the rotation (Figure 138).

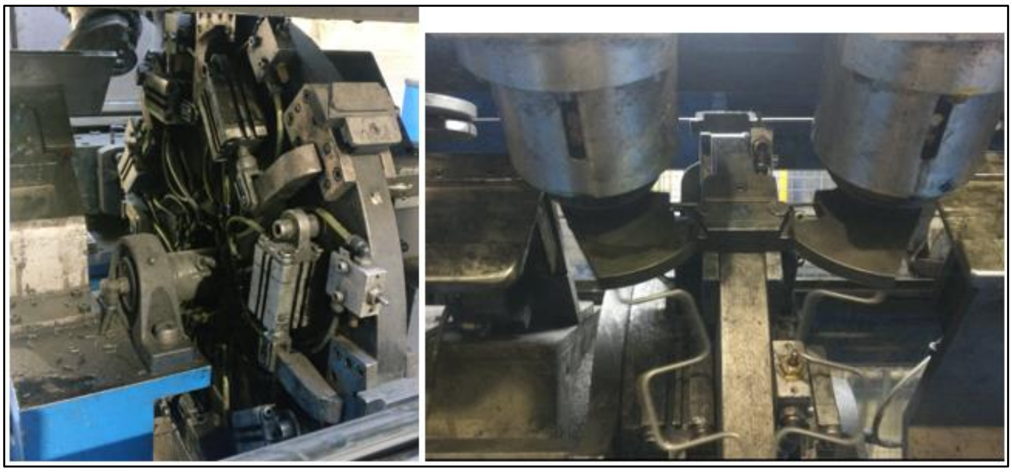


Figure 138 - Conformation head of an *Inovmaq* machine

After all the deformation operations are done, the wire falls to an extraction guide and the operator periodically transfers them into containers (Figure 139).

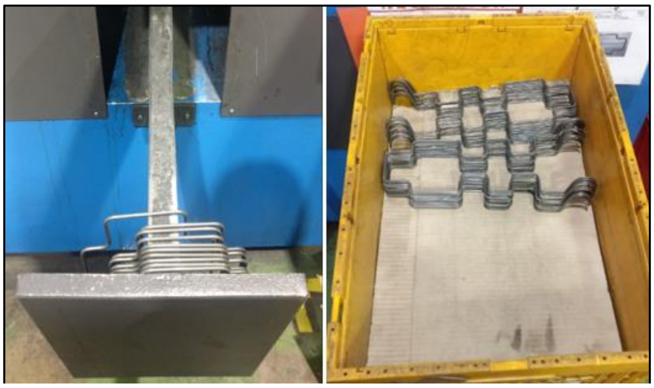


Figure 139 - Wire cut on the extraction guide (left) and wire placed in containers (right) (*Inovmaq*)

Stage 2 - Wire straightening, cutting and bending process (*Combination of straightening/cutting and bending wire machines*)

There are also machines that only perform the wire straightening and cutting operations (*Dorca* machines). Then, the cut wire is transferred to specific machines that carry out the deformation operations (*TEC* machines). In total, in the F4 module, there are eight *TEC* machines, two *Dorca* machines (1 and 6), that straighten and cut wire for *TECs*, and three *Dorca* machines (3, 4 and 5) that cute wire for assembly lines.

- *<u>Straightening and cutting process (Dorca machines)</u>*

The manufacturing process sequence for the *Dorca* machines is summarized in Figure 140. These machines have an average output of 2400 wires per hour.

Figure 140 – Wire straightening and cutting process of *Dorca* machines

The process of wire feeding in Dorca machines is similar to the other flexible and specific bending machines, with the wire that comes from the unwinder entering in a wire guide (Figure 141).

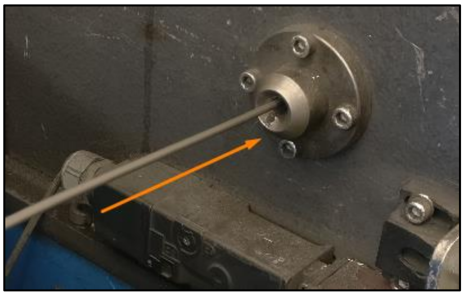


Figure 141 - Wire entrance guide (*Dorca* machine)

Then, the wire is pulled by the action of four traction wheels (Figure 142), positioned according to the wire diameter, and is straightened by a set of straightening rollers placed in a straightening rotating drum. These rollers are also adjusted in order to give more or less traction.

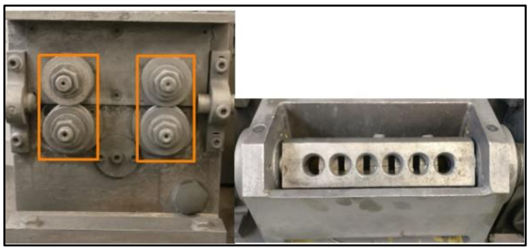


Figure 142 - Traction wheels (left) and straightening rollers (right) of a *Dorca* machine

In the next operation, the wire is cut by the action of a blade and counter-blade pair (Figure 143). It is necessary to periodically verify if the blade is producing shavings, in order to control the blade wear.

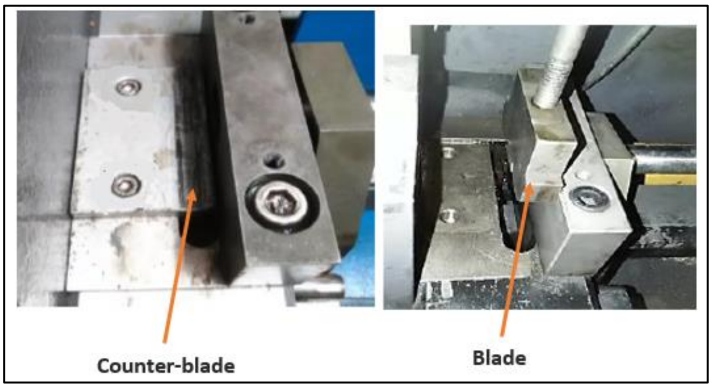


Figure 143 - Blade and counter-blade (*Dorca* machine)

The length of the cut could also be adjusted by the position of a sensor, represented in Figure 144.

Figure 144 – Length of cut sensor (*Dorca* machine)

After the cut, the wire falls into a drawer and the operator periodically transfers into containers (Figure 145) to be transported for the machines that perform the deformation process (TECs).

Figure 145 - Containers with wire straightened and cut in *Dorca* machines

- *Bending process (TEC machines)*

After the wire is cut by Dorca 1 and 6, it is deformed in the eight different TEC machines. This type of machines has an average output of 900 pieces per hour. The manufacturing process of TEC machines is summarized in Figure 146.

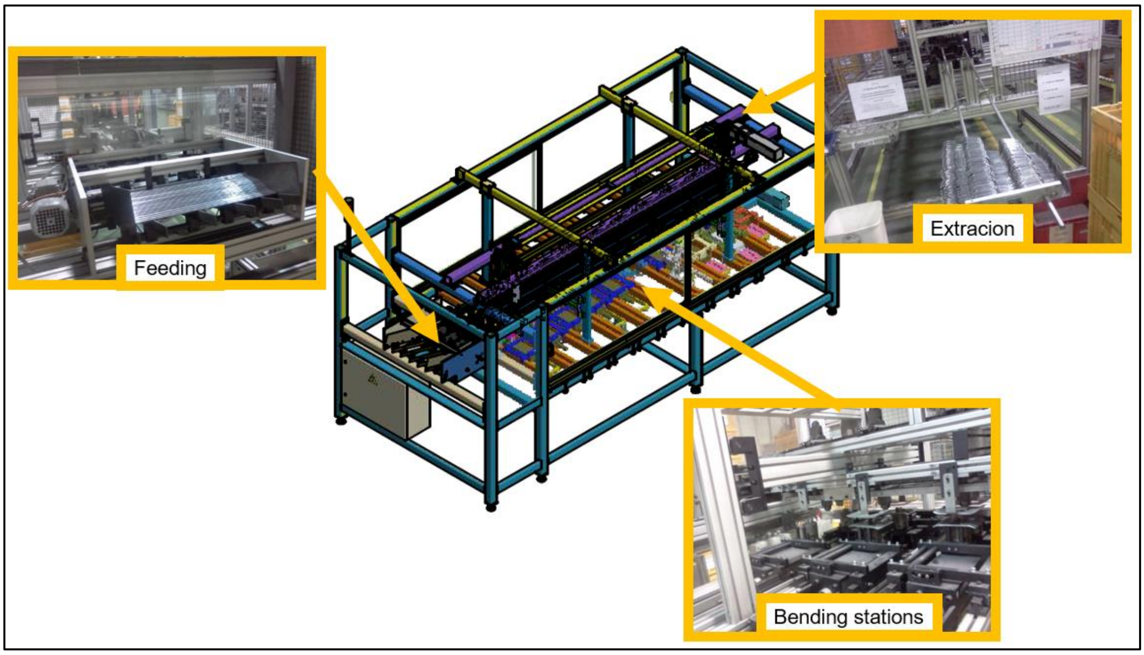


Figure 146 - Manufacturing process of TEC machines

The process starts with the manual introduction of the wires cut by Dorca machines in the feeder (Figure 147). An average of 150 wires is introduced.

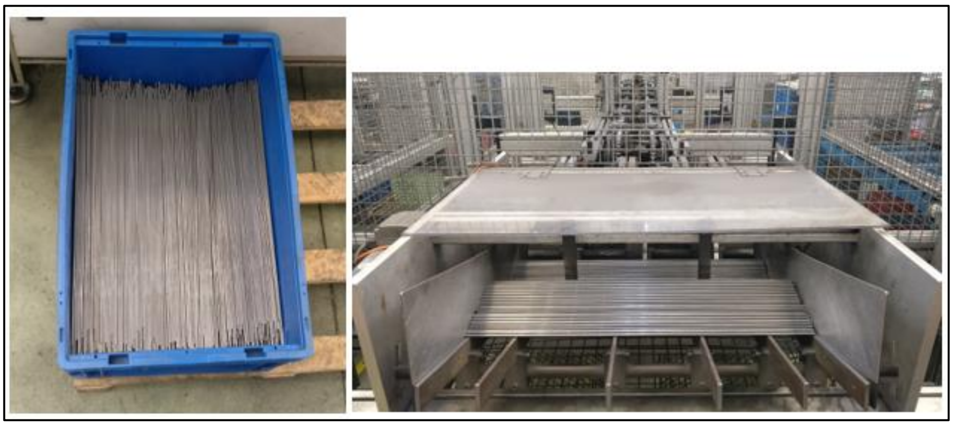


Figure 147 - Container with wire cut by Dorca machines (left) and wire feeding in TEC machine (right)

Then, a claw grabs the wire and moves it over the different conformation operations in the different stations (Figure 148).

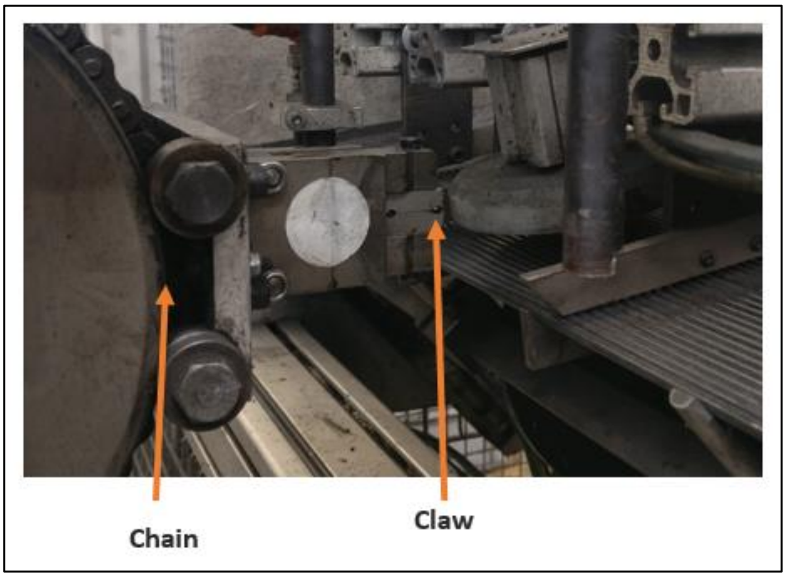


Figure 148 - Mechanism of the claw that grabs the wire from the feeder (*Dorca* machine)

With the movement of the chain, the claw with the wire moves from station to station and all deformation operations are carried out. As an example, the layout of *TEC* 5, as well as the first three bending stations (right side), are represented in Figure 149.

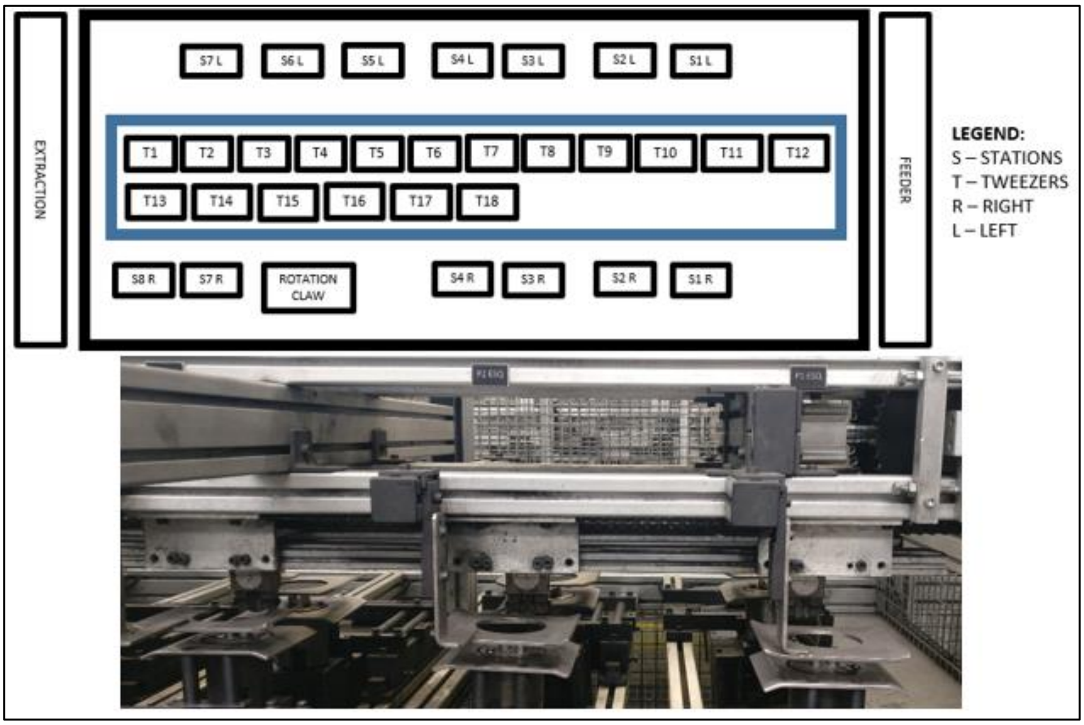


Figure 149 - Layout of TEC 5 (above) and initial bending stations (below)

The different conformation operations are made with the help of tweezers, distributed by the different bending stations. These tweezers rotate, bending the wire with specific radius and angles. In Figure 150 it is represented the tweezer 12 of *TEC* 5 (bending station 1, right side) and an example of all the deformation operations realized in a specific wire as well as the bending stations that perform them.

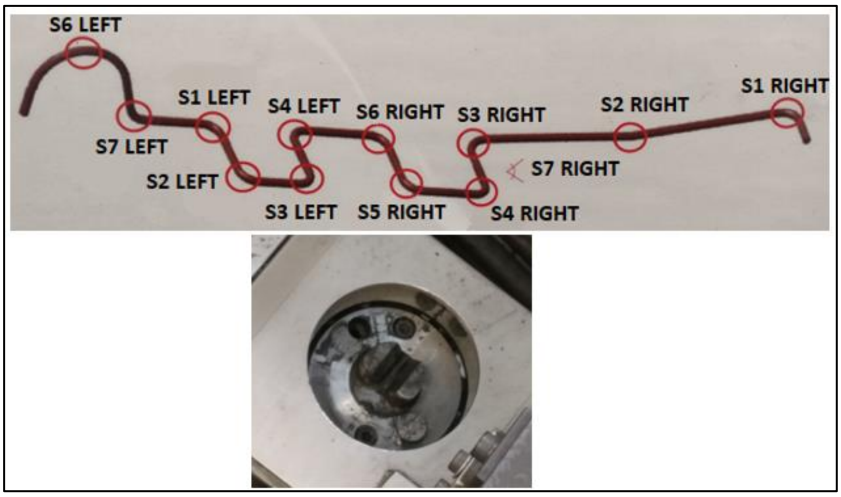


Figure 150 - Bending location of a wire produced in *TEC* 5 (above) and tweezer of 12 (below)

At the end of the deformation operations, an extraction claw grabs the conformed wire and places them into an extraction guide (Figure 151).

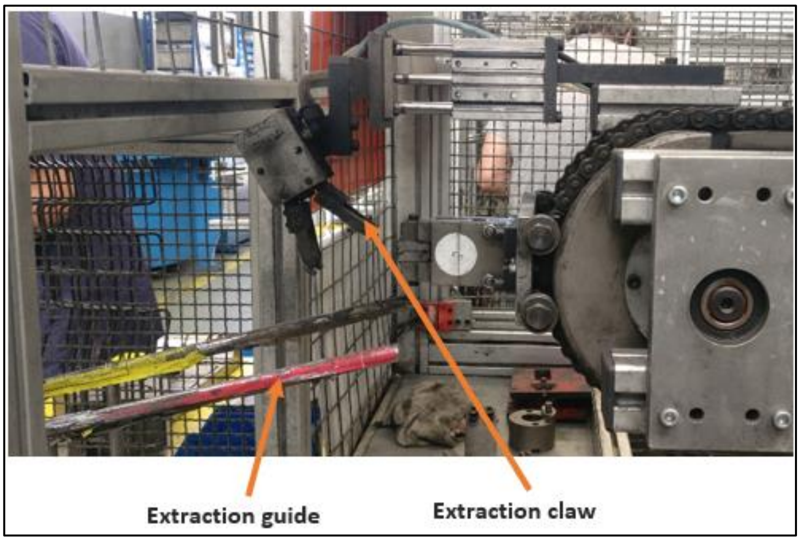


Figure 151 - Extraction claw and extraction guide of TEC 5

As in other bending machines, the operator periodically transfers the wires conformed of the extraction guide into containers that will proceed to the furnace or plastic injection operation (Figure 152).

Figure 152 - Conformed wires on the extraction guide of a *Dorca* machine (left) and on containers to proceed for the next operation (right)

Stage 3 - Heat treatment

Depending on the project that is being produced, some wires need to undergo a heat treatment before the plastic injection operation, in order to relieve internal stresses. The wires, disposed of in boxes with 60 wires each, enter in the electrical furnace and last for a period of 15 minutes at a temperature range between 275°C and 300°C. After exiting the furnace, the wires cool down through the use of fans, before the operator grabs them (Figure 153).

Figure 153 - Entrance of conformed wires in furnace (left) and cooling operation after the heat treatment (right)

In Figure 154 is resumed this heat treatment process.

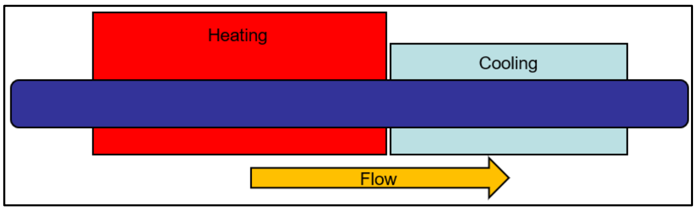


Figure 154 – Heat treatment process

Stage 4 - Plastic injection

The injection sector of the comfort systems of *Fico Cables* is constituted by 22 plastic injection machines. Regarding the manufacturing layout, 20 of the 22 machines are disposed in two rows of 10 machines, separated by a central corridor, arranged two by two, and positioned frontally forming a manufacturing cell. The other two machines are placed in the wire conformation sector. The view of this sector is shown as well in Figure 155.

Figure 155 – Injection sector of the F4 module

The injection molds developed for the manufacture of comfort systems are composed of a mold and a half. This means two lower bushes that are fixed to a sliding table and an upper bushing fixed to the head of the injector, where the spindle is located. This mechanism is represented in Figure 156, as well as an example of the type of injection machines used in this sector. The existent plastic injection machines are considered highly flexible, as almost all of them could receive every mold.

Figure 156 - Type of injection machine used for comfort systems manufacture (left) and constitution of the molds used (right)

The plastic injection process starts with the operator introducing the conformed wires into the corresponding cavities of one of the mold lower bushes (Figure 157). Then, the sliding table moves the lower bush to the head of the injector and the injection operation, by itself, starts. The average cycle time of this operation is between 20 and 25 seconds, with an operating temperature of around 300 °C. The raw material used for the injection is Polypropylene (PP), Polyoxymethylene (POM) or fiberglass, depending on the project that is being produced. For some cases where the plastic zone of the comfort system product is black, it is also used as a pigment.

Figure 157 - Operator placing conformed wires in the mold (left), injection operation occurring (middle) and product after injection operation (right)

Once the injection operation is completed, an automatic extractor removes the comfort system products from the mold and places them into a conveyor. In the next stage of the process, after the quality control, the operator manually places them into packaging boxes containing 100 final products each.

3.4.3.3 Measure stage

In this stage of the DMAIC cycle, it was analyzed the global scrap data of 2017, in order to identify the module and area of the factory that produces the higher value of scrap. Further, it was also created a specific data collection plan with the aim to identify which equipment, shift, type of scrap and adjustment operator (in the case that it was a setup that causes the production of scrap) that contributes more to the value of scrap.

3.4.3.3.1 Observation and data collection

In an initial stage of analysis, with the global values of 2017 (Figure 158), it was identified the module that contributes more to the overall scrap. The module F4 contributes 31% of the total scrap cost and, for this module, the wire bending submodule represents the biggest stake with almost 59%.

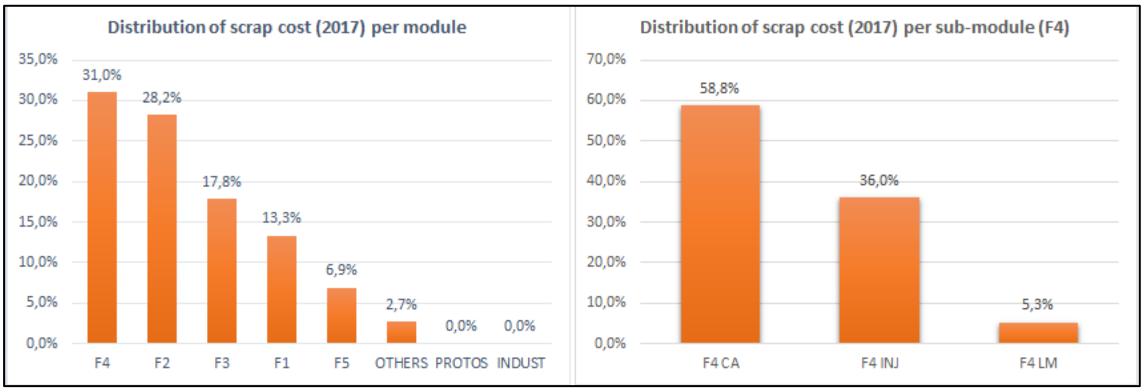


Figure 158 - Distribution of scrap cost per module (left) and distribution of scrap cost per F4 submodule (right)

According to the top-20 references for scrap, the bending wires area of F4 module represents 34% of the total scrap of 2017, that traduces on 69 511€ of scrap cost (Figure 159).

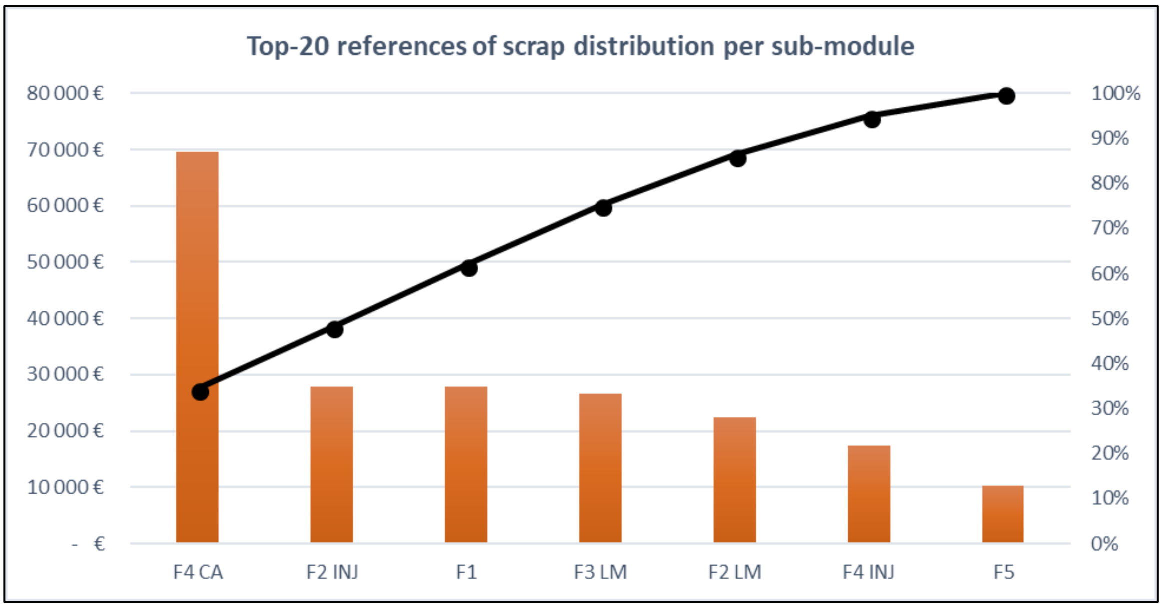


Figure 159 – Top-20 references that contribute to scrap cost per sub-module

After identified the sub-module where there was a major stake in scrap cost, it was necessary to identify which equipment produces a major number of scrap. Compiling the information of scrap present on the respective containers of each equipment, it was possible to identify that the Tecnogial equipment represents more than 25% of the total scrap value of the wire bending sub-module of F4. The combination of the Tecnogial equipment and Dorcas, that supply them, represents around 41% (Figure 160).

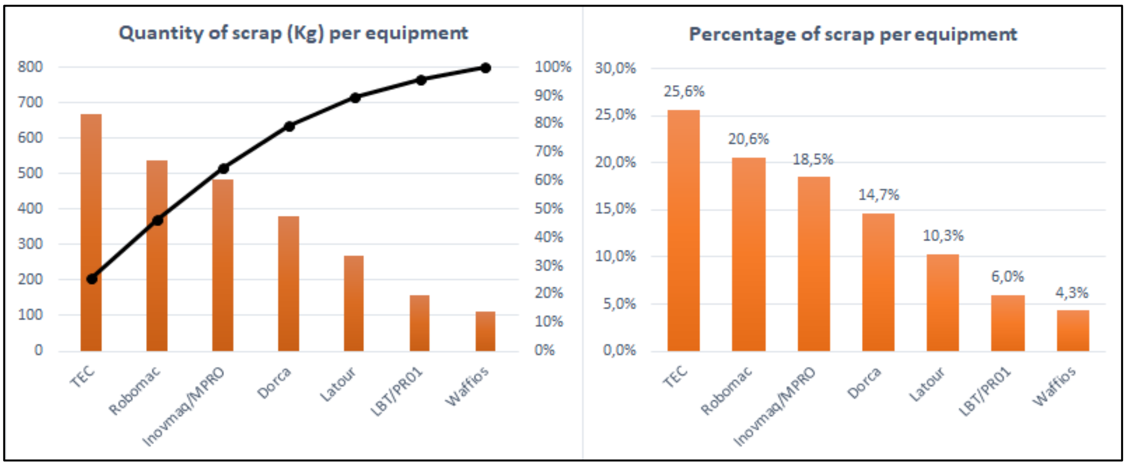


Figure 160 - Quantity (left) and percentage (right) of scrap per equipment

After identified the equipment that causes the major amount of scrap, it was necessary to undergo an accurate and complete data collection plan in order to reach the root causes of the scrap production in them. The previous existent formats of scrap report did not allow to have information as:

- Type of defect;
- Shift;
- Adjustment operator;
- The quantity of scrap over the shift (it was reported all the scrap at the end of the shift).

For this, it was necessary to create a data collection plan with the reformulation of existing formats and the creation of new ones, according to the CTQs previously defined for the project. The data collection plan that was created is defined in Table 66.

Table 66 - Parameters of data collection plan implemented

Data collection plan parameter	Description
What	Weight of scrap (kg)
How	The quantity of scrap placed on the container
Time	From January 2018 until the final of the project
Frequency	Every day

The different segmentation factors identified and included for this data collection plan are represented in Table 67.

Table 67 - Segmentation factors of the data collection plan

Segmentation factor No.	Description
1	Equipment
2	Shift
3	Adjustment operator
4	Type of defect
5	Raw material traction effort

In order to create a new scrap report sheet template, it was necessary to understand the sources of scrap and the variables associated with the equipment previously identified (Figure 161).

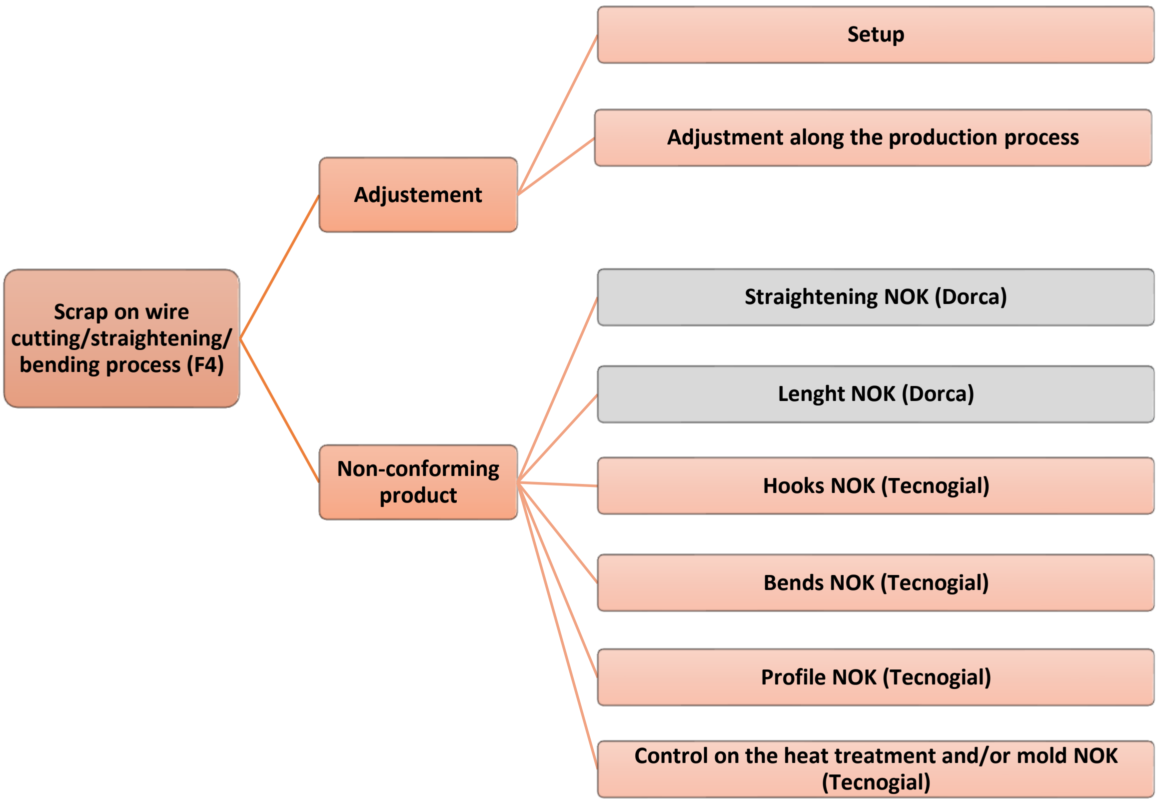


Figure 161 -Types of scrap sources and variables associated with the Tecnologial and Dorca equipment

In Figure 162, it is presented an example of scrap report using the created scrap sheet template. In the first row, on the February 19th and during the 2nd shift, at 21:00, Dorca 1 has produced 3.280 kg of scrap by adjustments and 0.800 kg by the straightening process, for the wire with the reference AR1302W2. In the second row, it was reported instead 0.500 kg of scrap by setup and 0.200 kg by non-conforming length.

Dia	Hora	Descrição do Equipamento / Ref. Arame		A	B	C	Causa / Quantidade (Kg)				
(dd-Mmm)	(00:00)			(ok)	(ok)	(ok)	AFINAÇÃO / SETUP / AVARIA	PRODUÇÃO Endireitamento	PRODUÇÃO Comprimento	BNC (nr BNC+Quant.)	OUTROS (colocar comentário)
19-Fev	21:00	Dorca 1	ref. AR1302W2				3,280 Kg	0,800 Kg			Afinação
19-Fev	05:00	Dorca 3	ref. AR13180E00				0,500 Kg		0,200 Kg		Setup

Figure 162 – Example of scrap report using the scrap sheet template

This initial data collection allowed to identify which equipment contributed more to the quantity of scrap produced, as it is visible in Figure 163. This data refers to the period between the beginning of January and the end of April.

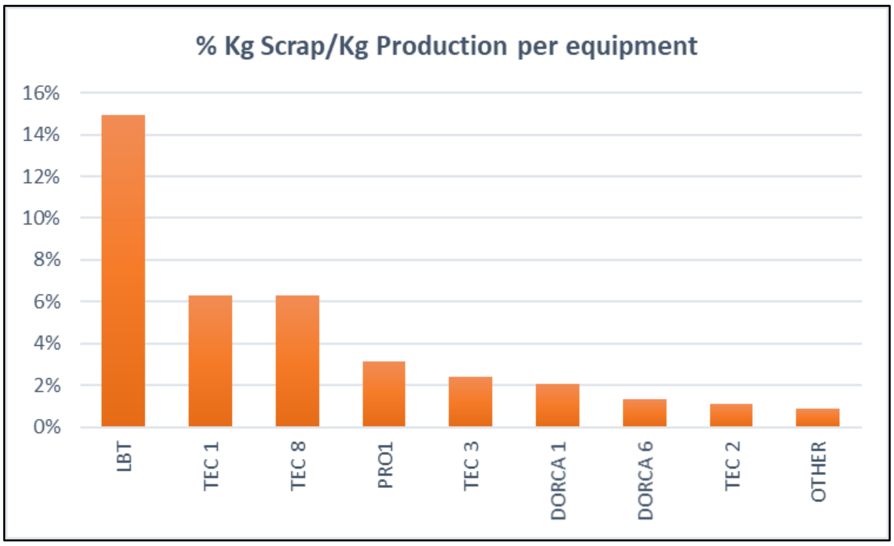


Figure 163 - Distribution of the ratio of scrap produced/quantity produced by equipment

The LBT, Tecnogial 1 and 8 are the equipment with a bigger ratio between the amount of scrap produced and the total quantity produced (Figure 163). The LBT stands out with a much higher percentage than the other equipment. This percentage allows visualizing a more real and accurate scenario in terms of scrap production, as it extrapolates the difference in quantity produced between the different equipment.

However, in terms of the total amount of scrap produced, the Tecnogial 8 and the LBT are the equipment that produces the higher quantity of scrap (in kg) (Figure 164).

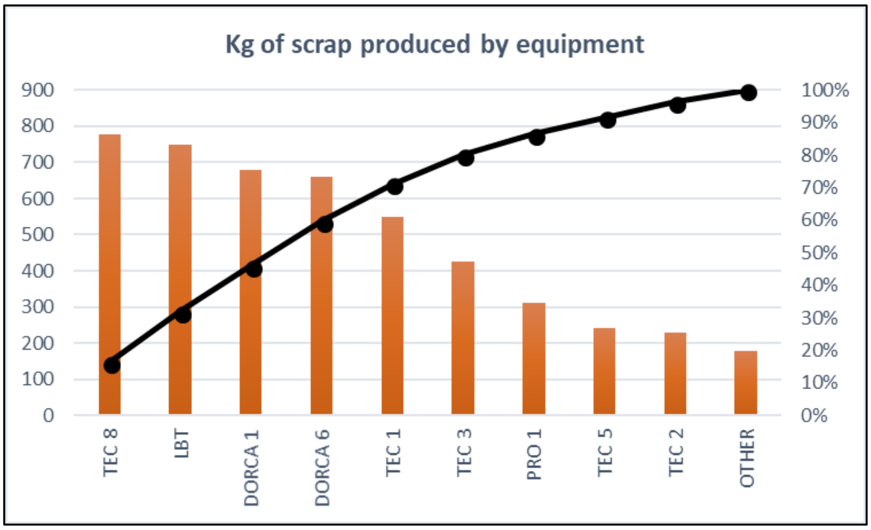


Figure 164 -Distribution of quantity of scrap produced by equipment

In terms of distribution per shift, the shift 1 and 2 are similar while the third shift has the smaller quantity of scrap per the total amount of scrap produced (Figure 165).

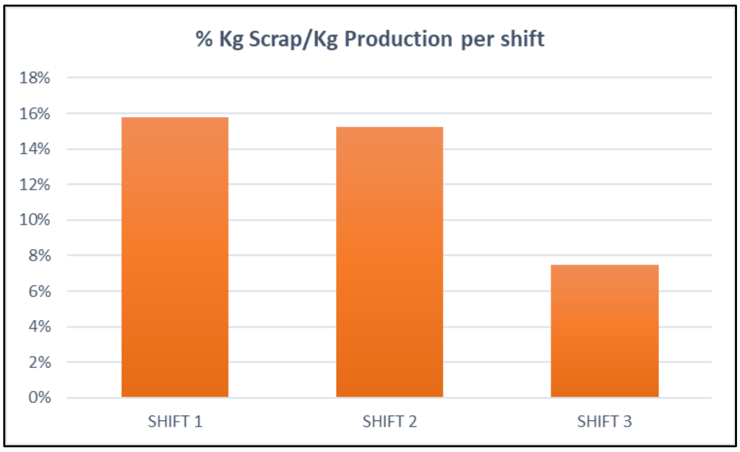


Figure 165 - Distribution of the ratio of scrap produced/quantity produced by the shift

In terms of distribution of the results, the first and the second shift has a higher dispersion, with a lot of outlier values, while in the third shift the dispersion is fewer, as it could be seen in Figure 166.

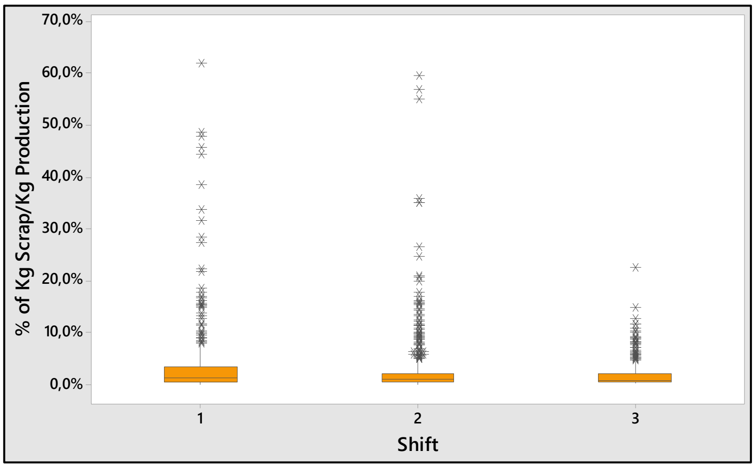


Figure 166 – Boxplot with distribution of the ratio of scrap produced/quantity produced by shift

According to the scrap source, it was made a box plot graph in order to understand the distribution and dispersion of data for each source. In terms of breakdowns, BNCs, maintenance interventions, and heat treatment, the values could be disregarded as they represent one-off situations (Figure 167).

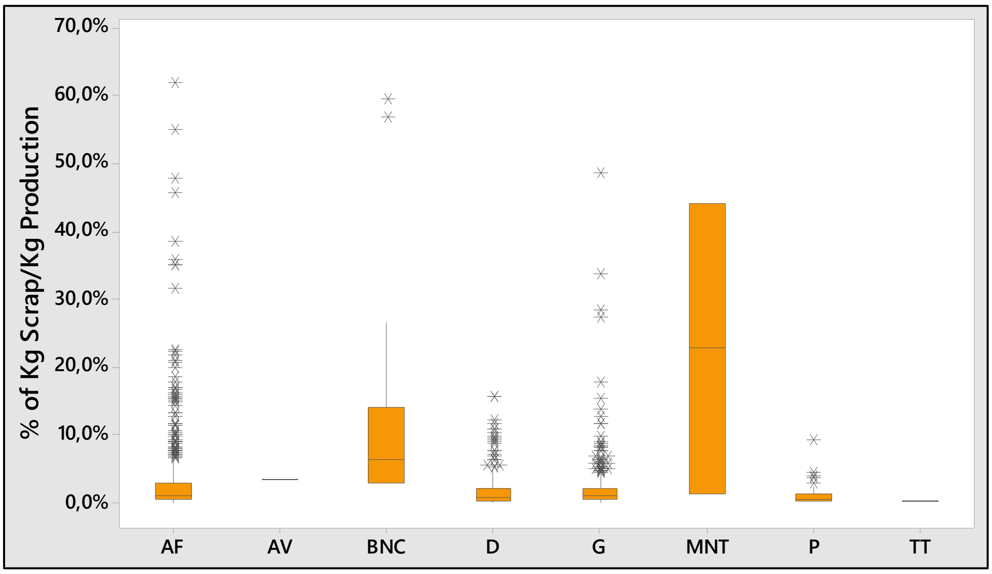


Figure 167 - Boxplot with distribution of ratio of scrap produced/quantity produced by source of scrap

The evolution of the data related to the percentage of the ratio between the amount of scrap produced and the total quantity produced is visible in the control chart present in Figure 168. There is a high amount of values above the upper control limit, that is automatically calculated according to the mean (a distance of 3σ from the mean). This control chart shows that the process is not systematic over the time.

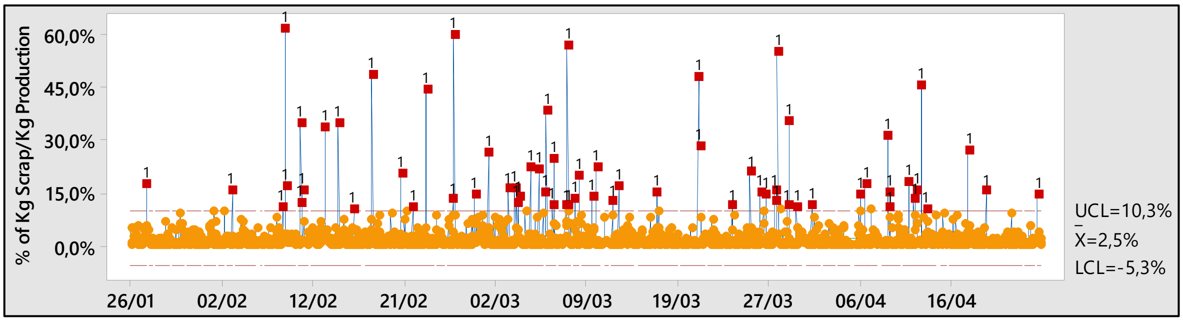


Figure 168 – Control chart with evolution of ratio of scrap produced/quantity produced

Dividing by the equipment that has a bigger contribution for the amount of scrap, and starting by Dorcas (1 and 6), the distribution of ratio between the amount of scrap produced and the total quantity produced is similar in all shifts (but there is a bigger number of reports for the first shift). Also, between the Dorca 1 and 6, the distribution of data is also similar, with the exception of the outlier for Dorca 1 (Figure 169).

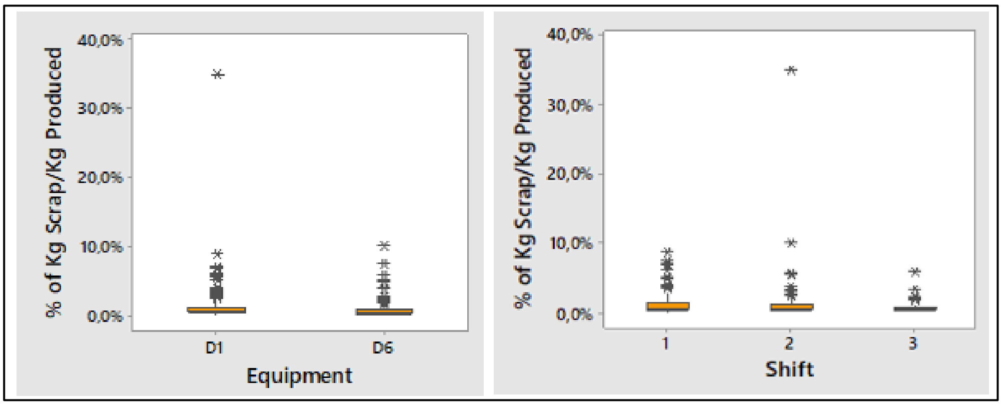


Figure 169 - Boxplot of Dorca equipment ratio of scrap produced/quantity produced by shift (left) and by each equipment (right)

For the Tecnogial 8 equipment, the first shift stands out with a lower performance than the others. In terms of sources for the scrap, the main cause is during the adjustment operations, as it could be seen in Figure 170.

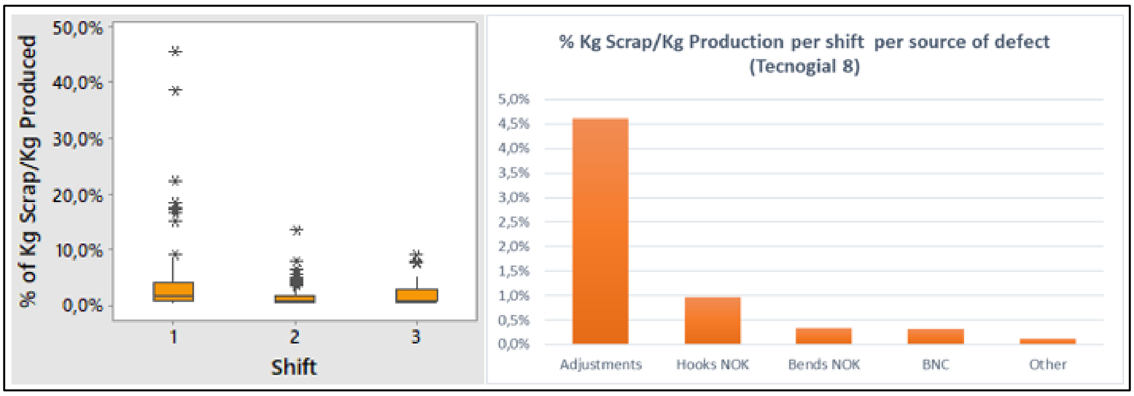


Figure 170 - Boxplot with Tecnogial 8 distribution of ratio of scrap produced/quantity produced by shift (left) and by source (right)

On the LBT equipment, the performance per shift is lower on the second shift, in terms of average values of the ratio between the amount of scrap produced and the total quantity produced. The second shift has also a bigger dispersion of values and higher outliers. In terms of the source of scrap, the adjustment operations are also the major one, but in this equipment, the hooks and bends NOK appear closer (Figure 171).

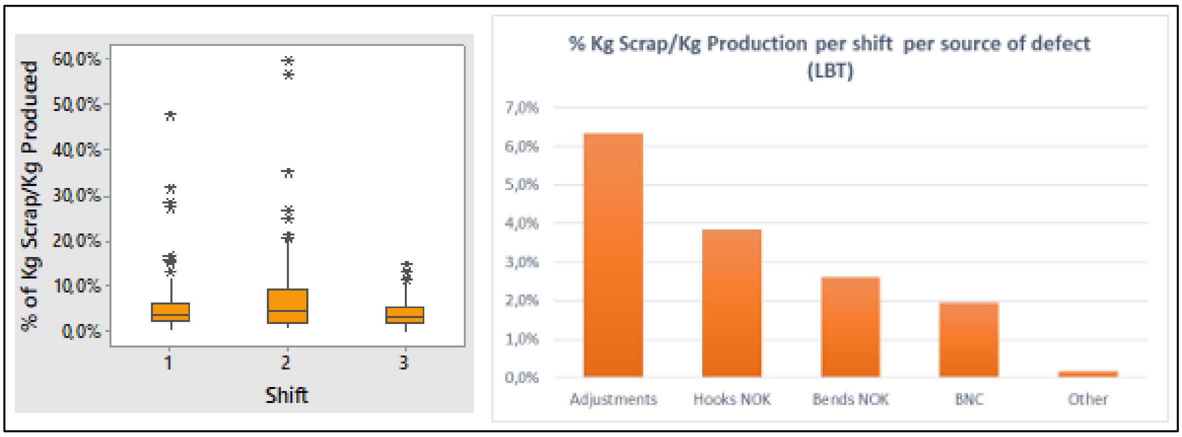


Figure 171 - Boxplot with LBT distribution of the ratio of scrap produced/quantity produced by shift (left) and by source (right)

For the Tecnogial 1 equipment, the data collected do not show a major difference between the different shifts (as visible in the Figure 172). Also, in terms of the source for the production of scrap, the adjustment operation represents the major one and the hooks NOK appear again closer to the main source.

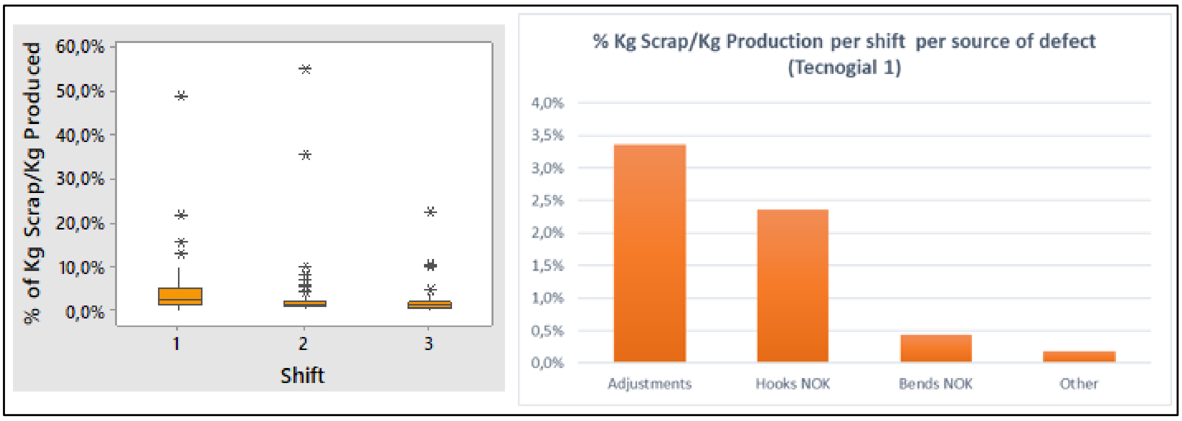


Figure 172 - Boxplot with Tecnogial 1 distribution of ratio of scrap produced/quantity produced by shift (left) and by source (right)

With this data collected during the *Measure* stage of the DMAIC cycle it was possible to undergo the necessary analysis about the factors and the root causes that causes the excessive amount of scrap verified.

3.4.3.4 Analyse stage

The initial data collection process allowed to identify the most critical equipment in terms of quantity of scrap produced and in terms of the ratio between the scrap produced versus the total quantity produced. The most critical equipment that was identified, in terms of the percentage of scrap per quantity produced, was the LBT and the Tecnogial 1 and 8. Also, the most frequent source of scrap that was identified is during the adjustment process.

In order to reduce this type of scrap, it was carried out brainstorming sessions with the support of the six sigma team members and operators/adjustment operators specialized in the respective equipment. These brainstorm sessions had the aim to reach the root causes through Ishikawa and *5 Why's 2 How're* technique (activity checklist with 5W – what, why, where, when and why – 2H – how and how much). For the root causes that were identified, it was further defined improvement actions plans for each equipment.

LBT equipment

The equipment LBT was the second major responsible for the scrap production among every equipment of the type Tecnogial and Dorca and related to the period between January and April of 2018, with 748 kg of scrap. This value corresponds to 15% of the total quantity produced of this equipment and for the same period, being the machine with the highest ratio quantity of scrap/quantity of production. The major scrap cause in this equipment is during the adjustment and setup operations by the adjustment operator, with 42.7%.

In Table 68 is represented the respective definition of the scrap problem on the LBT equipment with the help of the 5W2H technique.

Table 68 – a 5W2H technique to define the scrap problem on the LBT equipment

5W2H	Description
What?	% of kg Scrap/kg Produced and kg Scrap elevated
Where?	LBT equipment
Who?	Adjustment operator
When?	Data between January and April 2018
Why?	A major contributor for the % of scrap of the total quantity produced on wire straightening/bending process
How?	During adjustment/setup operations
How much?	15% of scrap/quantity produced; 748 kg of scrap

In Figure 173, it is represented the developed Ishikawa diagram for this equipment, with the major root causes for the defined problem.

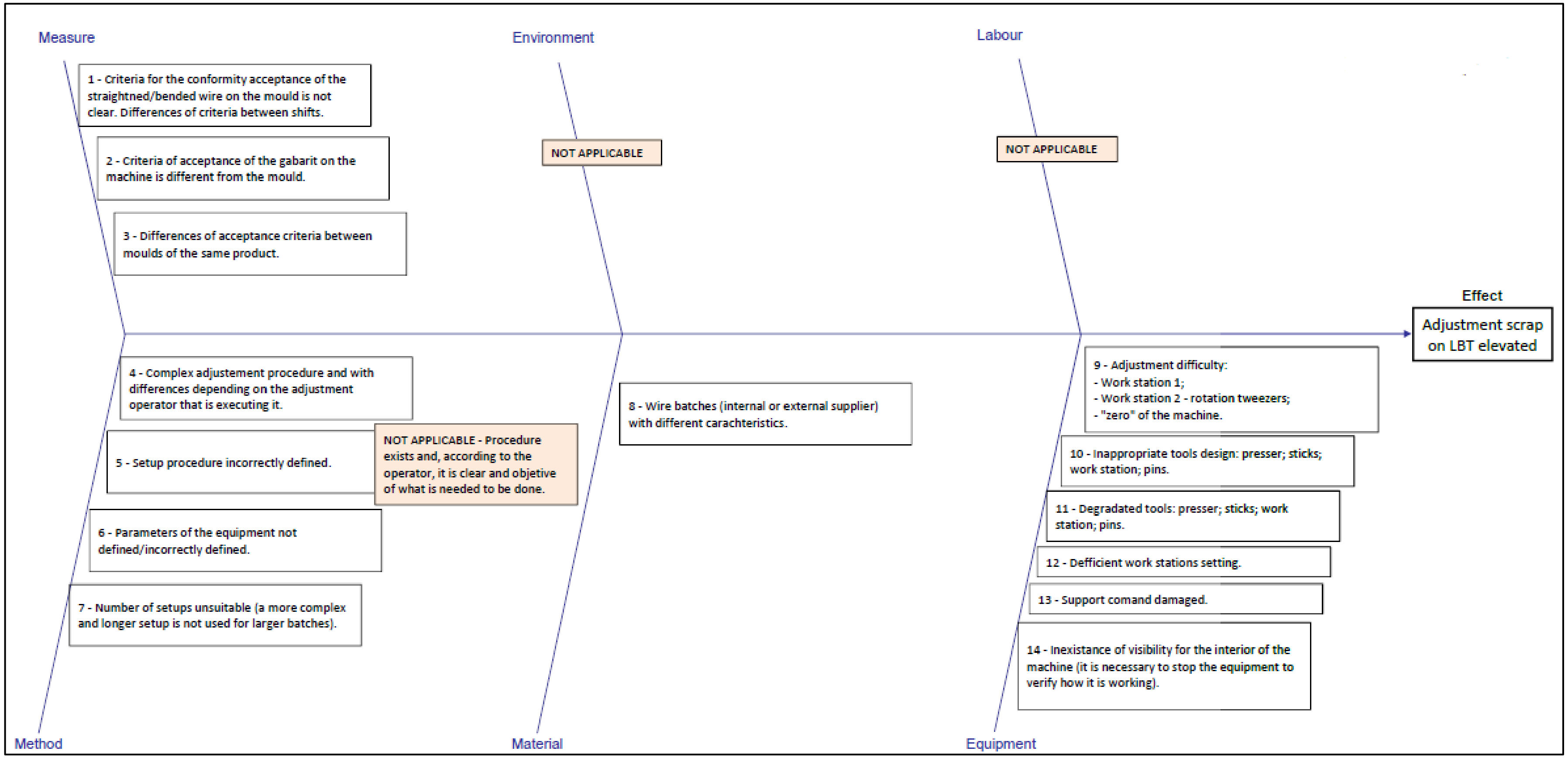


Figure 173 - Ishikawa diagram related to the scrap produced during the adjustment process on the LBT equipment

Tecnogial 8 equipment

For the same period of data collection, the Tecnogial 8 equipment represents the second biggest contributor in terms of percentage/ratio of scrap produced of the total quantity produced with about 6% (alongside with the Tecnogial 1 equipment), but it is the major contributor in terms of kg of scrap produced, with 778 kg. The major cause identified for the scrap production in this equipment was the adjustment process/setup performed by the correspondent adjustment operator.

In Table 69 is represented the respective definition of the scrap problem on the Tecnogial 8 equipment with the help of the 5W2H technique.

Table 69 - a 5W2H technique to define the scrap problem on the Tecnogial 8 equipment

5W2H	Description
What?	% of kg Scrap/kg Produced and kg Scrap elevated
Where?	Tecnogial 8 equipment
Who?	Adjustment operator
When?	Data between January and April 2018
Why?	A major contributor for the quantity of scrap on wire straightening/bending process
How?	During adjustment/setup operations
How much?	6% of scrap/quantity produced; 778 kg of scrap

The respective root causes identified for the defined problem and related to the Tecnogial 8 equipment are represented in the Ishikawa diagram presented in the Figure 174.

The unclear adjustment procedures, the quality acceptance criteria, the ineffective number of setups needed as well as the degradation of some key components and tools of the Tecnogial 8 equipment represents the biggest root causes for the excessive production of scrap in this equipment.

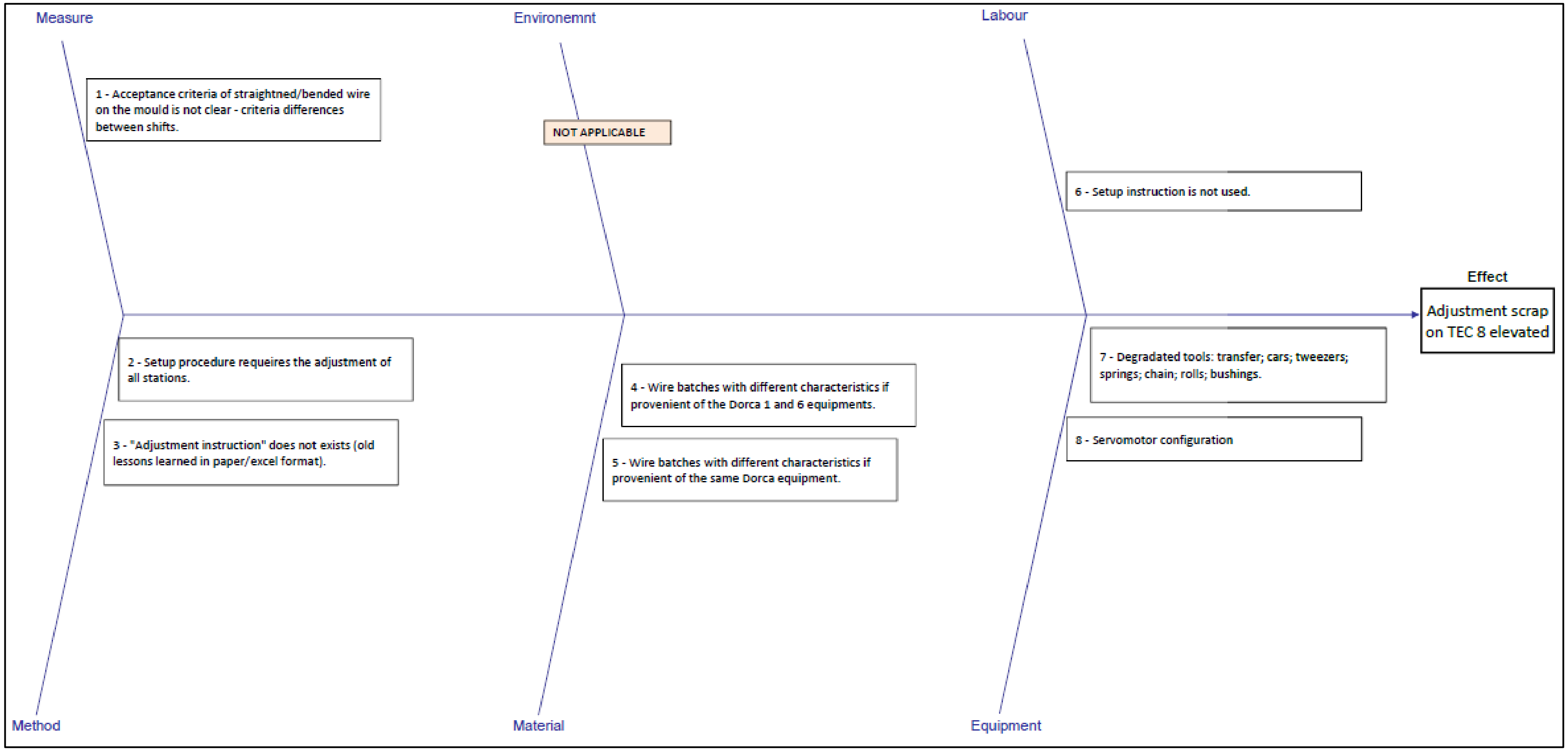


Figure 174 - Ishikawa diagram related to the scrap produced during the adjustment process on the Tecnogial 8 equipment

3.4.3.5 Improve stage

With the support of the data collection plan that was implemented, the experience of workers as operators, adjustment operators, the maintenance team, the processes team and the F4 production director and based on the developed Ishikawa's, it was possible to define improvement actions with the aim to reach the main goal of this project: reduce the quantity of scrap on the comfort systems module.

3.4.3.5.1 Definition of improvement actions

Based on the developed Ishikawa diagrams for the equipment and on the 6M method for cause and effect analysis (*Manpower, Machinery, Materials, Method, Mother-nature, Measurement*), that is frequently used on six sigma projects, it was possible to identify the elements that contribute to the variation in the process, there was defined a set of improvement actions. These improvement actions were also added by knowledge of the area and by the contribution of workers, maintenance team, quality control team, and production direction team.

LBT equipment

Table 70 -Potential causes for scrap production on the adjustment process and respective Improvement actions defined (LBT)

6 Ms	#	Potential cause	Improvement Action
Method	1	Complex adjustment process and with differences depending on the adjustment operator that performs it.	Replacement of tools to allow a faster setup and creation of detailed and precise setup instruction.
	2	Equipment parameters not defined or incorrectly defined.	Define all equipment parameters after implement improvement actions.
Machine	3	The difficulty with the adjustment process (rotation tweezers of workstation 1 and 2; “zero” of the equipment).	To be realized on the second phase of intervention (depends on the implementation of improved tools).
	4	Degradation tools: presser, sticks, workstation, pins and wire guide.	Replace tables, pressers, pins, bend tools, and wire guides.
	5	Deficient workstations fixation.	Repair old workstation welding's.
	6	Damaged controller.	Replace parameters and equipment movements controller.
	7	Inexistence of visibility for the interior of the machine.	Change the location of support documentation and the production board.

Tecnogial 8

The improvement actions defined for this equipment were also based on the respective Ishikawa diagram and they are summarized in Table 71.

Table 71 - Potential causes for scrap production on the adjustment process and respective Improvement actions defined (Tecnogial 8)

6 Ms	#	Potential cause	Improvement Action
Measure	1	Lack of visualization of scrap on this equipment by type of defect.	Divide scrap containers according to the type of defect.
Method	2	Adjustment process requires the change of all workstations.	Budget approval to "lock the center of the equipment" and to change the headers.
Machinery	3	Degradated tools of the transfer mechanism: cars; tweezers; springs; chains; rolls; bushings.	Evaluate tools replacement.

Dorca 1 and 6

Table 72 - Potential causes for scrap production on the adjustment process and respective Improvement actions defined (Dorca 1 and 6)

6 Ms	#	Potential cause	Improvement Action
Measure	1	Inexistence of enough data stratification reported.	Introduction of the data collection plan for Dorca 1 and 6.
Method	2	Adjustment process requires the change of all workstations.	Budget approval to "lock the center of the equipment" and to change the headers.
	3	Inherent variation of the process in this equipment is not controlled.	Introduction of a control workstation next to Dorca equipment.
	4	Setup times increased by lack of information about Dorcas planning.	Definition of a visual method of production planning for Dorca equipment by shift.
	5	Stoppage for adjustment in the change of shift.	Definition as a standard procedure to perform cleaning operations on Dorca equipment only at the end of the wire reel.

3.4.3.5.2 Implementation of improvement actions defined

LBT equipment

Replace tables, pressers, pins, bend tools, and wire guide

On the equipment with the highest ratio in terms of quantity of scrap produced by the quantity of production, it was crucial to carry out a deeper intervention in order to reduce the values of the scrap. All the stations were intervened, modifying the bend tools, wire guides, pressers, and pins.

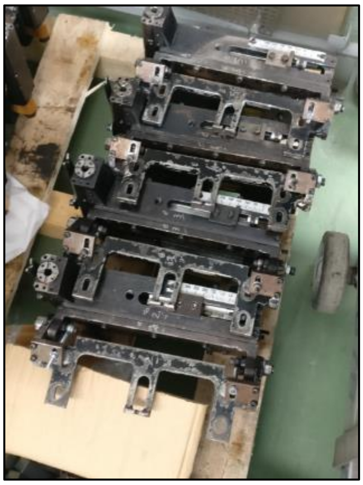


Figure 175 - LBT old stations after being removed

In Figure 176, it is visible the old combination of bend tools and wire guide as well as the new one. This new wire guides allows to improve the fixation of the wire and prevents it to move with small punches and jams on the machine, resulting in necessities of adjustment interventions.

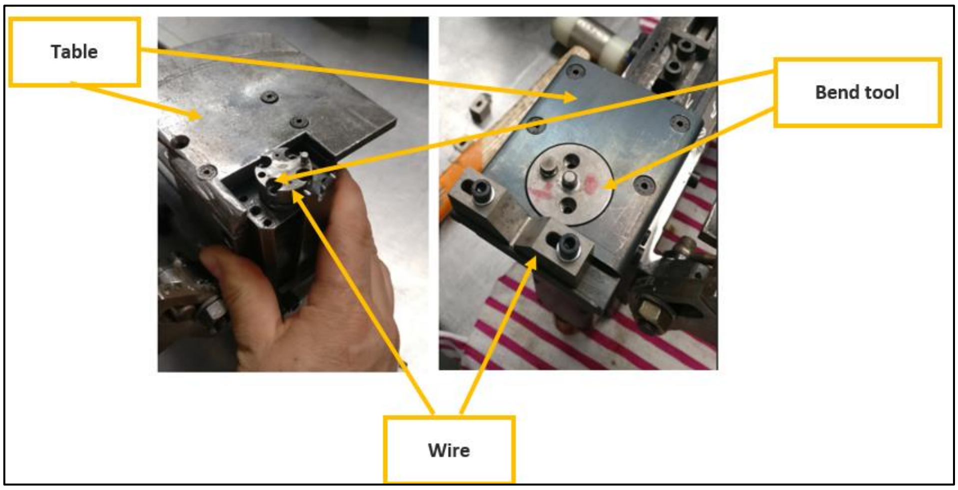


Figure 176 - Main intervention on the LBT stations

Change the location of support documentation and the production board

It was visible that an excessive quantity of documents was all over the walls of the LBT equipment. This did not to properly visualize for the interior of the equipment, being necessary to stop the equipment and open the gates in order to verify any kind of situation. The previous scenario of the equipment is represented in Figure 177.

Figure 177 - Excessive quantity of information on the sides of LBT equipment

After removing all the documentation, it was then adapted an old support to place the production board and to store the removed documentation. This support was placed alongside the LBT equipment and every document space was properly identified in order to keep documents organized and easily consulted (Figure 178).

Figure 178 - New document organization (LBT equipment)

Once the sides of the LBT equipment was cleared it was possible to easily visualize and control the operation of the equipment without needing to stop it and open the gates (Figure 179).

Figure 179 - LBT equipment after removing the excessive documentation

Dorca equipment

Introduction of the data collection plan for Dorca 1 and 6

It was created new templates for scrap reporting to could visualize more information about the scrap on this equipment. It gives visibility about the equipment where the scrap was produced, the reference of the wire, the source of scrap (adjustment, breakdown, setup), the cause (cut or straightening) and the corresponding weight. The template of this scrap report is represented in Figure 180.

Contentor Nº ☐ A= Parar e analisar; B= Usar lição aprendida; C= Confirmar eficácia "Trem" de recolha por turno

Dia (dd-Mmm)	Hora (00:00)	Descrição do Equipamento / Ref. Arame		A (ok)	B (ok)	C (ok)	Causa / Quantidade (Kg)					Team L. (rúbr.)	Superv. (rúbr.)	Dir.Prod. (rúbr.)
							AFINAÇÃO / SETUP / AVARIA	PRODUÇÃO Endireitamento	PRODUÇÃO Comprimento	BNC (nr BNC+Quant.)	OUTROS (colocar comentário)			
		Dorca 1	ref.											
		Dorca 3	ref.											
		Dorca 4	ref.											
		Dorca 5	ref.											
		Dorca 6	ref.											
		Dorca 7	ref.											

Figure 180 - Scrap report for Dorca equipment

Definition of a visual method of production planning for Dorca equipment by the shift

Through the observation of different setups, it was visible that the adjustment operator spends too much time identifying the next wire reference to be straightened/cut on the respective Dorca equipment. It was necessary for the team leader to verify the existent quantity in stock, in a number of boxes available, of each straightened/cut wire reference in order to verify which ones are the most necessary to produce. This was caused because there are no production planning for this type of equipment, as there are for Tecnogial equipment, for example.

To reduce this setup time and to have a better management of stock on Dorca equipment, it was designed a board to be placed next to this equipment area, allowing to easily visualize the actual stock, as well as the corresponding minimum and maximum allowed, for each wire reference. Also, the responsible for each Dorca equipment could fill the bottom of the board with the reference(s) that will be produced in the present shift.

As the main cause for the scrap production is the adjustment process it is vital to only perform setups when it is really needed and to take the most advantage of the current configuration. This board allows to easily visualize the present needs in order to perform the minimum setups needed and to minimize the effect of the inexistence of production planning for this equipment.

The respective board template and its presence on the production floor are represented in Figure 181.

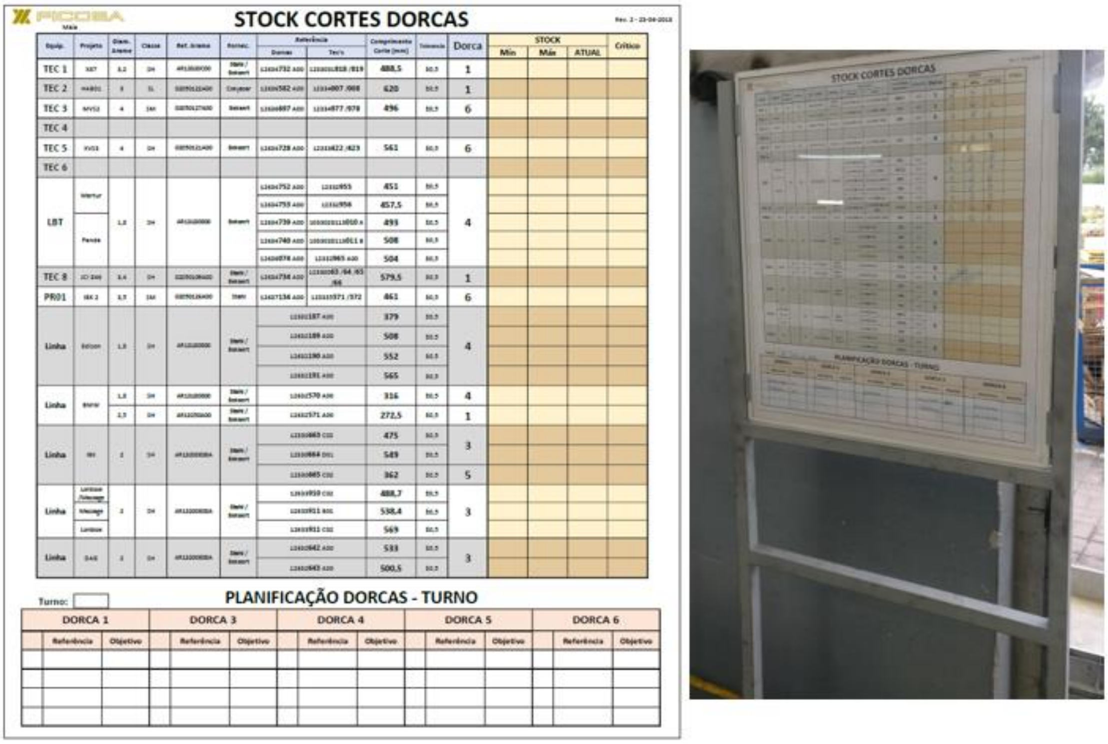


Figure 181 – Dorca equipment stock management board template (left) and presence on the gemba (right)

<u>Definition as a standard procedure to perform cleaning operations on Dorca equipment only at the end of the wire reel</u>

It was verified that, at the end of every shift, was made a stoppage for cleaning operations included in the first maintenance level program. These cleaning operations are carried out in the rotating drum and straightening rollers but there is no necessity to clean these components every eight hours. Also, with the increase in the number of interventions on the equipment, there is a bigger risk to produce scrap as a result of unnecessary operations.

So, it was defined as a standard that these cleaning operations on these components must only be performed at the process of changing the wire reel, except if it is detected any unconformity in the control operations by the operator, as for example the validation of quality conformity for the first unit produced or other auto controls. This information was placed next to the equipment in order to be visible for every operator (Figure 182).

Figure 182 - Cleaning operations standard for Dorca equipment

Introduction of a control workstation next to Dorca equipment

One situation that was verified is that straightened/cut wire batches from different Dorca equipment (1 and 6) and even from the same Dorca equipment has different characteristics. This is caused by the inherent variation of the process in this equipment.

In order to minimize this effect and to prevent an excessive quantity of NOK wires to be produced, it was implemented a control workstation next to this equipment, as represented in Figure 183.

Figure 183 - Control workstation for Dorca equipment

In this equipment are performed two control operations: wire gauge control and wire bend validation, which are carried out to support the validation of quality conformity for the first unit produced.

In the wire gauge validation, the wire is introduced in the respective gauge (according to the thickness of the wire) and it needs to fall through the gauge in order to validate the correct straightening operation (Figure 184). If this situation does not happen, the adjustment of the respective Dorca equipment needs to be rectified.

Figure 184 – Gauge for straightening validation

For the wire bending validation (Figure 185), it is performed a bend operation in the straightened wire and it is verified if it fits in the jig groove without any type of effort. This control is made with the aim to verify the respective mechanical characteristics of the raw wire and if the adjustment parameters are properly configured.

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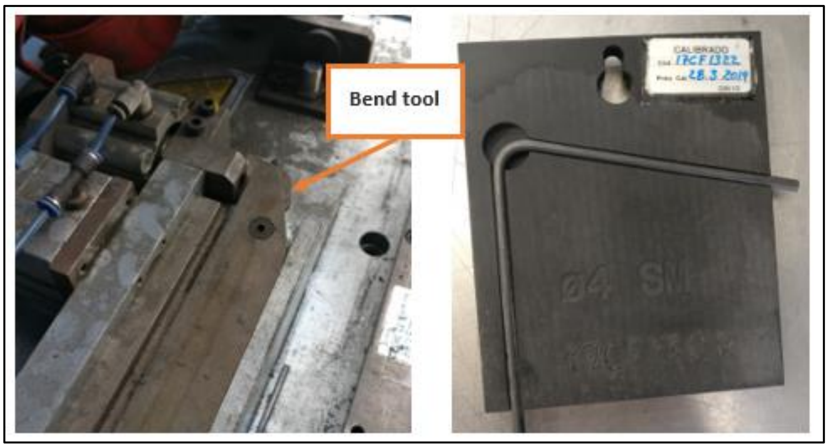


Figure 185 - Wire bending tool of the control workstation (left) and wire bend jig (right)

Tecnogial equipment

<u>Divide scrap containers according to the type of defect</u>

For the creation of the data collection plan, it was identified that, on Tecnogial equipment, the scrap produced was not being separated according to the type of defect detected during the production. Because this information was not being collected it could not also be reported and, more important, be analyzed for future projects and problem-solving purposes.

With the aim to solve this problem, the existent scrap containers were divided into compartments for each major possible types of defects:

- Hooks NOK;
- Bends NOK;
- Profiles NOK.

The respective scrap containers with the specific compartments according to the type of defect are represented in Figure 186.

Figure 186 - Scrap container before (left) and after implementation of compartments according to the type of defect (right)

Most of the improvements actions that were planned for this project were not finished by the end of the internship. These actions were related mostly to the purchasing of new tools for replacement and represent the most important interventions and improvements that will allow reproducing the desired results in terms of the scrap produced.

3.4.3.6 Control stage

The LBT was one of most critical equipment regarding the scrap production, being the one with the highest percentage of the quantity of scrap per quantity of production (kilograms) and the second most representative in terms of kilograms of scrap produced.

Also, in terms of improvement actions completed, the LBT was the equipment that could receive the most complete and deep intervention, with an higher number of actions, replacing the most important tools.

In Figure 187, it is represented a control chart regarding the variable *quantity of scrap produced per quantity of production*. After completing this main intervention, on August 3rd, it is visible that the values have a lower dispersion between them, comparing to the period before the intervention where it is visible a bigger variety of values.

The control limits are tighter for the correspondent period after the intervention, that has an average value of 4.9%, with the superior moving from 23.8% to 16.0% and the inferior from -8.9% to -6.1%.

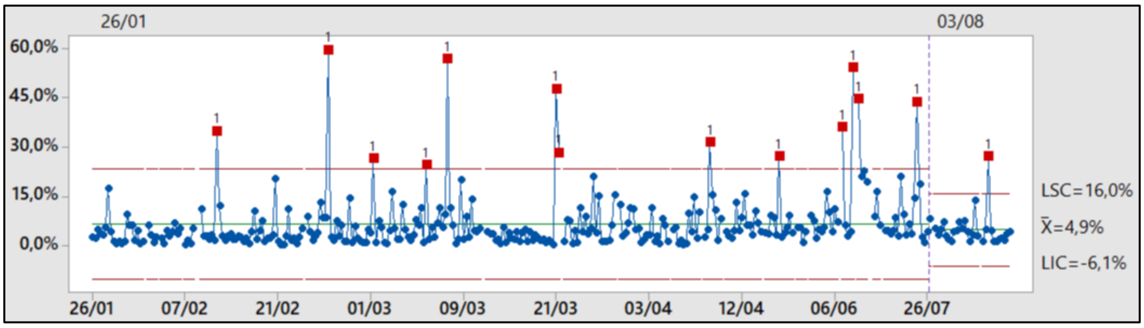


Figure 187 - Control chart of quantity of scrap per quantity produced (LBT)

However, the modifications that were made change the daily work of the adjustment operators, that have to adapt themselves and be comfortable with such modifications in order to get the best results.

3.4.4 Critical analysis of results

Since the start of the project, at the beginning of 2018, the scrap cost value per month has been gradually reducing, as it is visible in Figure 188.

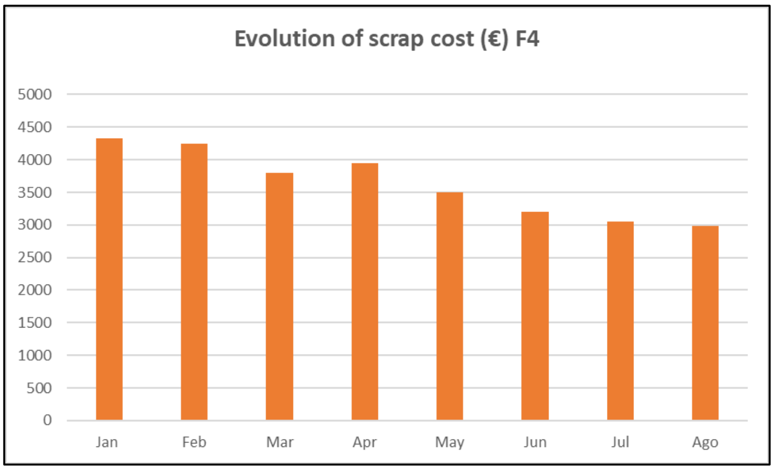


Figure 188 - Evolution of scrap cost (€) during the beginning of the project

In terms of equipment, for the LBT equipment, where it was implemented the major improvement actions, it is already visible a positive effect. This equipment was identified as the top producer of scrap for the first four months of the year. In the weeks before the intervention, it was produced between 40 and 60 kg of scrap per week, representing, on average, about 15% of the production. After two weeks of the intervention of this equipment, it was noticed that the defined improvements allowed to reduce the quantity of scrap produced for values between 25 and 35 kg, on the first four weeks of activity (Figure 189).

It is common that this value reduces in the month of August due to the diminution of demand. However, it is visible that, in relation to the quantity produced, the amount of scrap represents a lower portion, confirming that the implemented modifications led us to expectable results.

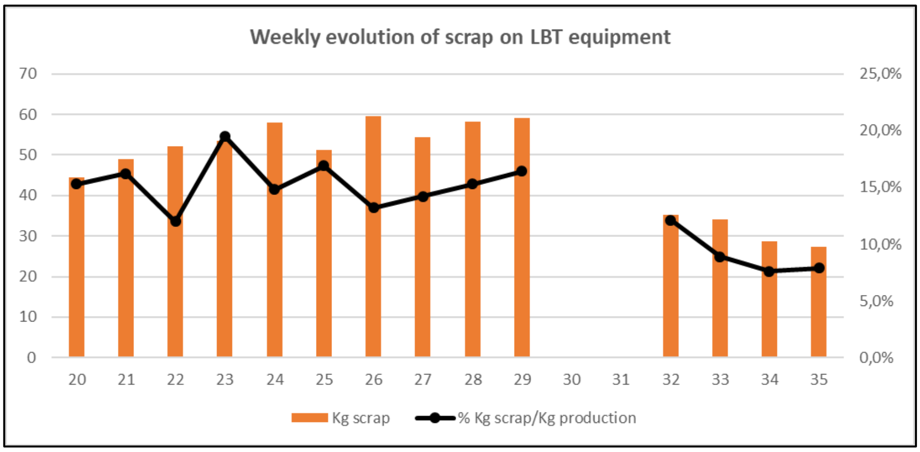


Figure 189 - Weekly evolution of scrap on LBT equipment

Relating to the Dorca 1 and 6, the implementation of the improvement actions with a focus on reducing the number of unnecessary interventions, promoted some positive results, as visible in Figure 190. For Dorca 1, values of scrap quantity of around 160 kg starting to become closer of the

140 kg, as well as on the Dorca 6 equipment where it was produced about 150 kg per month of scrap and now it is visible values close to 140 kg.

In the month of August, it was produced less quantity of comfort systems due to the diminution of the demand, resulting in less quantity of scrap produced.

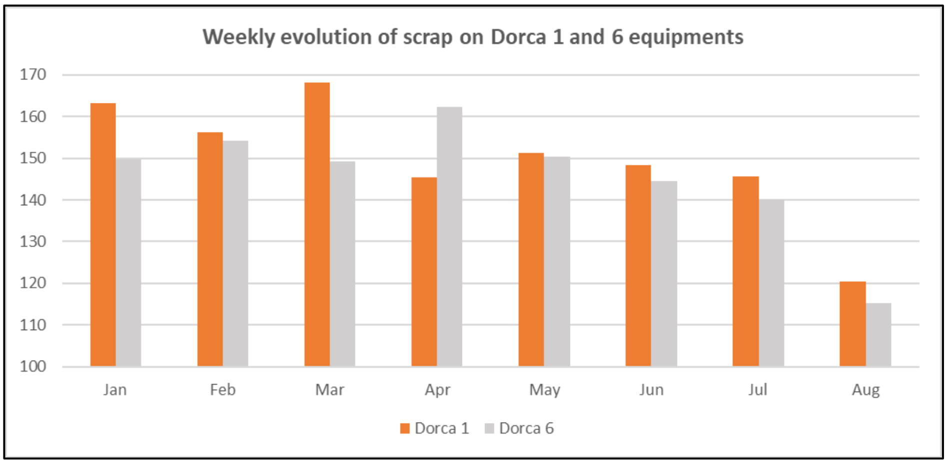


Figure 190 - Weekly evolution of scrap on Dorca 1 and 6 equipment

A summary of the different stages of the development of this project are summarized in the Table 73.

Table 73 – Description of the different stages of the six-sigma project

Period	Description of stage
January 2018	Analyse of existent data in order to define the project.
January – April 2018	Implementation of a specific data collection plan regarding the type of source related to the quantity of scrap reported
April 2018	Analyse of the data collected and discussion with team about the possible scrap sources
May 2018	Definition of improvement actions plans for the most critical equipments
June 2018	Submitted budget proposals to the administration
June 2018 – July 2018 (End of the internship period)	Budget proposals subject to approval from administration. Implementation of some of the defined improvement actions.

3.4.5 Future improvements

Although it is visible some positive results and impact of the improvement actions implemented, the major improvements that were defined were not already implemented due to budgets pending of approval. Major improvements that will be carried out on Dorca 1, Dorca 6 and Tecnogial 8 are summarized in Table 74. It is expected that these improvements, which are focused on critical points of the corresponding equipment would allow achieving the results pretended for this project.

Table 74 - Future improvement actions defined

Equipment	Improvement action
Dorca 1	Replacement of traction wheels
Dorca 1	Complete maintenance
Dorca 6	Complete maintenance
Dorca 6	The conception of new straightening block allowing a faster setup
Tecnogial 8	Budget approval to “lock the center of the equipment” and to change the headers.
Tecnogial 8	Substitution of components: tweezers and chain.
LBT	Replace parameters and equipment movements controller.
LBT	Replacement of tools to allow a faster setup and creation of detailed and precise setup instruction.
LBT	Repair old welding’s workstation.

This improvement actions was discussed with the correspondent departments of *Fico Cables* in order to assure that this actions are properly listed with a responsible for their execution as well as an expected deadline to have the action completed.

It was also reinforced to the administration the importance of the approval of some budget proposals to the expected gains in terms of reduction of scrap.

3.5 Case study no. 3

3.5.1 Characterization of the problem

With the development of the previous case studies, it was verified and recognized the importance to, continuously and accurately, monitor the different Key Performance Indicators (KPI) used on *Fico Cables*. This monitoring process allows to identify improvement opportunities as well as detect where the problems are located and concentrate efforts in that/those areas. It is also important to understand and visualize their historical evolution as well as check if the expected results are being achieved.

Fico Cables uses an A3 model to follow the evolution of the most important KPIs used in production management. However, it was identified that the different workers responsible to manage these documents spends too much time updating them (non-value added), instead of use that time to analyze the real problems. Also, as the update process of these documents is manual, it is frequently and relatively easy to introduce errors when the data is being updated. Another important factor that was identified is that the current A3 methodology concentrates too much information in just one A3 sheet, making it difficult to visualize problems for the different workers that are analyzing it.

The most important KPIs used on *Fico Cables*, for production management, and that this case study is focused are:

- Direct Labour Deviation (MOD);
- OEE;
- Scrap;
- Availability.

As this methodology could be applied for the entire organization, it is important to have a universal format and have the possibility to co-relate information easily. Currently, the different A3 sheets applied are not interconnected. For example, A3 sheets do not present data update intervals, data stratification, improvement actions and their impact on the global panorama, among other factors that will be further described.

An example of a previous A3 sheet (KPI: MOD deviation, in terms of number of people) is represented in Figure 191.

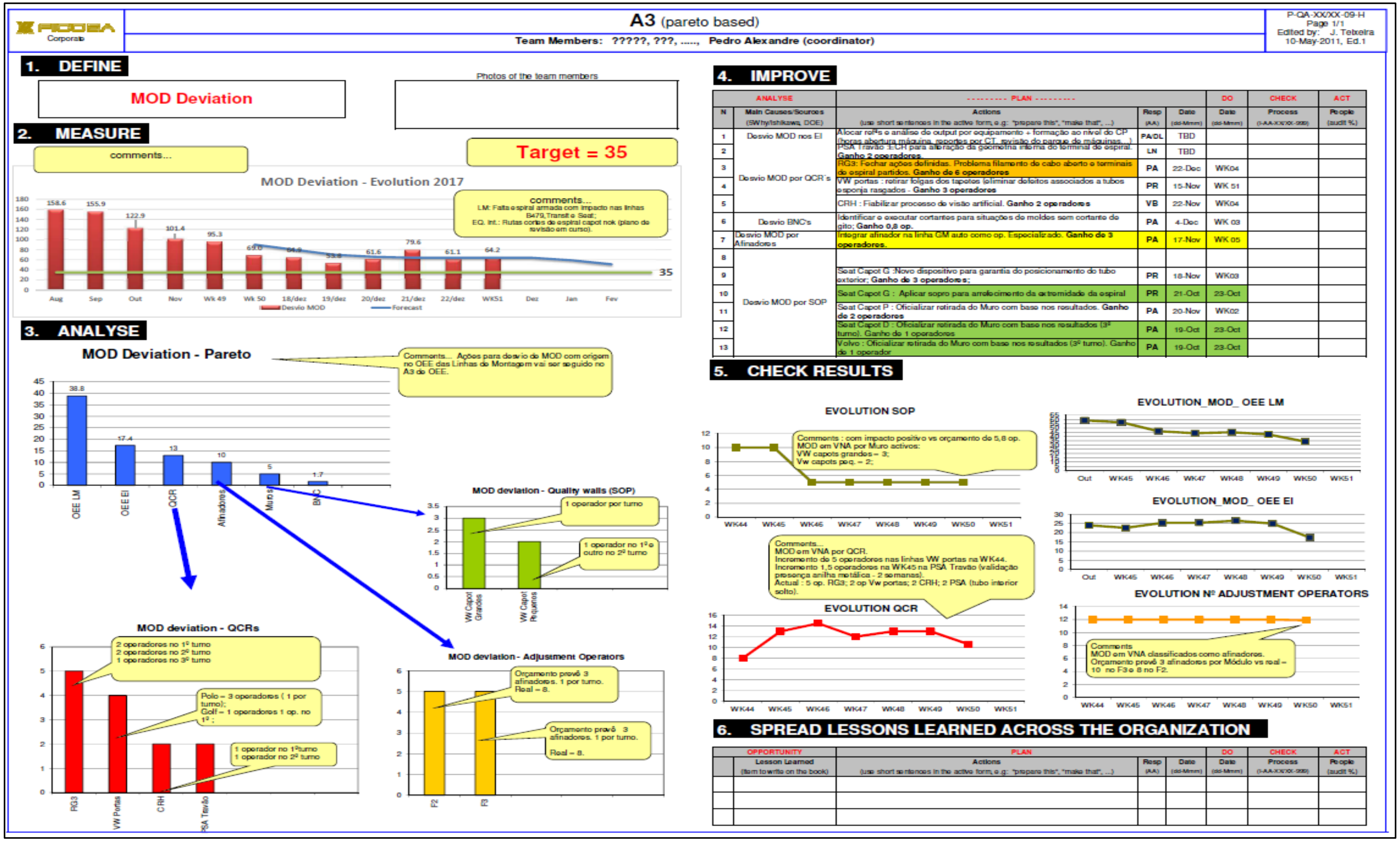


Figure 191 - Previous A3 model used for the MOD deviation KPI

Another method that is used on *Fico Cables* to analyze and follow the different KPIs is an application created by the DSI department called *War Room*. This application resumes different KPIs in a window view and it is one of the key tools used in the one-hour daily meeting that realizes in the center of *gemba*. However, this application has some limitations as for example:

- Only allows to visualize data with a time window of one day;
- Data on a specific day is only updated during the next day and then "freezes";
- It does not allow to agglomerate data of different submodules.

An example of the *War Room* view related to the OEE KPI and for a specific day and a specific module is represented in Figure 192. On the right side of the window is visible the detail of the equipment with the higher and lower OEE.

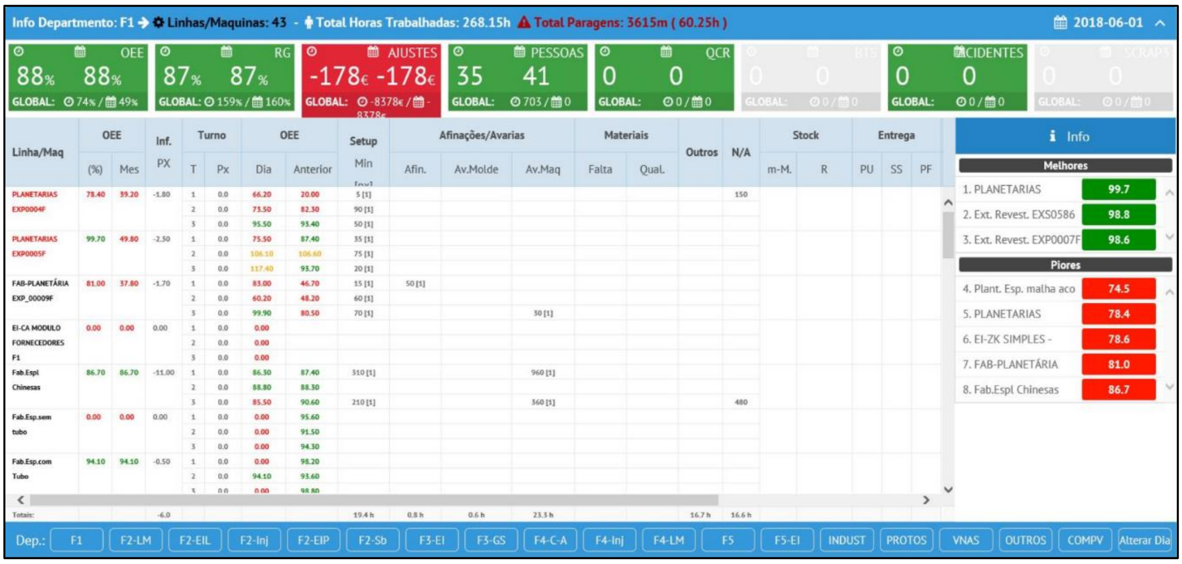


Figure 192 – Example of a *War Room* view

3.5.2 Requirements to comply

As it was mentioned before, the most important KPIs that are used for production management on *Fico Cables* are MOD deviation, OEE, and Scrap. These indicators, with the addition of the availability, were also the ones used to apply the new A3 methodology approached in this case study. Below, it is described in what consists each of these KPIs and their application to *Fico Cables* production management approach.

Direct Labour Deviation – MOD

As *Fico Cables* follow a labor-intensive model and has an elevated number of operators, this KPI is important because it measures the difference between the real number of operators that was working in a specific assembly line or machine and the theoretical number of workers that was necessary to produce the reported quantity of conforming units, according to production rate previously established. This deviation is also measured considering a certain OEE value included in the budget. This indicator allows measure inefficiencies in terms of a number of people in the different assembly lines/machines and to better manage where people are working avoiding their stoppage when a certain assembly line or equipment is not working.

According to the different types of labor, the way to calculate this indicator is also different. In *Fico Cables*, there are operators that work in assembly lines, operators that work in machines and operators that perform non-value-added, but necessary, operations (VNA).

Also, it is necessary to divide the number of hours for 7.75 hours (number of hours worked per shift) in order to get the number of workers.

MOD calculation for operators that work in assembly lines:

$$MOD = \sum number\ of\ hours\ reported - \frac{\sum number\ of\ theorical\ hours}{OEE\ considererd\ on\ budget} \times Ratio \qquad (5)$$

$$MOD = \sum number\ of\ hours\ reported - \frac{\frac{\sum conforming\ units\ produced}{Production\ rate}}{OEE\ considererd\ on\ budget} \times Ratio$$

In the case of assembly lines, there is always a ratio of one operator for one machine.

MOD calculation for operators that work in machines:

For machines, the calculation method is similar, but with the difference that the ratio is different. In this case, we could have more than one operator per machine (ratio operator/machine below 1) or less than one operator per machine (ratio operator/machine above 1).

MOD calculation for non-value-added operators (VNA):

In *Fico Cables,* there are a certain number of workers that perform non-value-added, but necessary operations. These operators are considered a direct inefficiency and the main purpose is to minimize this number. The different types of VNA existent on *Fico Cables* described in Table 75.

Table 75 -Different types of non-value-added workers (VNAs)

Type of non-value-added operator	Description
Non-conforming bulletin (BNC)	Workers that are analyzing different problems and defects that result in a non-conforming report.
QCR	Workers that are executing quality walls due to a customer client.
SOP	Workers that are executing quality walls due to the initial stage of a project.
Adjustment operators	Workers responsible for setups or other necessary second level interventions.
Planning stoppages	Workers that are occupied in other planned stoppages (example: training, plenaries, medical, exams, among other)

The way to calculate MOD deviation for this type of workers is also different. Instead of a theoretical number of hours, there is established in the budget a certain number of this non-valued-added workers.

$$MOD = \sum number\ of\ hours\ reported - \sum number\ of\ VNAs\ on\ budget \quad (6)$$

Overall Equipment Effectiveness (OEE)

This indicator is divided into three different components: Quality (Q), Performance (Pf) and Availability (Av). It is calculated for each assembly line or machine, as well as an entire sub-module, module or the entire factory. The calculation of the different OEE components is described above:

Quality (Q):

This parameter reflects the number of conforming units in relation to overall production. However, this percentage does not represent the overall quality ratio of *Fico Cables*. It only demonstrates the number of final products that are classified as non-conforming and does not represent the overall value of scrap of the entire manufacturing process. In order to follow the quality parameter over the process, it is used another indicator that will be further described.

$$Quality\ (\%) = \frac{\sum non\ conforming\ units}{\sum overall\ production} \quad (7)$$

Performance (Pf):

The performance measures the quantity produced (conforming or non-conforming) over the total operation time available. In terms of operation time, the number of hours available (TT) are different for assembly lines or machines. For assembly lines, it is considered 7.75 hours per worker per shift (with 15 minutes included for rest), although in the case of machines it is considered a period of 8 hours.

$$Performance\ (\%) = \frac{\sum Production}{Operation\ Time} \tag{8}$$

$$Performance\ (\%) = \frac{\frac{\sum conforming\ units}{Production\ rate} + \frac{\sum non\ conforming\ units}{Production\ rate}}{Number\ of\ hours\ available\ - Stoppages}$$

Availability (Av):

The availability parameter measures the relationship between the time that the assembly line/machine was operating (operation time) *versus* the total available time. The total available time is calculated by two different ways, that results in two derivations of the OEE indicator that is used on *Fico Cables*: OEE and RG. In the case of the traditional OEE indicator, the available time represents the total amount of hours that the assembly line/machine could have worked (TT) excluding the number of hours that the assembly line/machine was not working due to lack of order.

$$Availability\ (\%) = \frac{\sum Operation\ Time}{\sum Available\ Time} \tag{9}$$

$$Availability\ (\%) = \frac{Number\ of\ hours\ available\ - Stoppages}{Number\ of\ hours\ available - Number\ of\ hours\ for\ Lack\ of\ Order}$$

In the case of the RG indicator, the available time does not exclude these stoppage hours for lack of order.

$$Availability\ (\%) = \frac{\sum Operation\ Time}{\sum Available\ Time}$$

$$Availability\ (\%) = \frac{Number\ of\ hours\ available\ - Stoppages}{Number\ of\ hours\ available}$$

For this reason, the RG percentage is always equal to or less than OEE.

$$OEE\ and\ RG = Quality \times Performance \times Availability \tag{10}$$

Scrap

As it was mentioned before, the overall value of scrap is not represented in the OEE indicator as this indicator just measure the quantity of scrap related to final products and does not allow to evaluate the quantity and the value of scrap that is produced along the process. The overall value of scrap could come from:

- Raw materials/components;
- Subgroups;
- Final products.

The reports of scrap produced allows to identify the production reference that is associated (and thus identify if it is a component, a subgroup or a final product) as well as the type of defect, where it was produced (machine or assembly line), the respective quantity (weight or units) and the quantity, allowing to traduce it in cost.

In addition to the scrap value, it is also measured the adjusts value (quantity and cost). The adjusts represents inventory hits that are made. Since the date of the last inventory, a certain quantity is produced, and a certain quantity is purchased, which results in a certain value. If the real value is more or less, it is necessary to make an adjustment in order to keep information real and accurate.

3.5.3 Previous situation

As it was briefly described before, it already existed an A3 methodology to follow the major production related KPIs, with an exception for the scrap and availability. However, the current methodology has some major inefficiencies with the major one being the lack of data automatization, that consumes an excessive time for the workers that are responsible to manage these documents. In this chapter, it will be detailed described, for the different A3, the previous situation with the corresponding limitations as well as the improvement opportunities that was detected. The previous A3 module is divided into these major fields:

- Define;
- Measure;
- Analyse;
- Improve;
- Check results.

Each production director is responsible for different modules and submodules. For the MOD deviation and the OEE KPIs, it only existed an A3 sheet for each production director and their team members to manage. The different production directors and the submodules that they are responsible for are represented in Figure 193.

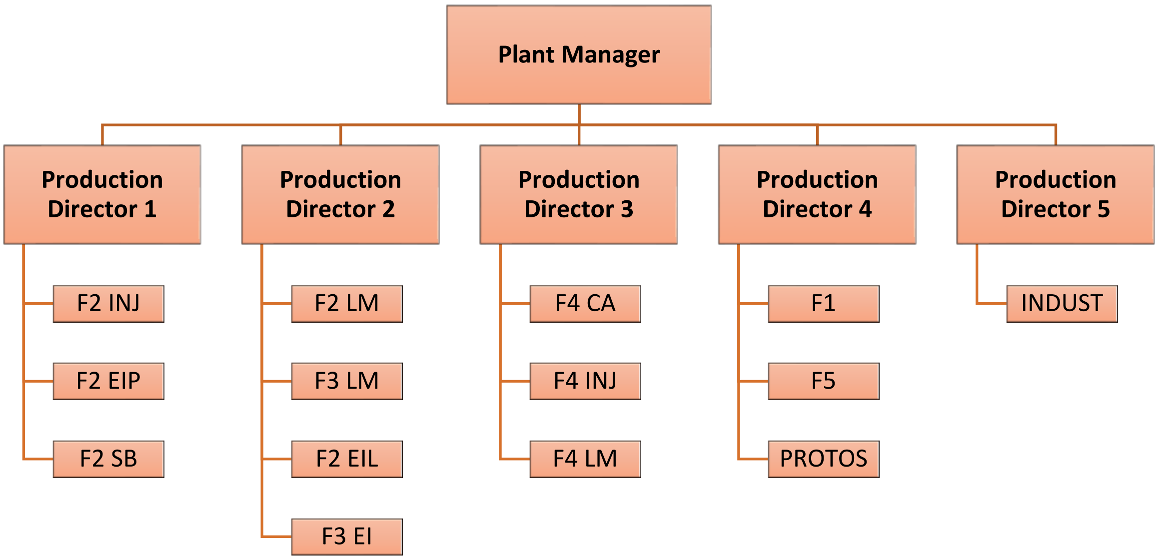


Figure 193 - Distribution of the submodules management responsibility for the different production directors

A3 of Direct Labour Deviation (MOD)

<u>*Define and Measure fields*</u>

For the MOD deviation KPI, the initial fields of the A3 sheet layout describes the problem (in this case, the KPI) that is being followed as well as the real evolution over the current year, with the forecasted values (based in the improvement actions that are scheduled) and the respective and actual target that is being pursued (Figure 194).

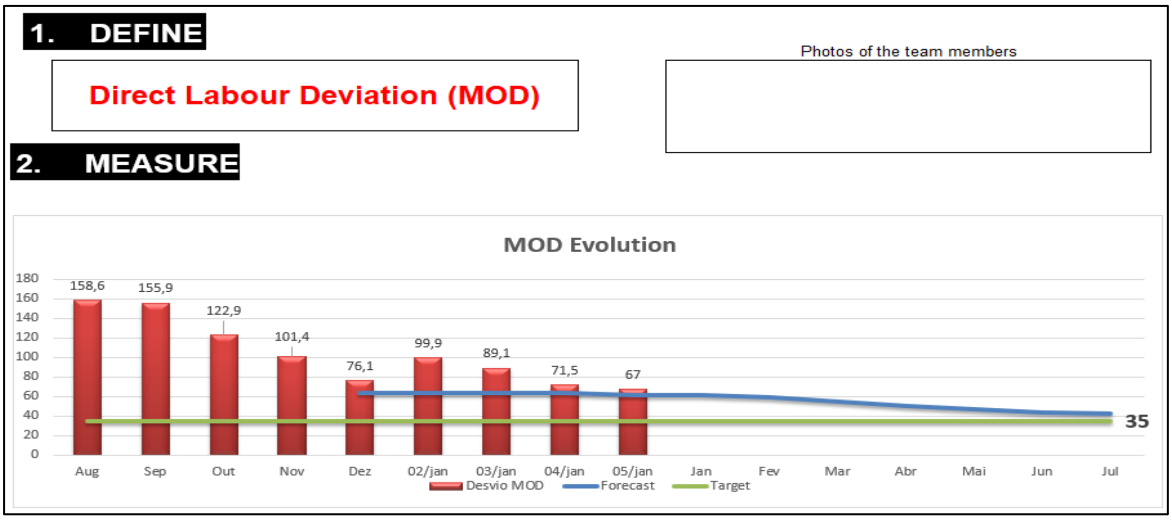


Figure 194 – Previous *Define* and *Measure* fields of the MOD deviation A3 sheet

To feed the evolution graph with data, it was necessary to consult the internal web app *War Room* (Figure 195) and to, for the different submodules, copy the sum of MOD deviation of the respective submodule for the A3 excel. Besides this process of consulting, copy and paste values takes some time, there exists a considerable possibility to make an error. Also, as the worker just consults the War Room once, if there is some update, the values that are on the A3 are not the most recent and correct ones.

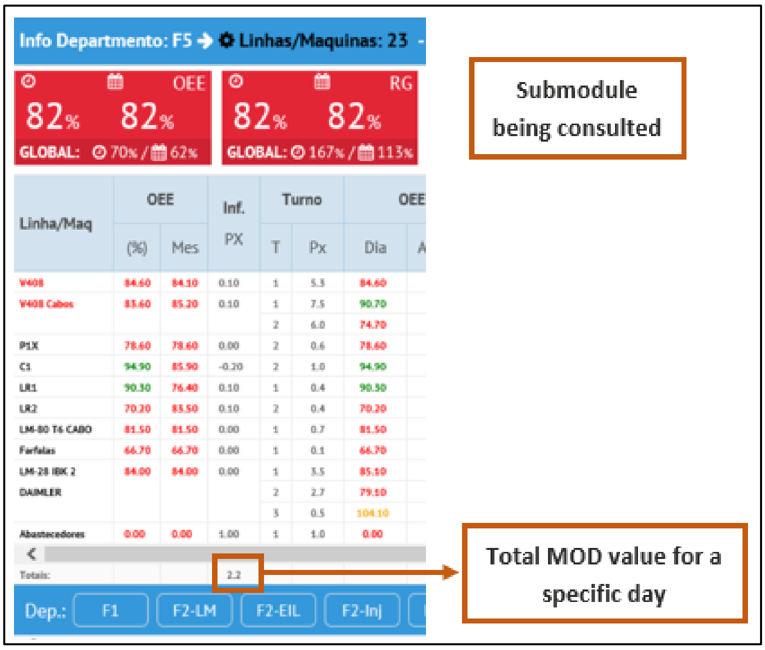


Figure 195 - Consult of MOD deviation values for a specific submodule and specific day on *War Room*

Analysis field

In terms of the *Analysis field*, it is made a Pareto analysis in order to verify which submodules has the bigger MOD deviation and concentrate actions to improve those areas (Figure 196). Individual Pareto analysis for the most critical submodules was also made in the same A3 sheet, concentrating too much information and not allowing to immediate visualize where is the problem.

When it is necessary to visualize this sub-level Pareto analysis of, for example, the submodule with the biggest MOD deviation o detected on the main Pareto, it was necessary to copy and paste values all the MOD deviation values that are on the *War Room* window, for every day of the analysis period. As an example, if the Pareto has a temporal window of one month, and if the submodule that we are analyzing is the F2 LM, that has 22 assembly lines, it is necessary to copy 660 values manually for the A3 sheet.

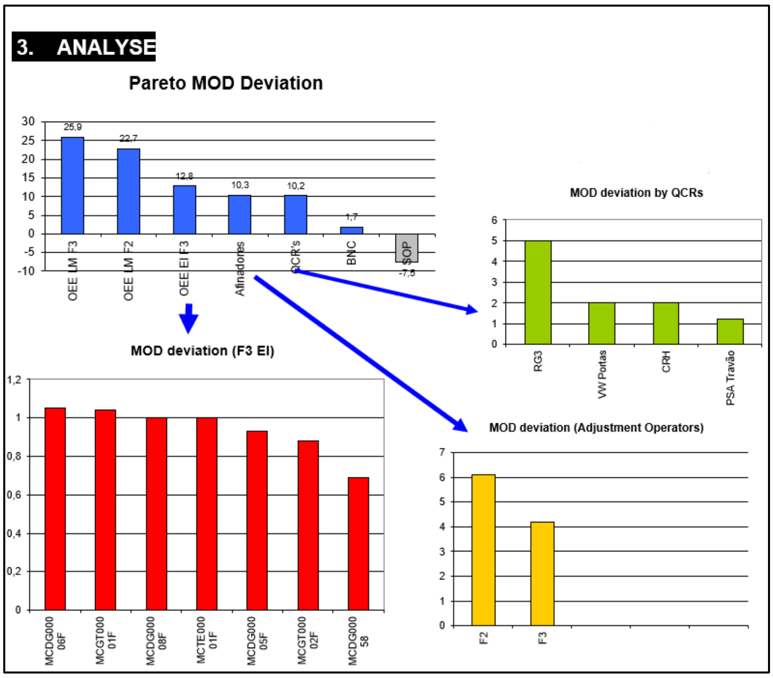


Figure 196 – Previous *Analysis field* of the MOD deviation A3 sheet

Improvement actions field

In order to solve or reduce the effects of inefficiencies that are visible through the previous Pareto analysis, improvement actions based on a PDCA cycle are set and schedule. These actions have an associated expected gain of MOD deviation that traduces in the future forecasted MOD deviation values.

For the different improvement actions, the following parameters are defined:

- A responsible for its follow-up;
- A deadline date;
- The expected gain (in terms of number of operators)
- Process number;
- Audit percentage.

These improvement actions (Figure 197) are followed with more detail in a specific platform called *Kanboard*, allowing to have just enough detail on the A3 sheet and to not concentrate it with excessive information.

ANALYSE		--------- PLAN ---------			DO	CHECK	ACT
N	Main Causes/Sources (5Why/Ishikawa, DOE)	Actions (use short sentences in the active form, e.g: "prepare this", "make that", ...)	Resp (AA)	Date (dd-Mmm)	Date (dd-Mmm)	Process (I-AA-XX/XX-999)	People (audit %)
1	Desvio MOD nos EI	Alocar refªs e análise de output por equipamento + formação ao nível do CP (horas abertura máquina, reportes por CT, revisão do parque de máquinas...)	PA/DL	TBD			
2	Desvio MOD por QCR´s	PSA Travão :ECR para alteração da geometria interna do terminal de espiral. **Ganho 2 operadores**.	LN	TBD			
3		RG3: Fechar ações definidas. Problema filamento de cabo aberto e terminais de espiral partidos. **Ganho de 6 operadores**	PA	22-Dec	WK04		
4		RG3: Fechar ações definidas. Problema filamento de cabo aberto e terminais de espiral partidos. **Ganho de 6 operadores**	PR	15-Nov	WK 51		
5		CRH : Fiabilizar processo de visão artificial. **Ganho 2 operadores**	VB	22-Nov	WK04		
6	Desvio BNC's	Identificar e executar cortantes para situações de moldes sem cortante de gito; **Ganho 0,8 op.**	PA	4-Dec	WK 03		

Figure 197 - Previous *Improve* field of the MOD deviation A3 sheet

Check results

The check results field follow and verify the results of the different improvement actions already carried out. Also, as in other fields of the A3 sheet, there is an excessive quantity of information that dissipates the focus of the person who is visualizing and managing this A3 sheet (Figure 198).

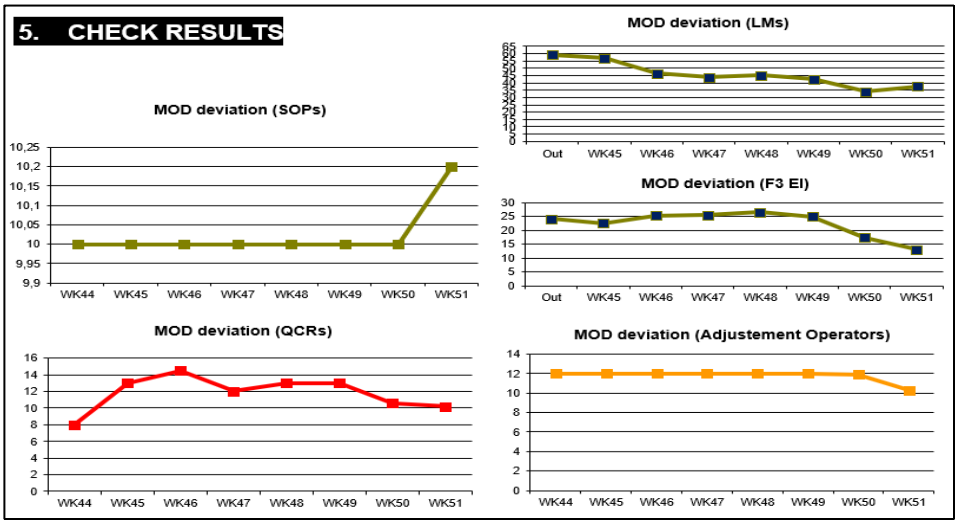


Figure 198 - Previous *Check results* field of the MOD deviation A3 sheet

A3 of Overall Equipment Effectiveness (OEE)

Define and Measure

As in the MOD deviation A3 sheet, these initial fields define the problem (in this case, the OEE is below the target of 83%) and represents the evolution of these submodules (F2 and F3 LM) over the year. Also, following the same structure, it is represented the forecasted values of OEE based on the execution of the planned improvement actions (Figure 199).

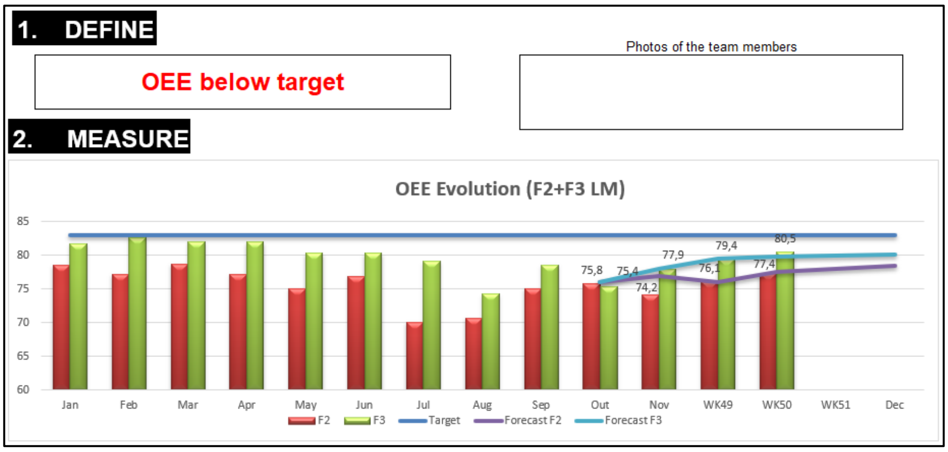


Figure 199 - Previous *Define* and *Measure* fields of the OEE A3 sheet

In order to feed the A3 with the OEE values, it is necessary to export them from an internal software called *CP Auto*, that summarizes production data from the main production report software (*CP*). However, this software has a significative limitation: it only summarizes that data by department and not by module/submodule. As some submodules are mixed with others in the same department it is not possible to get the global value of OEE and their components of the entire submodule. For example, the different assembly line submodules (F2 LM, F3 LM, F4 LM, and F5 LM) are together in the same department: 291; in the other hand, the department 294 just refers to the machines included in the F4 Plastic Injection submodule (F4 INJ).

A view of the software *CP Auto* and the type of information that it gives is represented in Figure 200.

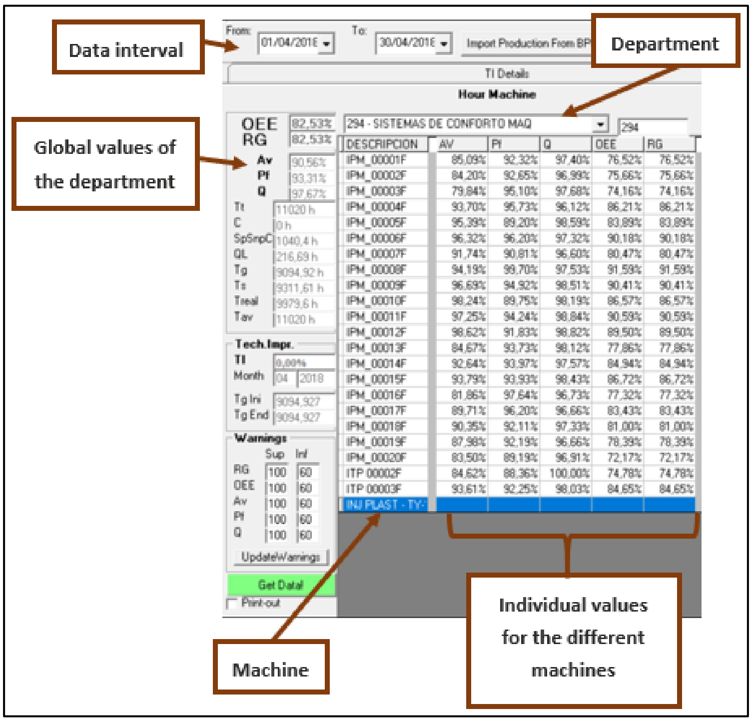


Figure 200 – View of the CP Auto software

Analyse

In the analyze field (Figure 201), it is made a Pareto decomposes the OEE in the three components (quality, performance, and availability) for the different submodules in the analysis. Also, for each OEE component, another Pareto's shows the major impacts in terms of percentage of OEE loss.

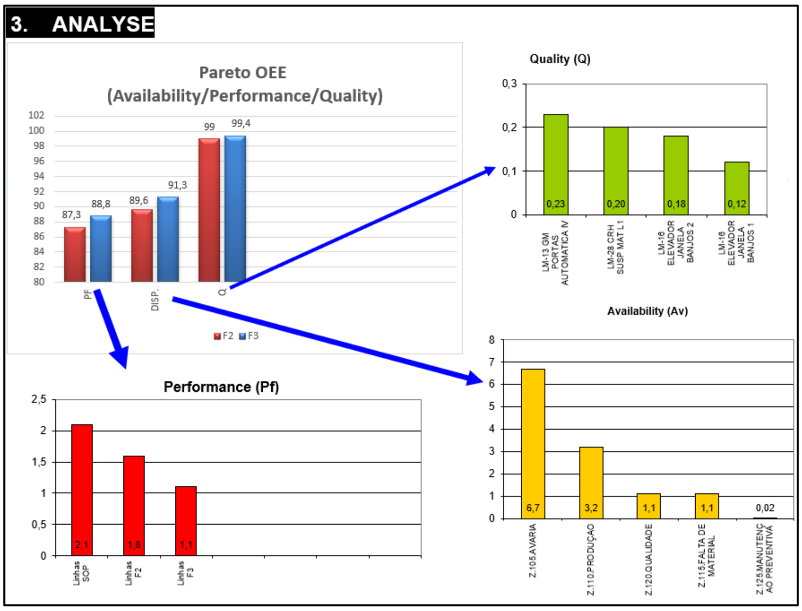


Figure 201 - Previous *Analysis field* of the OEE A3 sheet

Improvement Actions

In terms of improvement actions (Figure 202), it is similar to the MOD deviation A3 sheet. There are described the planned actions and attributed the respective follow-up responsible as well as the forecasted date to conclude them and the corresponding expected gain (in terms of percentage of OEE).

4. IMPROVE

ANALYSE		--------- PLAN ---------			DO	CHECK	ACT
N	Main Causes/Sources (5Why/Ishikawa, DOE)	Actions (use short sentences in the active form, e.g: "prepare this", "make that", ...)	Resp (AA)	Date (dd-Mmm)	Date (dd-Mmm)	Process (I-AA-XX/XX-999)	People (audit %)
1	Forte impacto pela indisponibilidade F2 (AV_2,9% + setups_3,45%)	Seguimento diário BTS da IP e ajustar MOD numa base diária com BH.Repôr o standard de setups (2,7%). Actual 3,45% - **0,7% Setup + 0,6 Avarias** (tempo de espera estimado pelo aumento do impacto dos	PA	WK50		Anexos\Prioridades_Wk49.xlsx	
2							
3		Seguir PDCA específico para problemas sistémicos das linhas Automáticas da GM **_0,2% (impacto tb na Qualidade)_0,1%**	PA	WK49			
4	Paragens por falta de subconjuntos IP (1,1%)	A3 IP para aumento output **_1,1%**	RD	WK 51		..\..\1a - Modulo Injecção\A3	
5	Desvios de velocidade (5%)	Identificar operadores com baixa performance e ajustar MOD (30 operadores)**_1,3%**	PA	WK46	WK 47	Anexos\Plano de Redução	
6		VW Polo portas: Alterar posto de montagem de cabo por forma a incorporar montagem do clip no terminal de cabo no posto de aparar (reduz 1 operador/turno) **_0,8%**	HF	WK 51	20-Dec		
7		Seguimento diário BTS da IP e ajustar MOD numa base diária com BH. **_1,6%**	RD	WK 50		Anexos\Prioridades_Wk49.xls	
8	Impacto por problemas de qualidade (0,5%)	Reformular plano de Manutenção preventiva para linhas automáticas da GM (paletes e linha) _ ganho **0,2%**	BP	WK44	WK 50		

Figure 202 - Previous *Improve* field of the OEE A3 sheet

Check results

In the check results field of the OEE A3 (Figure 203), it is also visible that co-exists an excessive amount of information with sub-analysis for the availability component as, for example, the evolution of lack of material stoppages for the F2 LM submodule and evolution of percentage of unavailability for the GM Automatic assembly lines.

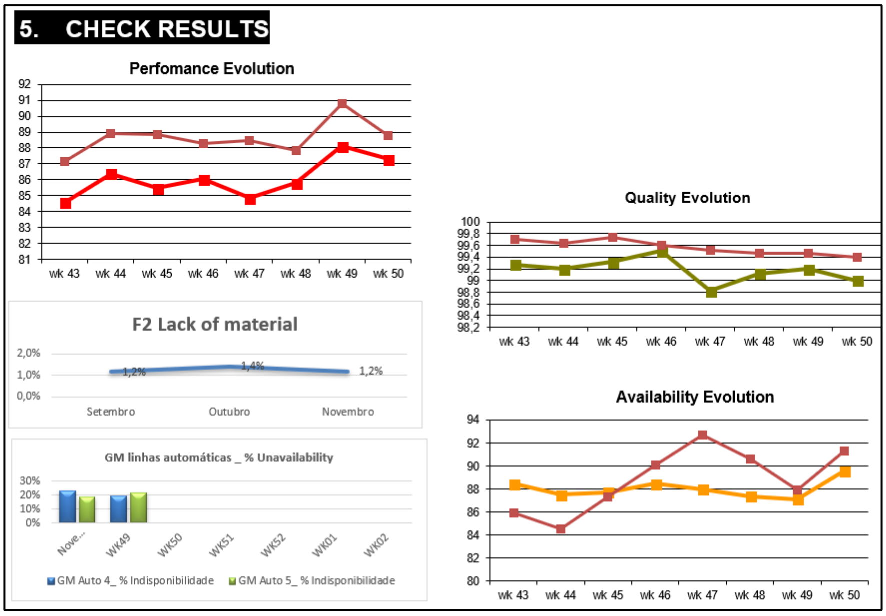


Figure 203 - Previous *Check Results* field of the OEE A3 sheet

3.5.4 Improvement opportunities

With the analysis of the actual A3 methodology it was identified several improvement opportunities that aim to achieve three main goals:

- Get a clear and non-confusing view of what is being analyzed;
- Stratify information in different A3 sheets according to the level of management responsibility;
- Minimize the time spent on non-value-added activities in order to spend more time to analyze the existent and crucial problems.

The improvement opportunities that were identified are represented in Table 76.

Table 76 – Improvement opportunities for the A3 methodology identified

Improvement	Description
Automatize data collection and update process	It was verified that, in most cases, the data that was already on the A3 document was not updated and so, report corrections or delayed reports, was not considered for the monitoring process of the indicator. Also, several times, the data that was already on the A3 was not updated and so, report corrections or delayed reports were not considered for the monitoring process of the KPI.
Display only information for the corresponding level of analysis	Information must be stratified in a way that, for example, if an A3 sheet is related to a group of submodules, the corresponding Pareto must only the global values of each submodule. The Pareto by the different assembly lines/machines should only be included on the A3 of the level below (specific submodule A3).
Create a "House of A3" structure	The different A3 must be interconnected between them since they are a partial analysis of the global panorama. This structure allows establish a connection of data and improvement actions between the different A3 of the same KPI and allows an easier access and search for the different existing A3 documents.
Automatically prioritize actions by the expected gain	In the Improvement Actions field of the A3 sheet, the different actions must be ordered by the corresponding gain that is expected to be achieved in order to easily visualize the most important actions.
Create specific A3 for Scrap	As the quality parameter of the OEE does not give a completely true vision of the quality panorama, an A3 for Scrap would allow to easily visualize production references that produces biggest values of scrap and that have more impact in terms of cost.
Create specific A3 for Availability	The creation of an A3 for the availability component of the OEE allows understanding the most important causes and motives that caused a specific stoppage. This A3 would allow to create and follow specific actions and to not over detail the OEE A3.

3.5.5 Implementation of improvements

Further, it will be described the implementation and the corresponding effects of the different improvement opportunities that were identified before.

Improvement 1 - Automatize data collection and update process

This could be classified as the biggest improvement done since the time that the members of the production direction teams spend was huge. As this time consumed in the update and data fuelling process is entirely unproductive and non-value-added, it was imperative to develop almost fully automatic documents that allow the different team members to focus in analyzing the real problems and follow the respective improvement actions that traduce in value added for the process.

The previous data collection process involved consulting different internal software carried out different searches and export data for the excel or manually copy the necessary values. These activities consumed a lot of time and easily induce errors. The different software that was needed to consult for fuelling the different A3 is represented in Table 77.

Table 77 – Source of data for the different KPIs

KPI	Software
MOD deviation	War Room
	CP (indirectly)
OEE	CP
	CP Auto
Scrap	BPCS
Availability	CP
	CP Auto

With the support of the DSI department, it was possible to create libraries of data related to specific searches that would be manually performed on the respective software. These libraries allow having a database with the necessary values to calculate the KPI that is being analyzed. Thus, this data could be automatically updated and refreshed on the Excel as the KPI calculation is also done on the Excel (Figure 204).

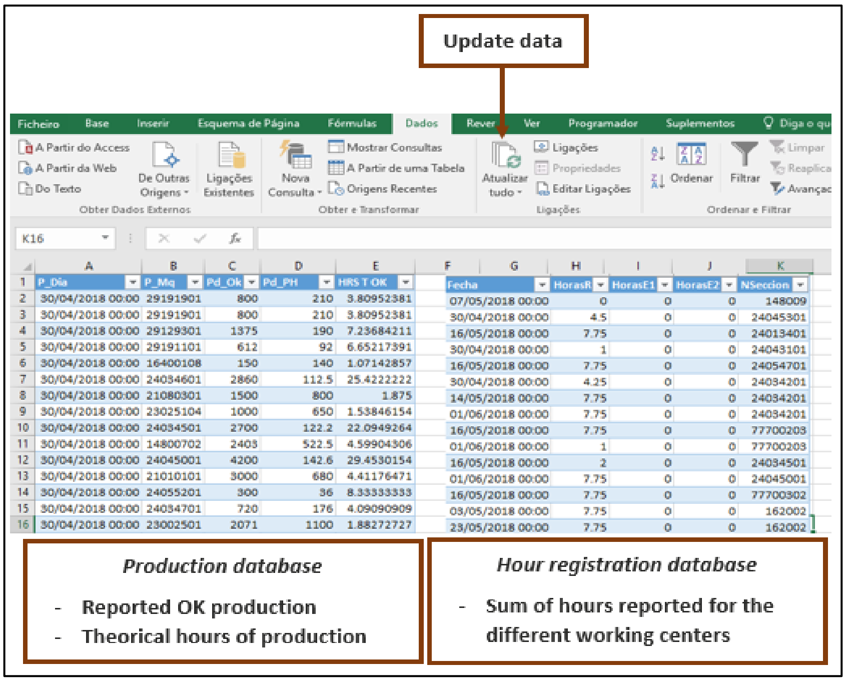


Figure 204 - Example of database created by the DSI department in the Excel

In Figure 205 it is represented the *Measure* field of a MOD deviation A3 sheet with the corresponding macros to update the databases. Then, this automatic process develops the necessary values that allow to calculate the KPI and to refresh the different A3 sheet graphs.

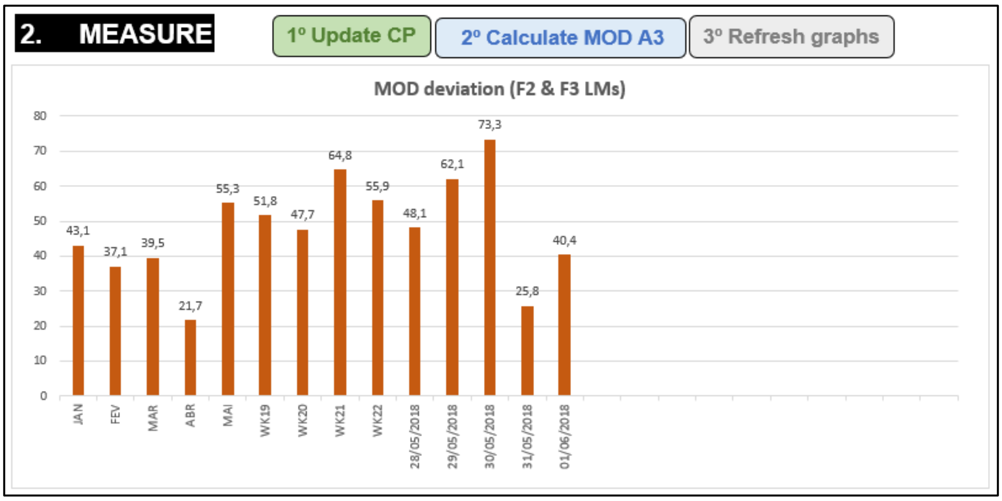


Figure 205 - Improved measure field of a MOD deviation A3 and macros to update data and calculate the KPI

Improvement 2 - Display only information for the corresponding level of analysis

In the previous A3 format it was shown too much information in the same A3 sheet. This condensation of information distracted the attention and the focus of the person who was analyzing the data. In order to improve this situation, the different A3 sheets must only contain information in a resolution view according to the respective level of responsibility.

Fico Cables structure, in terms of submodules responsibility distribution, is represented in Figure 193. The structure of the A3 must follow the same principle, with a specific A3 for each level of responsibility. A specific case of this principle is represented in Figure 206.

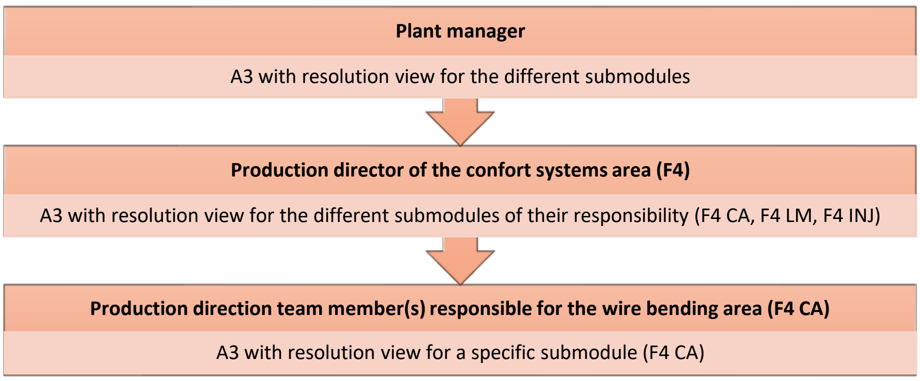


Figure 206 – Distribution of the A3 sheets of the different KPIs and for the different levels of responsibility

This principle must be mainstreamed and standardized for all components of the A3 sheet, including the measure, analyze, the improvement actions and the check results fields. For the case of the MOD deviation KPI, the A3 sheet's stratification and resolution of the main fields are represented in Figure 207.

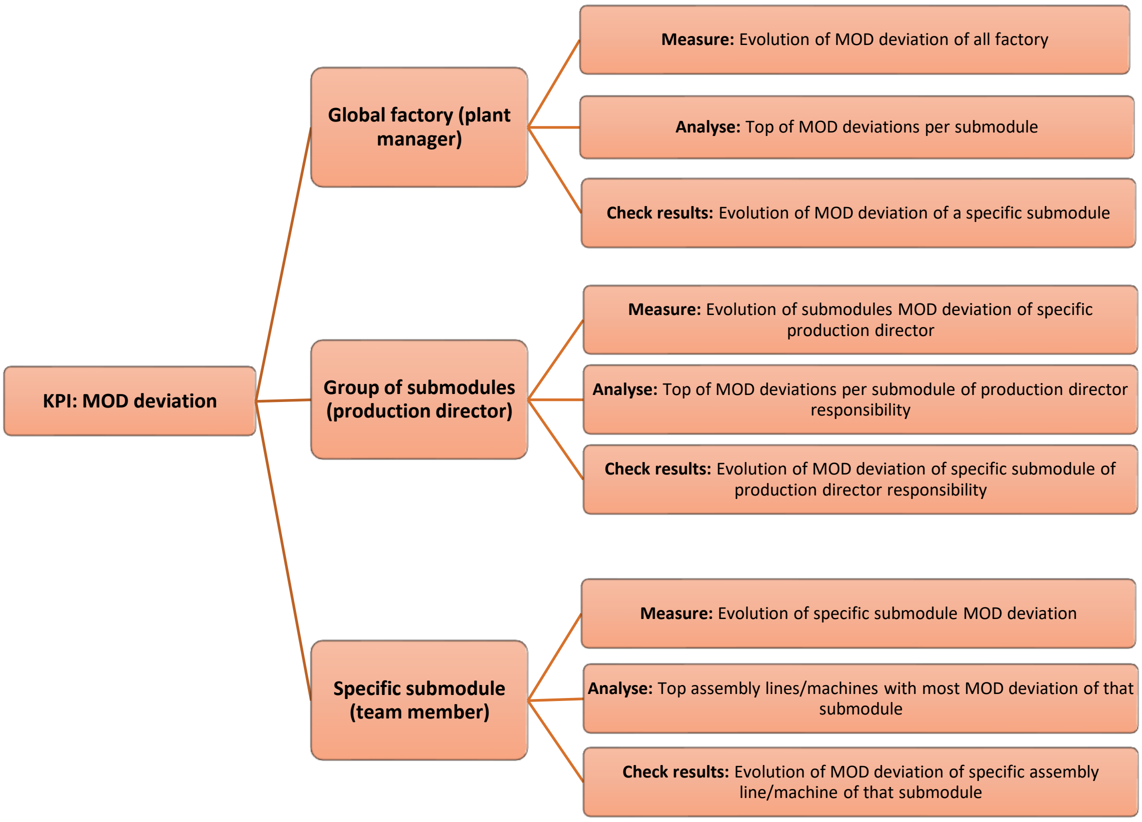


Figure 207 – A3 sheet's stratification for the MOD deviation KPI and resolution view of the main fields

As an example, for the MOD deviation A3 sheet of the plant manager, it is important to have a global, macro and embracing view of inefficiency through the different submodules. The measured field follows the evolution of MOD deviation values related to the entire factory and the Pareto present on the analyze field must identify the submodules that have a bigger MOD deviation, for the current month, in order to focus actions and efforts to reduce this inefficiency in these submodules (Figure 208). This A3 sheet allows the plant manager to visualize, for example, that in the present month of May, two submodules of the comfort systems module (F4) contribute with a deviation of 25 people of the global inefficiency of 60 people.

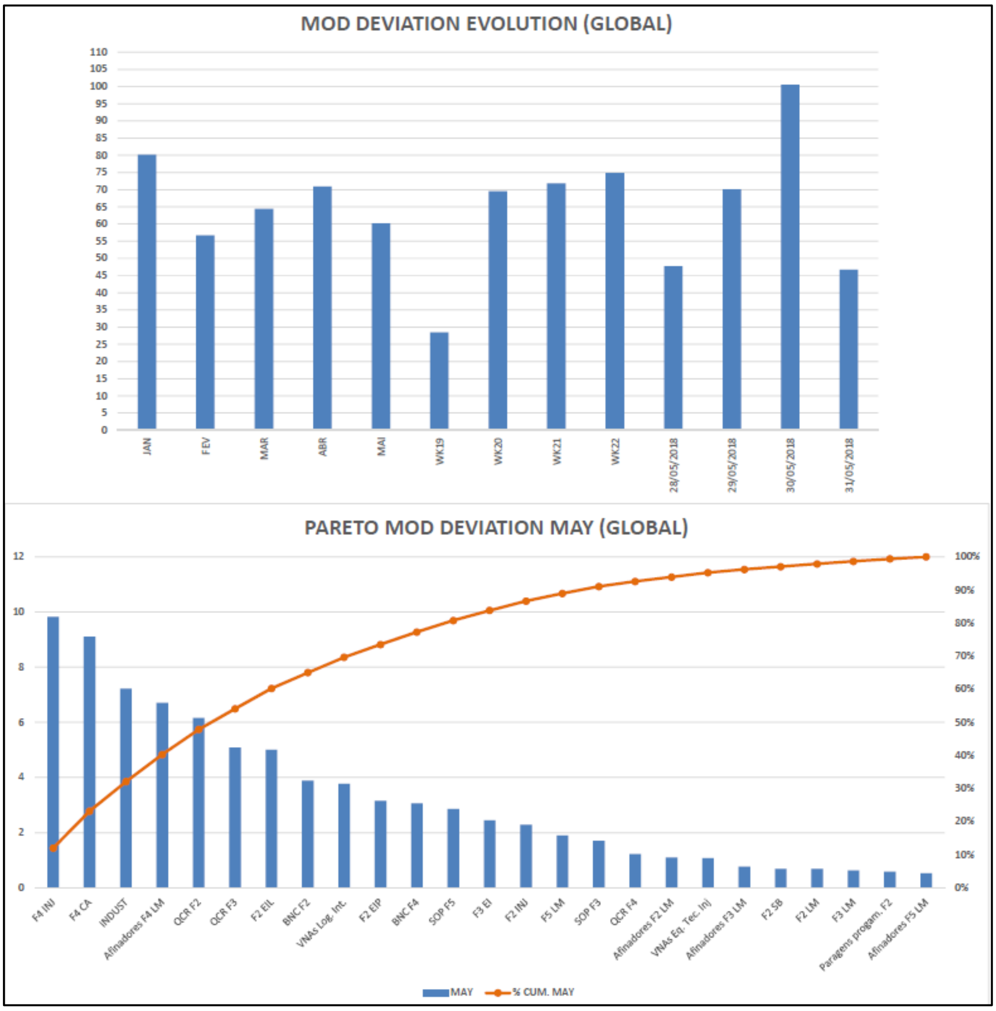


Figure 208 - *Measure* (above) and *Analyse* (below) fields of the MOD deviation A3 sheet managed by the plant manager

In order to descend the level of analysis and to increase the resolution view to a more micro scale, being in the scope of a production director, it was created other A3 sheets. For the F2 and F3 modules, that are (partially) of the responsibility of the production director 2, the corresponding MOD deviation values of the different submodules included is followed in the measured field. In the same logic, the analyzed field identifies the submodules of this area that has the bigger inefficiency.

In Figure 209 it is visible that the bigger inefficiency for these submodules is concentrated in VNAs (non-value added), representing around almost 50% of the total MOD deviation. However, it is important for the assembly lines submodules, that has a bigger number of different working centers, to follow the corresponding submodules values of MOD deviation. In order to achieve this, different and a more specific A3 was created allowing to visualize and monitor this kind of information.

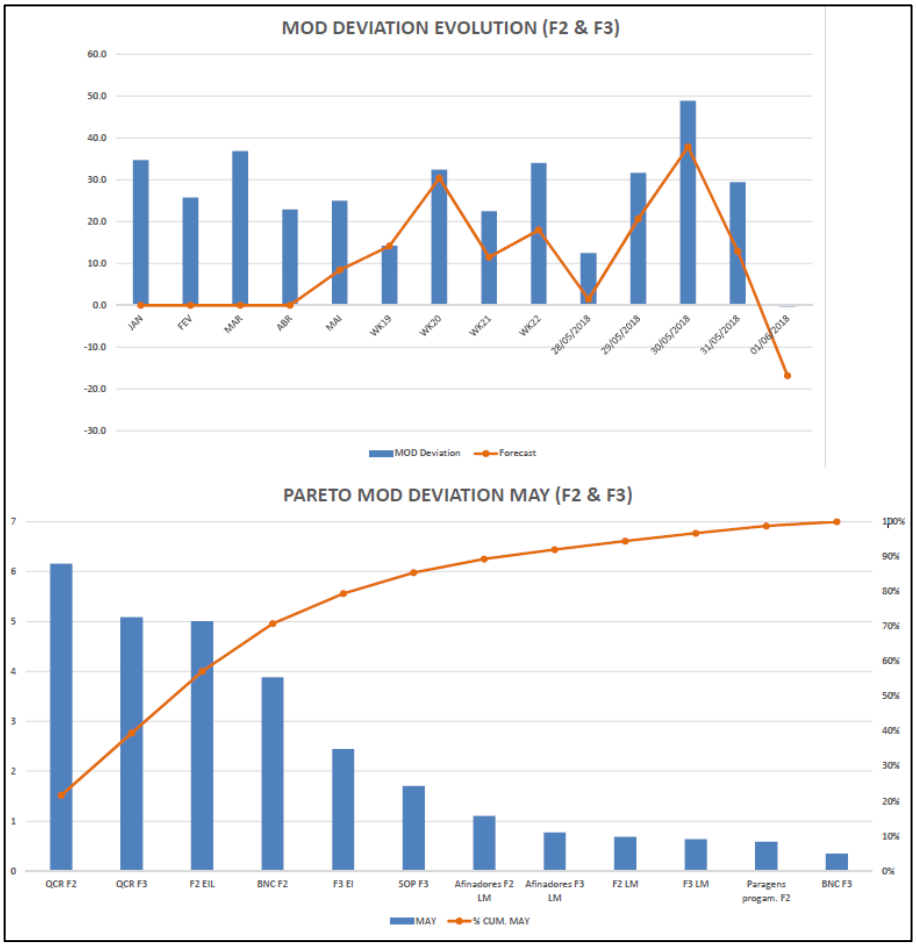


Figure 209 - Measure (above) and Analyse (below) fields of a MOD deviation A3 sheet of the production director 2

For the assembly lines submodule of the F3 (F3 LM), that includes about 40 assembly lines it is important to follow and analyze the MOD deviations of the different assembly lines, even if the global submodule has a small inefficiency. In this case, the F3 LM submodule has an inefficiency of around one person for the month of May. However, the different assembly lines have upper and lower inefficiency values that compensate for each other. The assembly lines with bigger deviation represent great improvement opportunities to reduce inefficiencies and to better manage where people are located (Figure 210).

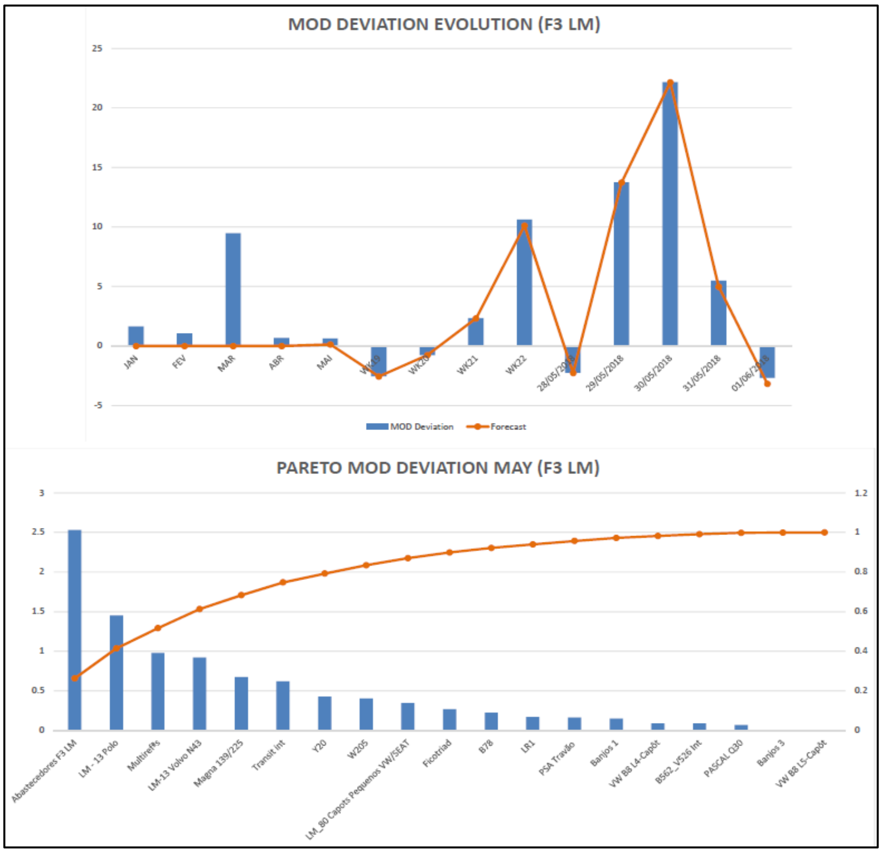


Figure 210 - *Measure* (above) and *Analyse* (below) fields of a MOD deviation A3 sheet of the F3 LM submodule

Referring to the A3 sheets of OEE, the methodology is similar. The respective documents stratification and content on the main field is represented in Figure 211.

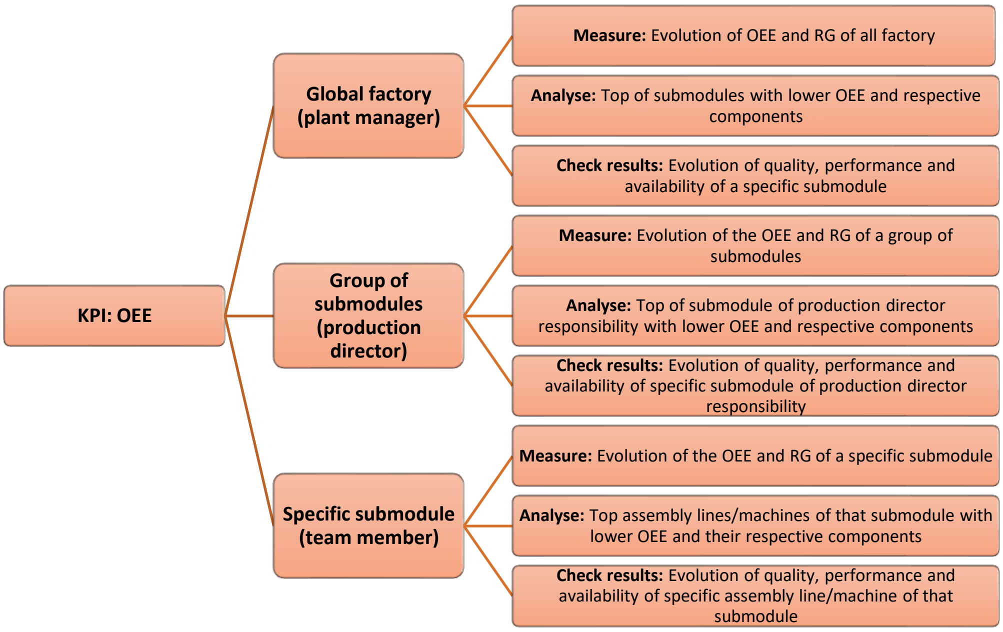


Figure 211 - A3 sheet's stratification for the OEE KPI and resolution view of the main fields

Improvement 3 – Create a "House of A3" structure

In order to keep an appropriate document organization and navigation flow between the different A3 sheets, it was created a tree diagram that represents the stratification of the different A3 for each KPI with the corresponding divisions and subdivisions, as well as linkages for each document. In the present example (Figure 212), it is represented the *House of A3* related for the OEE KPI with the three levels of responsibility (plant manager, production director, and production director team members). This house could also be expanded when a new and a more specific A3 is justified (case, for example, of a specific assembly line or machine). An identical structure was created for the other KPIs (MOD deviation, Scrap, and Availability).

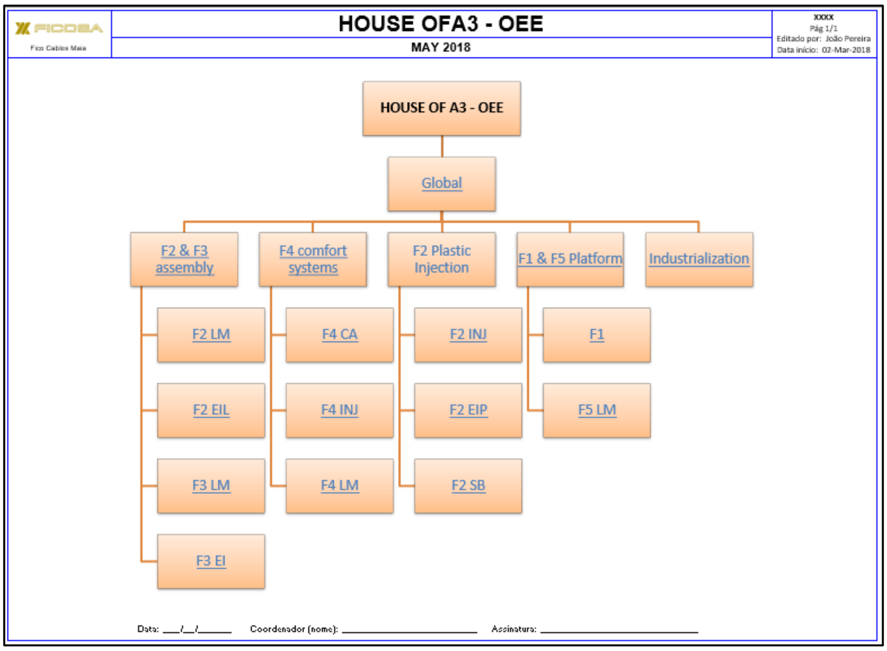


Figure 212 - Document "House of A3" of the OEE KPI

Improvement 4 – Automatically prioritize actions by the expected gain

The improvement actions represent the most important field of the A3 sheet. It does not matter if problems and inefficiencies are identified if there are no defined actions properly planned, performed, verified and controlled to solve them.

Fico Cables uses a software called *Kanboard* where improvement actions are created, the responsibility of execution is delegated, and it is defined as a deadline. After this process, every development step of the action could be exposed and supported by documents and analysis. An example of the view of one improvement action is represented in Figure 213.

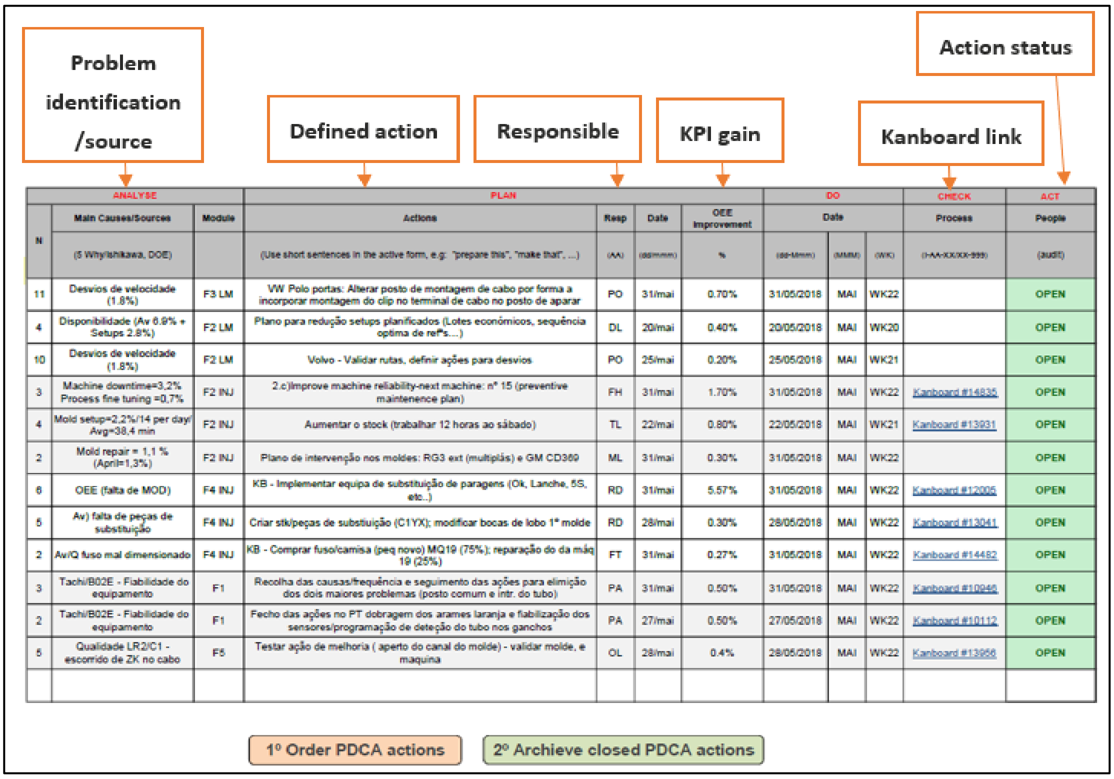
In the A3 sheet, it is important to resume and summarize the existent actions that were created in order to solve a problem or inefficiency identified through the measure and analysis field. The previous improvement actions board of the A3 template was slightly adapted and it is shown in Figure 214.

It is important to have in the A3 information as:

- *Source/problem identification*: Definition of the main cause(s) through techniques as 5 Why, Ishikawa, DOE, among others;
- *Module*: Defines the module/submodule where the action will be carried out;
- *Action*: Describes summarily the action to be performed;
- *Responsible*: Defines the person responsible to carry out the defined action;
- *Date*: Defines the deadline;
- *Improvement*: Measures the expected gain with the implementation of the defined action;
- *Check*: Link for the corresponding action on the Kanboard;
- *Act*: Open or closed status of the action.

Figure 213 - Example of action information view on *Kanboard*

In order to facilitate the management of the document, it was developed two macros for this field: one to order the defined improvement actions by the bigger expected gain first; and another to move and achieve for another excel sheet the completed actions classified as "closed" (Figure 214).



ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	OEE Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
11	Desvios de velocidade (1.8%)	F3 LM	VW Polo portas: Alterar posto de montagem de cabo por forma a incorporar montagem do clip no terminal de cabo no posto de aparar	PO	31/mai	0.70%	31/05/2018	MAI	WK22		OPEN
4	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Plano para redução setups planificados (Lotes económicos, sequência optima de refs....)	DL	20/mai	0.40%	20/05/2018	MAI	WK20		OPEN
10	Desvios de velocidade (1.8%)	F2 LM	Volvo - Validar rutas, definir ações para desvios	PO	25/mai	0.20%	25/05/2018	MAI	WK21		OPEN
3	Machine downtime=3,2% Process fine tuning =0,7%	F2 INJ	2.c)Improve machine reliability-next machine: nº 15 (preventive maintenence plan)	FH	31/mai	1.70%	31/05/2018	MAI	WK22	Kanboard #14835	OPEN
4	Mold setup=2,2%/14 per day/ Avg=38,4 min	F2 INJ	Aumentar o stock (trabalhar 12 horas ao sábado)	TL	22/mai	0.80%	22/05/2018	MAI	WK21	Kanboard #13931	OPEN
2	Mold repair = 1,1 % (April=1,3%)	F2 INJ	Plano de intervenção nos moldes: RG3 ext (multiplás) e GM CD369	ML	31/mai	0.30%	31/05/2018	MAI	WK22		OPEN
6	OEE (falta de MOD)	F4 INJ	KB - Implementar equipa de substituição de paragens (Ok, Lanche, 5S, etc..)	RD	31/mai	5.57%	31/05/2018	MAI	WK22	Kanboard #12005	OPEN
5	Av) falta de peças de substituição	F4 INJ	Criar stk/peças de substiuição (C1YX); modificar bocas de lobo 1º molde	RD	28/mai	0.30%	28/05/2018	MAI	WK22	Kanboard #13041	OPEN
2	Av/Q fuso mal dimensionado	F4 INJ	KB - Comprar fuso/camisa (peq novo) MQ19 (75%); reparação do da máq 19 (25%)	FT	31/mai	0.27%	31/05/2018	MAI	WK22	Kanboard #14482	OPEN
3	Tachi/B02E - Fiabilidade do equipamento	F1	Recolha das causas/frequência e seguimento das ações para elimição dos dois maiores problemas (posto comum e intr. do tubo)	PA	31/mai	0.50%	31/05/2018	MAI	WK22	Kanboard #10946	OPEN
2	Tachi/B02E - Fiabilidade do equipamento	F1	Fecho das ações no PT dobragem dos arames laranja e fiabilização dos sensores/programação de deteção do tubo nos ganchos	PA	27/mai	0.50%	27/05/2018	MAI	WK22	Kanboard #10112	OPEN
5	Qualidade LR2/C1 - escorrido de ZK no cabo	F5	Testar ação de melhoria (aperto do canal do molde) - validar molde, e maquina	OL	28/mai	0.4%	28/05/2018	MAI	WK22	Kanboard #13958	OPEN

Figure 214 - Adapted improvement actions board of the A3 sheet

As the interconnection of data is an important principle of the A3 methodology implemented, the improvement actions are linked between the different A3 sheets related to the same KPI. In Figure 214, it is represented the improvement actions board of an OEE A3 of the global factory (plant manager) and every three rows represent the most important improvement actions classified as "open" of the level of analysis below (production directors).

Although some improvements have been made in this A3 field, more automatisms and connections of data could be created and assured. One important improvement to be made in a future stage is to automatically fuel and update the A3 with the improvement actions information from the Kanboard.

__Improvement 5 – Create A3 for the Scrap indicator__

As it was explained before, the quality component of the OEE does not give a true vision of the quality across the different types of equipment and processes, so that was a necessity to create a better analysis mechanism.

The principle of data update automatization for this series of A3 sheets is the same as for the OEE/MOD deviation KPIs. The only difference is the source, that in this case is the *BPCS* software. Also, the different A3 sheets stratification follows the same principle of division between plant manager (global), production director (a group of submodules) and team member (specific submodules) and it is summarized in Figure 215.

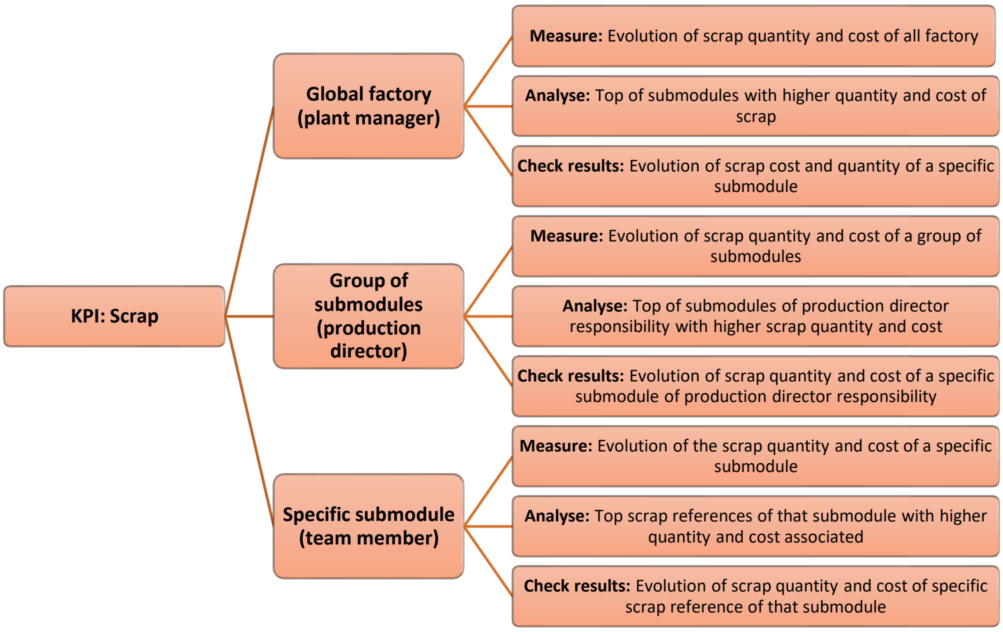


Figure 215 - A3 sheet's stratification for the Scrap KPI and resolution view of the main fields

In terms of the plant manager A3 (global) and starting for the measured field (Figure 216), it is important to follow the number of units scrapped and, more importantly, the associated cost. It is important to understand that a report of, for example, 200 units with a cost of 5 euros each has bigger consequences and effects than a report of 1000 non-conforming units of just two cents each. However, it is also important to identify the causes for a bigger quantity of scrap, even if it represents a lower cost, as this causes could have severe consequences in the future with a more expensive raw material or subgroup product.

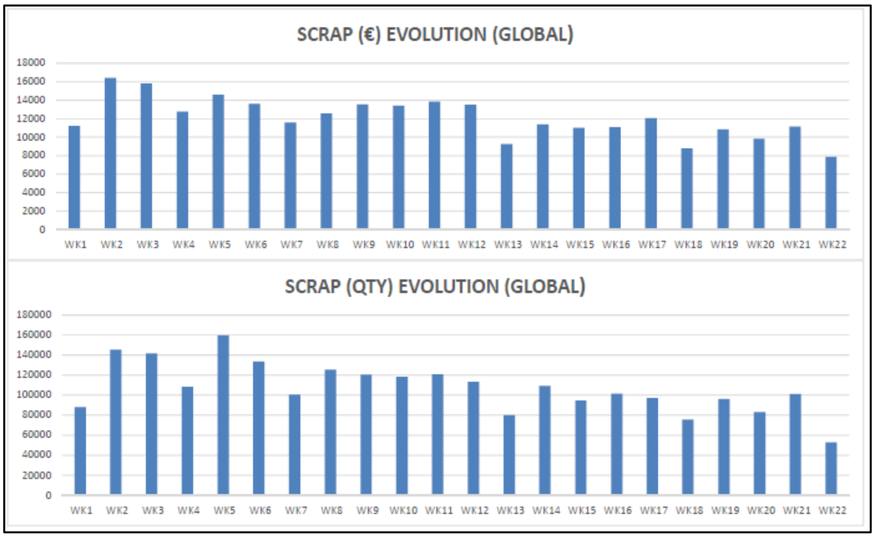


Figure 216 – *Measure* field with evolution of scrap cost (above) and quantity (below)

In terms of the analysed field (Figure 217), a Pareto graph gives the information of the submodules that contribute most to the quantity and the associated scrap cost. It is visible that the F4 plastic injection submodule (F4 INJ) just appears as sixth in the top for scrap quantity but is the one that represents the major cost of scrap.

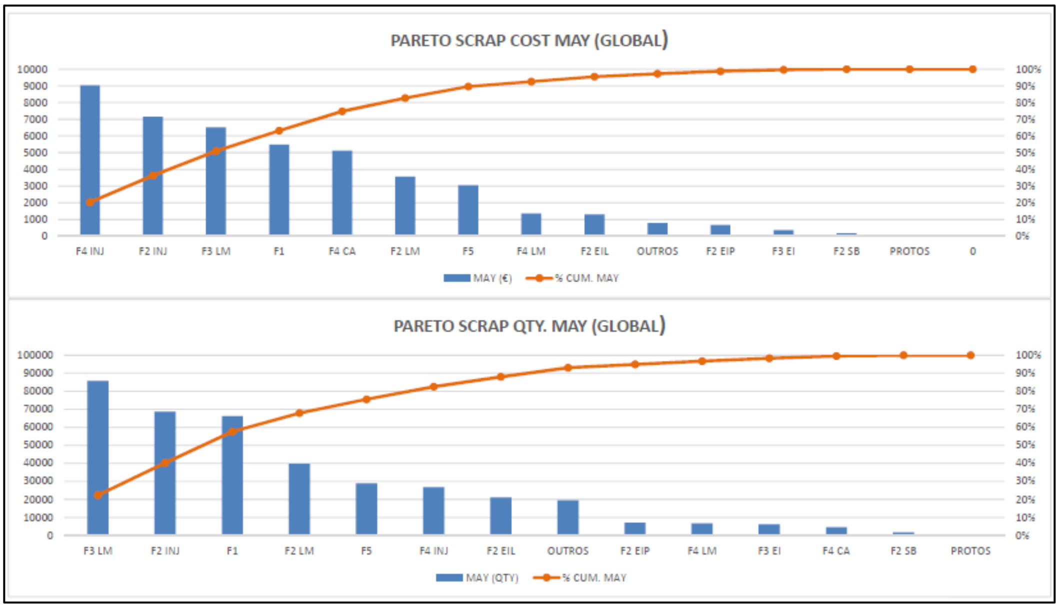


Figure 217 - Analysis field with the pareto of scrap cost (above) and scrap quantity (below)

With the definition of improvement actions to reduce the scrap cost in the most impacting submodules, the evolution could be followed through the check results field as represented in Figure 218.

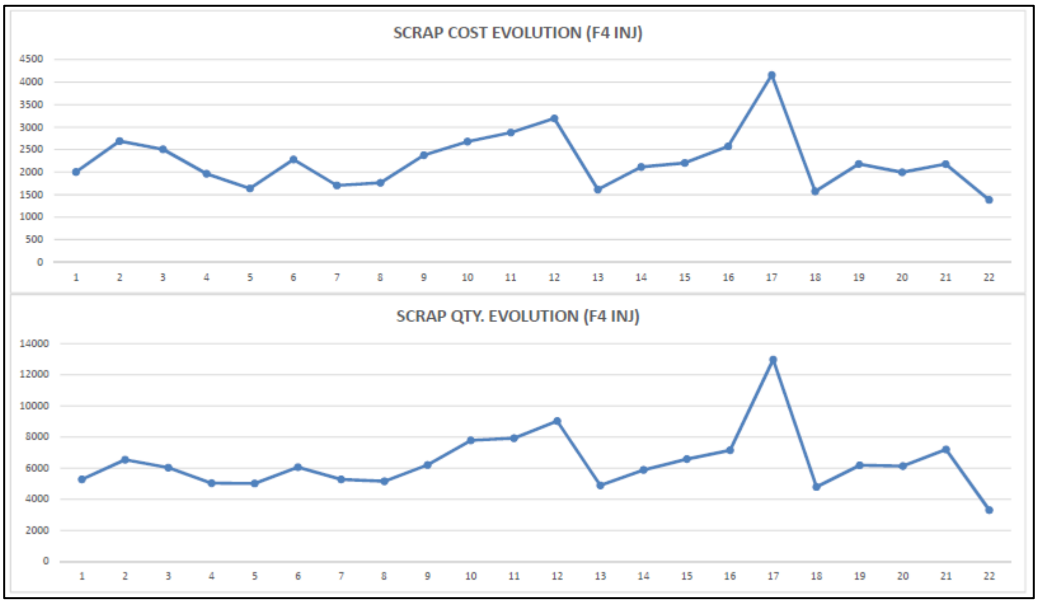


Figure 218 – *Check Results* field with the evolution of scrap cost (above) and scrap quantity (below) for the F4 INJ submodule

The A3 sheets of the different production directors follow the same principle as the plant manager A3 (global) described before. In terms of the A3 of a specific submodule (managed by one or more team members of a production direction team), the analyze field identifies in the Pareto the most important scrap references (with combination with the description of the defect) as shown in Figure 219.

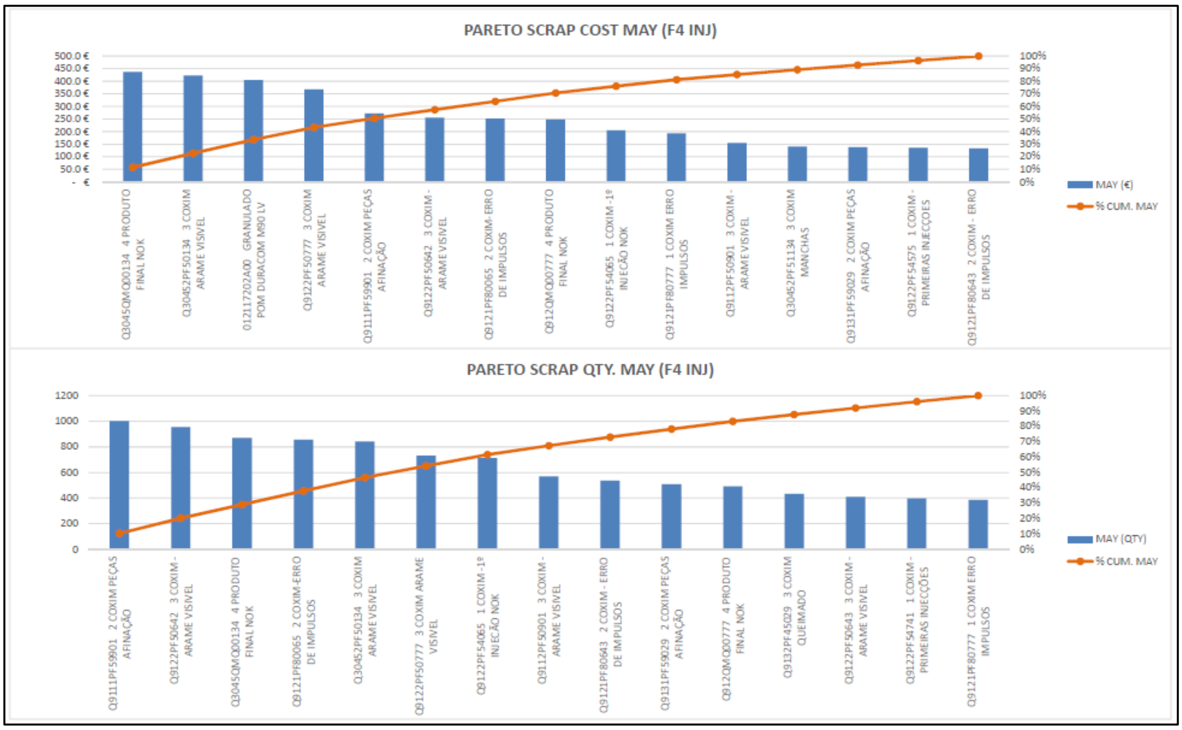


Figure 219 - *Analysis field* of the top references of scrap quantity and cost for a specific submodule (A3 team member)

<u>*Improvement 6 – Create A3 for the Availability indicator*</u>

Another improvement opportunity that was identified was to create a specific A3 to better follow and evaluate the availability component of the OEE. The availability traduces the number of stoppages and the time that specific machines and equipment were not working. The analysis of this stoppages allows to better understand the corresponding causes and, consequently, to define improvement actions in order to eliminate them or to minimize their occurrence.

In *Fico Cables*, for each stoppage, the operator/team leader/maintenance needs to report it in the system with the respective duration and classify with the cause and the motive. There are 21 pre-classified stoppage causes that are identified in Table 78.

Table 78 – Different stoppage causes codes used in Fico Cables

Stoppage causes (assembly lines)	Stoppage causes (machines)	Stoppage causes (both)
Z.105.AVARIA	Z.205.AVARIA MÁQUINA	Z.901.FALTA DE ORDEM
Z.110.PRODUÇÃO	Z.210.REPARAÇÕES NO MOLDE	Z.902.FALTA DE ORDEM
Z.115.FALTA DE MATERIAL	Z.215.CABEÇA SOPRO	
Z.120.QUALIDADE	Z.220.MUDANÇA DE MOLDE	
Z.125.MANUTENÇÃO PREVENTIVA	Z.225.MUDANÇA DA REFERÊNCIA	
Z.130.FALTA DE ABASTECIMENTO	Z.230.PERIFÉRICOS	
Z.135.OUTRAS ATIVIDADES	Z.235.COMEÇAR	
	Z.240.MANUTENÇÃO PREVENTIVA	
	Z.245.FALTA DE MATERIAL	
	Z.250.FALTA DE ABASTECIMENTO	
	Z.255.FALTA DE PESSOAS	
	Z.260.ENSAIOS	

For the different stoppage causes, there are different classified motives. As an example, the stoppage cause "Z.115.FALTA DE MATERIAL" has the following motives represented in Table 79.

Table 79 - Different stoppage motives codes for the cause Z.115.FALTA DE MATERIAL used in Fico Cables

Stoppage motives (*Cause: Z.115.FALTA DE MATERIAL*)
00 – Componentes dos Fornecedores
01-Componentes para Moldes
02 – Componentes para Impressão
03 – Componentes para os Sopros
04 – Componentes para a Fundição
05 – Outros Componentes Processo Interno
06 – Embalagem
07 – Consumíveis
08 – Logística

In terms of "House of A3", this KPI follows a slightly different principle as it is necessary to follow the availability problems of specific machines, creating also a specific A3 for them. The stratification of the A3 sheets for this KPI is represented in Figure 220.

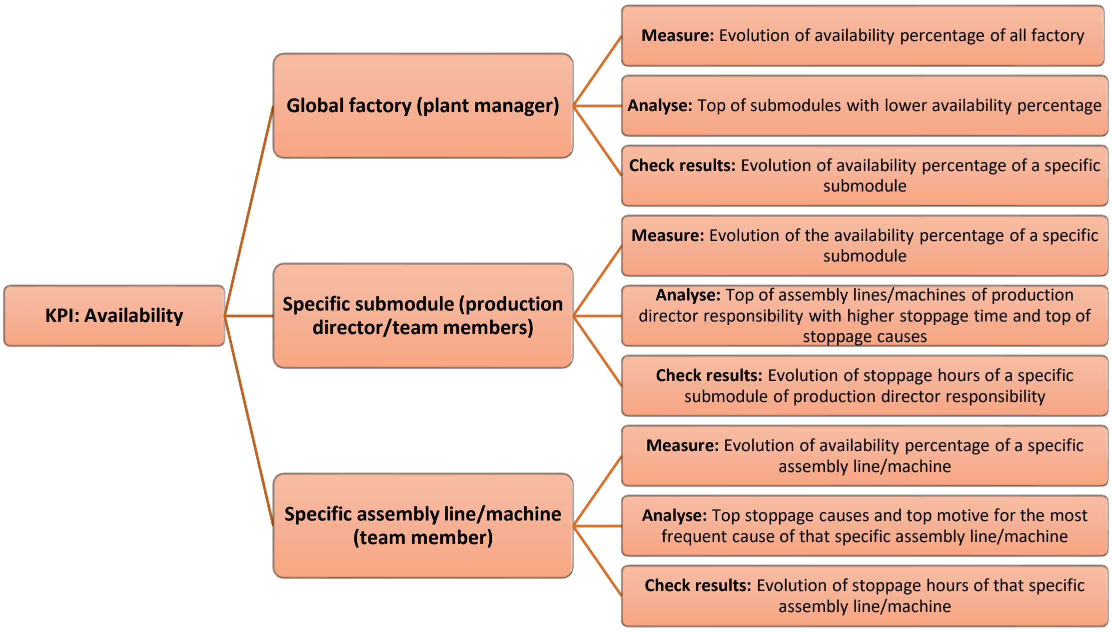


Figure 220 - A3 sheet's stratification for the Availability KPI and resolution view of the main fields

In terms of the plant manager A3 sheet (top-level of analysis), the measured field follows the evolution of the corresponding OEE availability component percentage of the global factory as represented in Figure 221.

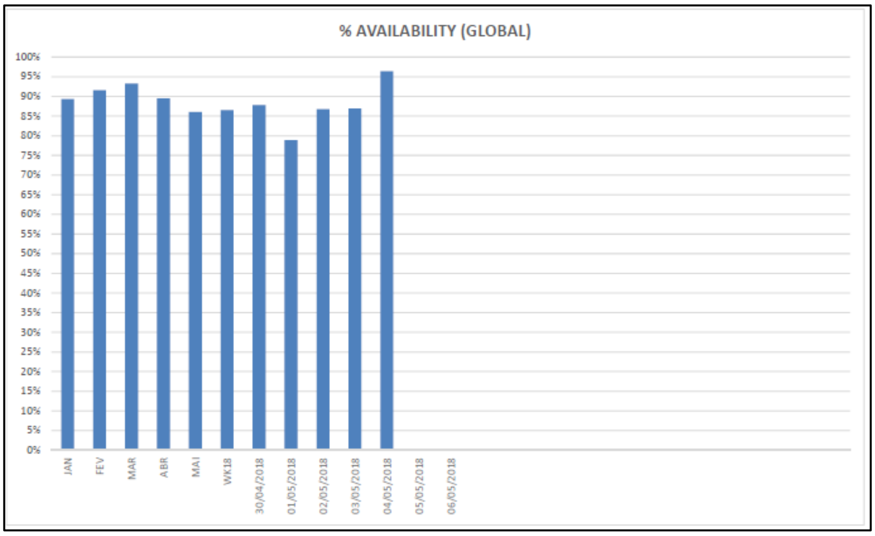


Figure 221 - Evolution of the global percentage of availability (A3 plant manager)

In the analyze field, a Pareto chart allows identifying which submodules has the lower availability percentages in order to, again, focus efforts and concentrate the definition of improvement actions for them (Figure 222). It is visible that the bending wire submodule (F4 CA) has the lower availability percentage with around 82%.

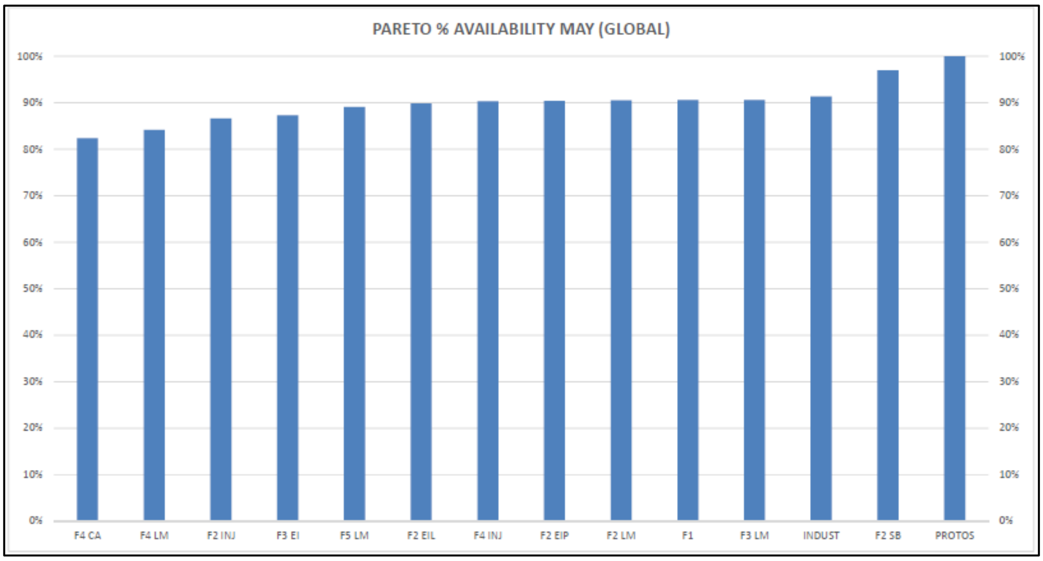


Figure 222 - *Analysis field* of the plant manager Availability A3 sheet

The evolution of this percentage and the effectiveness of the improvement actions performed for this specific submodule could be analyzed in the check results field (Figure 223).

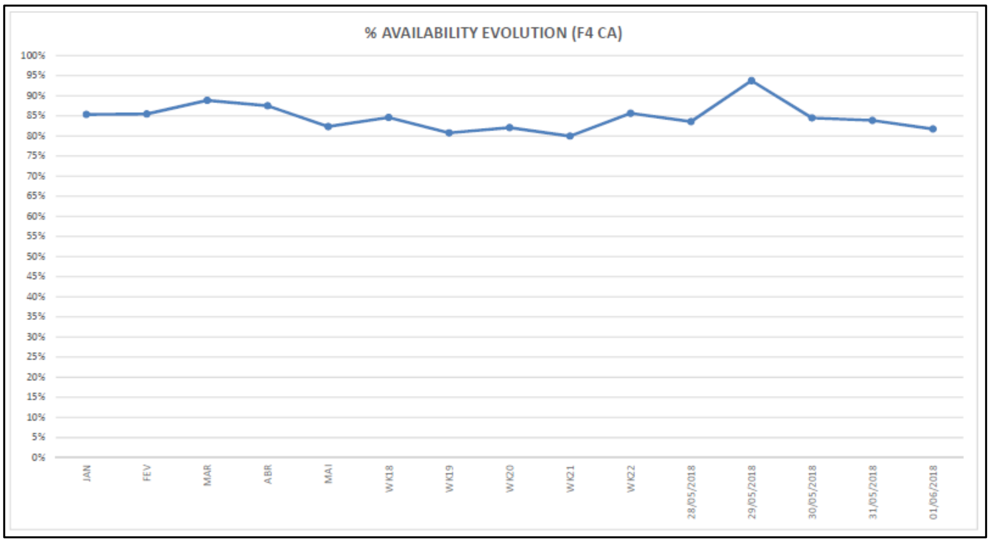


Figure 223 - *Check Results* field of the plant manager Availability A3 sheet

In the case of the specific submodule and specific machines A3 sheet, the measured field has the same type of graph, with the evolution of the corresponding evolution of the availability percentage.

In terms of the A3 of a specific submodule (for example, the F2 INJ), the analysis field has two Pareto graphs, allowing to identify which machines have the most number of stoppage hours and the most frequent causes of the overall stoppage hours of the F2 INJ submodule, as represented in Figure 224.

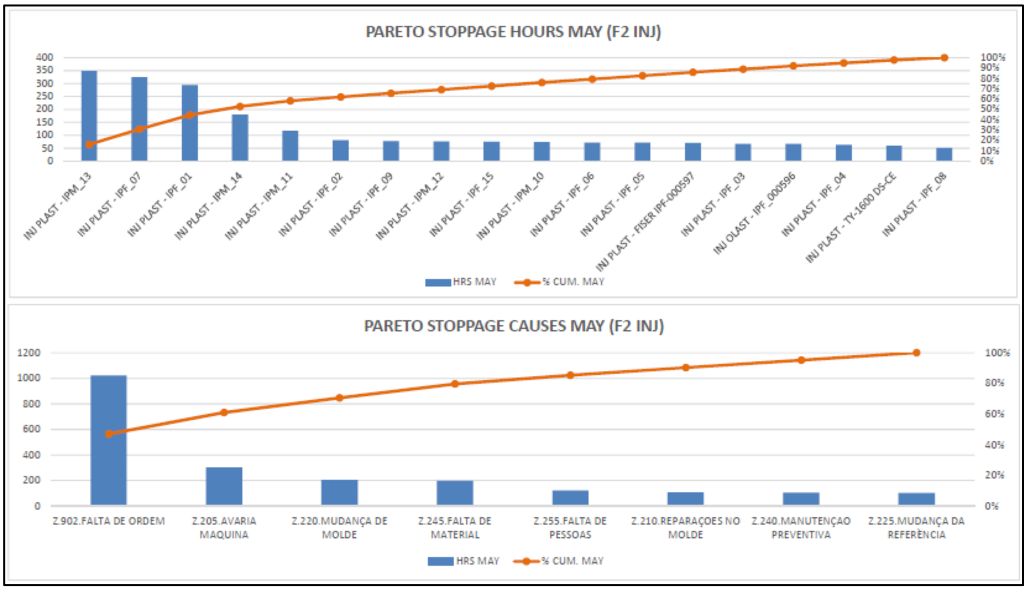


Figure 224 - *Analysis field* of a specific submodule availability A3 sheet

In order to evaluate the effectiveness of the improvement actions, the check results in the field of this type of A3 measures the evolution of stoppage hours, as represented in Figure 225.

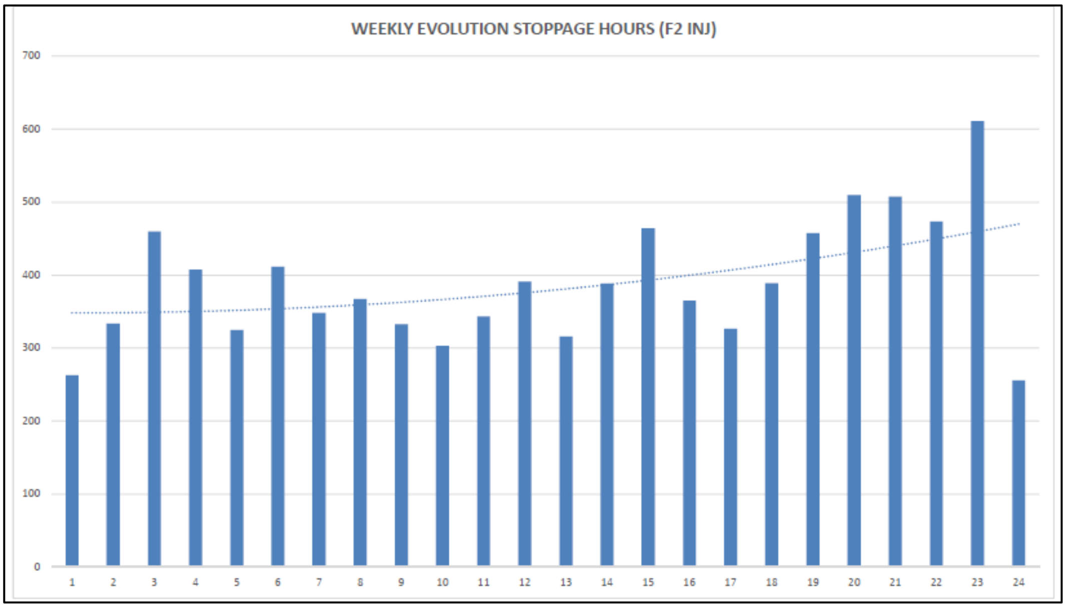


Figure 225 - *Check Results* field of a specific submodule availability A3 sheet

In the first Pareto of the specific submodule A3 sheet (stoppage hours), it is visible that the IPM 13 is the machine of the F2 INJ submodule that has the most number of stoppage hours. In order to evaluate and analyze the availability of this machine, a specific machine A3 sheet could be created.

In the analyzed field of this A3, it is identified the most common causes as well as the most main motives for the top cause identified in the first Pareto (Figure 226).

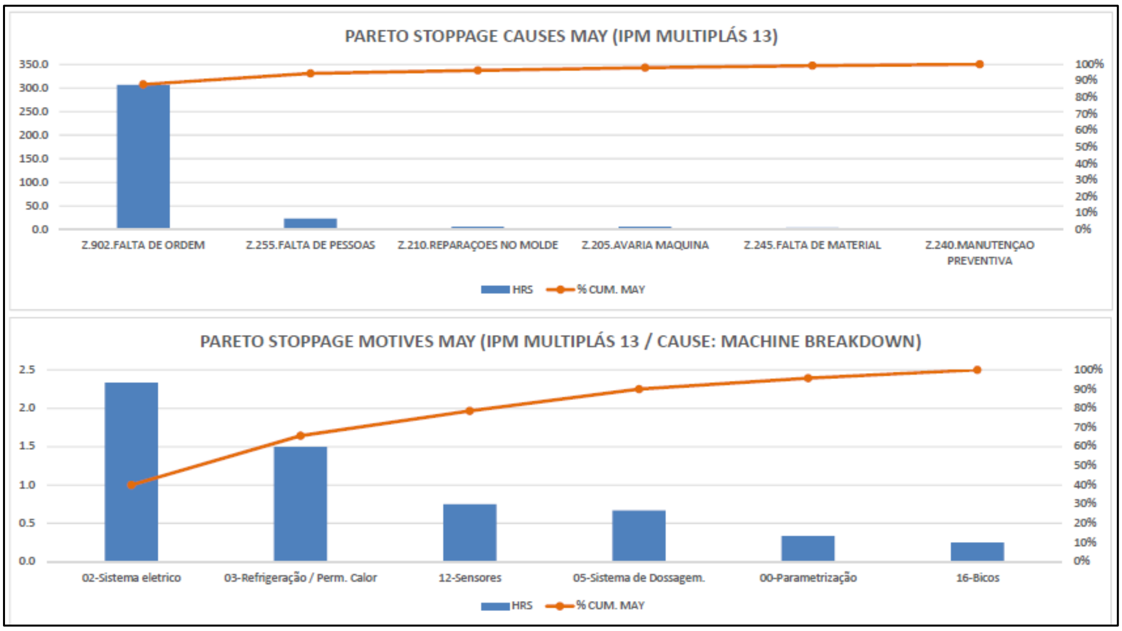


Figure 226 - *Analysis field* of a specific machine availability A3 sheet

3.5.6 Critical analysis of results

Generally, the implementation of this case study allowed to get a better and accurate vision of the most important KPIs used on *Fico Cables*. As the A3 is considered a problem-solving tool, it is crucial to have important and relevant information present on the A3, that would allow to support new decisions and to follow the results of the implemented actions.

One of the most important aspects relating to the improvement of the A3 methodology used on Fico Cables where the transformation for manual to fully automatic documents, increasing the available time for who is analyzing these documents to really analyzing them instead of spending the biggest stake of this available time updating the document and with other non-value-added tasks. This update process was used to take about one hour to complete instead of about 2 minutes. his document automatization characteristic allowed also to inter-connect data between the different A3 sheets created, assuring that everyone, from an up level to a down level, is visualizing the same information.

In terms of KPIs involved in this methodology, it was added the scrap and availability for the existent OEE and MOD A3 documentation, allowing to get a bigger view of the current status of Fico Cables on a highly effective tool model as the A3.

Another important improvement achieved was the stratification of documentation, with the creation of different A3 sheet for each level of analysis as well as the visualization of only relevant and crucial information. This stratification evolution for a one-level level of analysis (module responsible) for a three-level analysis (plant manager, module responsible, submodule responsible), each one with the essential information needed to make a decision on the corresponding level.

Also, as one of the biggest important fields of the A3 is the *Improvement Actions* and because it is key to keep things organized and to focus attention with only the necessary, it was added the capacity to prioritize improvement actions by the expected gain as well as have a connection for the PDCA platform: *Kanboard*.

Summarizing, it was vital to improve one of the most important problem-solving tools associated with monitoring the major KPIs of *Fico Cables.* With summarized information, it is possible to have a clear view of the real problems expressed in a specific KPI and how they evolved during a specific period of time. This better-disposed support information allows then to quicker and, in a more agile way, define countermeasures for their occurrence and follow their effectiveness.

CONCLUSIONS

4 CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

4.1 CONCLUSIONS

With the conclusion of the internship period, it was possible to highlight several gains for the company, expressed in operational and efficiency terms, and for the student, in terms of skills and knowledge acquired.

4.1.1 Project gains

Based on the goals defined and described on the first chapter of this dissertation, it is synthesized in Table 80, **Erro! A origem da referência não foi encontrada.** and **Erro! A origem da referência não foi encontrada.** the corresponding solutions and improvement actions implemented, for each case study approached on this dissertation.

Table 80 - Summary of the defined goals and respective implemented actions for the *improvement of 'PSA Travão' assembly line* case study

Goal	Solution/Implemented action/Gain	Status
Analysis the previous status of the assembly line, with the measurement of the different operations carried out, visualization of the previous assembly line balancing and calculation of the possible output.	Determination of the different operations cycle time through the use of time measurement techniques with the identification of the assembly line bottleneck and visible wastes/*mudas*.	✓
Critical analysis of the results and identification of justified improvement opportunities.	Definition of an improvement actions plan, based on the different type of wastes verified and with defined deadlines and supervisors for the finishing of each action.	✓
Create conditions and follow the implementation of the defined improvement opportunities.	Continuous involvement and dialogue with different departments (production, processes, maintenance, continuous improvement) and with the workers of the assembly in order to ensure the commitment and execution of the defined improvement actions plan.	✓

Goal	Solution/Implemented action/Gain	Status
Verify the success of the improvement actions implemented.	With the new measurement of the different operations cycle time, it was verified that all the operations are now below the takt time, allowing to accomplish the customer deadlines. The implementation of the improvement actions allowed to reach the following quantified gains: - Increased the output from 187 to 225 cables per hour; - Increase in OEE percentage from 65/70% to 75/80%; - Increased the line balance efficiency rate from 85 to 93%; - Increased the result in 5S audit from 28% to 92%.	✓
Identify possible future opportunities for the second stage of improvement.	Identification of a possible operation transformation from manual to automatic assembles, supported by the elaboration of a VSM and quantification of the possible productivity gain and cost saving.	✓

Table 81 - Summarization of the defined goals and respective implemented actions for the diminution of scrap produced case study

Goal	Solution/Implemented action/Gain	Status
Identify and understand the causes, and the equipment associated, for the excessive scrap production on the most critical module.	Creation of a specific data collection plan in order to be possible to visualize which equipment produce more quantity of scrap and the types of defect associated.	✓
Discuss, with workers and maintenance teams, possible improvements and modifications that could be realized on the most critical equipment.	Undergo of *brainstorming* sessions with members of the processes, maintenance, production and continuous team, and application *of 5 Why's* and *5W2H* techniques in order to fulfill *Ishikawa* diagrams with the aim to understand possible causes for the scrap production. Definition of improvement actions plans to contain the scrap rates.	✓

Goal	Solution/Implemented action/Gain	Status
Follow the implementation, verify and control the result of the improvement actions implemented.	Continuous communication and involvement with the different departments involved and with the administration, in order to approve the different budgets for equipment interventions. Several defined improvement actions were not still completed at the time of the conclusion of this internship for budget reasons. However, the implemented actions allowed to visualize positive results, as a decrease in the monthly scrap cost of about 1000€ from January to August. The implementation of the improvement actions allowed to reach the following quantified gains: - Reduced the quantity of scrap produced on LBT (weekly) from 40/60 kg to 25-35 kg; - Reduced the quantity of scrap produced on Dorca 1 (weekly) from 160 kg to 140 kg; Reduced the quantity of scrap produced on Dorca 1 (weekly) from 150 kg to 140 kg.	✓

Table 82 - Summarization of the defined goals and respective implemented actions for the A3 methodology case study

Goal	Solution/Implemented action/Gain	Status
Identification of the fundamental KPIs related to the production management of *Fico Cables* and apply/improve the A3 methodology associated.	Identification of the MOD deviation and OEE as the most fundamental production KPIs, through discussion with production directors, and proposal of the A3 methodology application to scrap and availability KPIs.	✓
Improvement of the level of automatization related to the data collection process of the different A3 documents.	Developed work with the DSI department in order to create libraries of data from the different software's used to report production and scrap (CP and BPCS). With the integration of on the Excel software, it was then possible to automatically update these libraries and, by consequence, update the raw data that feed the KPIs calculations.	✓

Goal	Solution/Implemented action/Gain	Status
Interconnect the different A3 documents, in order to allow the user to easily switch between them.	Creation of linkages between the different A3 documents, inside a determined KPI, leading everyone along the hierarchy chain could visualize the same information. Creation of a "House of A3" tree with quick links for the existent A3 documents.	✓

4.1.2 Company gains

There were also different gains for *Fico Cables*, that are transversal to the developed case studies, which are summarized below:

- Better knowledge of the common and typical source of wastes on the different assembly lines;
- Dynamization of productivity culture with the *Lean* implementations realized on the 'PSA Travão' assembly line;
- Deeper knowledge and comprehension of one of the most process flows and modules of *Fico Cables* (comfort systems);
- Knowledge of future needs for the most critical *Fico Cables'* equipment;
- Standardization of a methodology to analyze and follow KPIs.

4.1.3 Personal skills and achievements

The development, participation and collaboration on the whole case studies showcased allowed the author of this dissertation, as a student and on the beginning of his career, to achieve some personal gains, in terms of skills and experience acquired, which are explicit as follows:

- Excel functions and Visual Basic (VBA);
- *Six Sigma* methodology;
- Several *Lean* tools;
- Communication skills;
- Quick adaptation skills;
- Organizational skills.

Also, as *Fico Cables* globally recognized the positive results of the internship period, allowed the author to continue proceeding with his career and developing himself on the company, with the proposal of a contract.

4.2 PROPOSALS OF FUTURE WORKS

With the development of the showcased case studies, different necessities and improvement opportunities were appearing, which can be summarized as follows:

- Promote SMED projects on several assembly lines, in order to reduce the internal setup time and raise the operation time;
- Creation of smaller improvement teams focused on specific equipment of the F4 submodule (case study 2) and based on the scrap causes detected by the *Six Sigma* project. Application of simpler improvement methodologies as PDCA cycle for these teams;
- Improve the scrap report process on the F4 submodule, in order to have more and instantly information about the equipment associated, the type of the defect, the source of the defect, etc.;
- Expand the A3 methodology adopted to follow production KPIs for another type of KPIs used on *Fico Cables*;
- The complete connection of the improvement actions management software (Kanboard) with the KPI A3 documents.

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5 REFERENCES AND OTHER SOURCES OF INFORMATION

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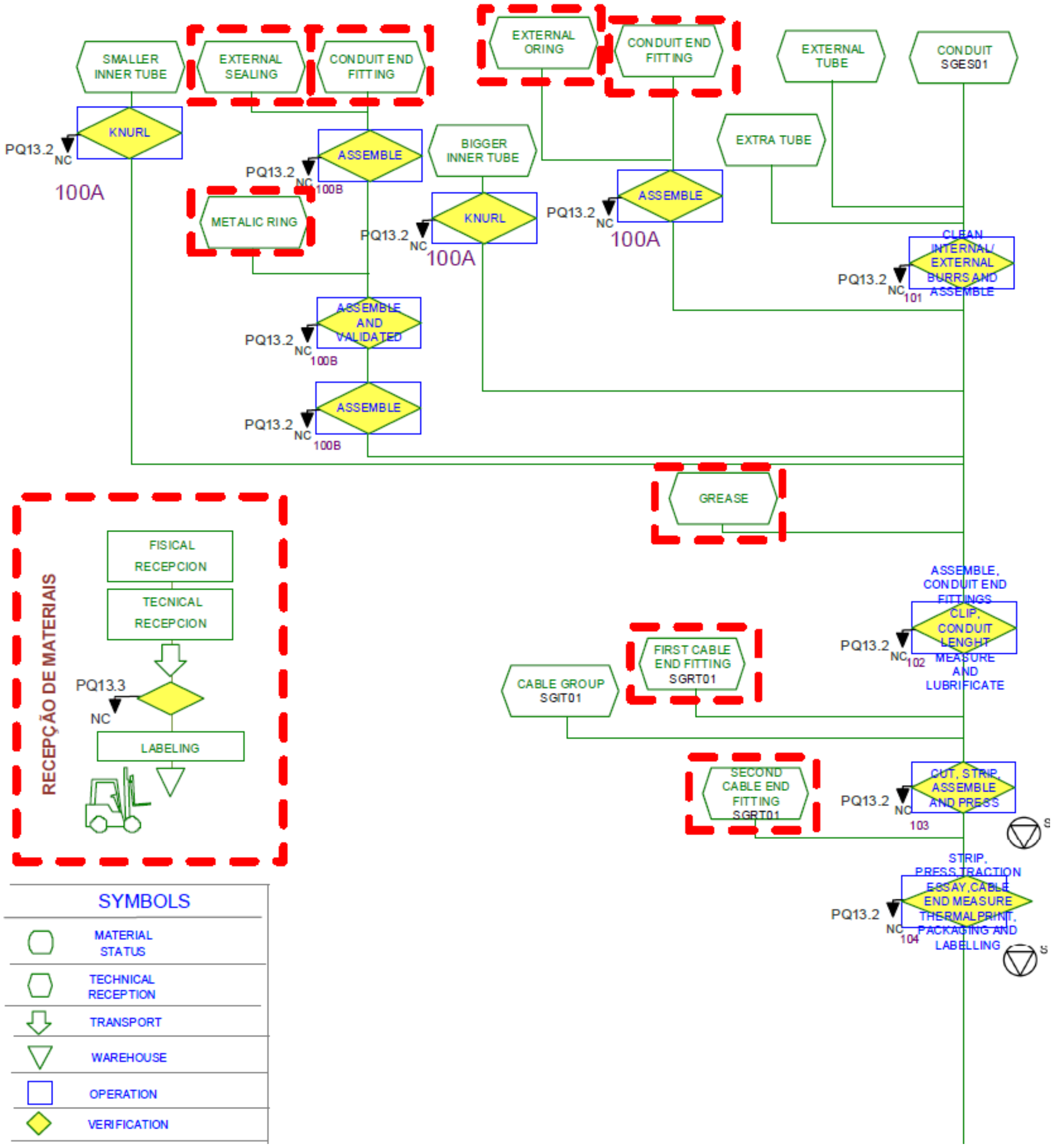
ANNEXES

6 ANNEXES

6.1 ANNEX 1 – Flow chart of operations of the 'PSA Travão' assembly line



6.2 ANNEX 2 – Standard 4S developed for 'PSA Travão' assembly line

Metodologia 5S

4ºS - Standardizar

Revisão: 1

Data: 13/07/2018

Módulo: F3

Linha: PSA Travão








Checklist Limpeza

N.º	Actividade	Freq.	Resp.
1	Limpar toda a área envolvente da linha.	Turno	Operadores
2	Limpar cada posto de trabalho.	Turno	Operadores
3	Organizar racks de componentes / subconjuntos e zonas de stock conforme identificação.	Turno	Team Leader / Operadores

N.º	Actividade	Freq.	Resp.
4	Organizar zonas de armazenamento de ferramentas de setup e validação	Turno	Team Leader / Operadores
5	Validar identificação das zonas dos equipamentos e dos locais de armazenamento de ferramentas, produtos e materiais.	Semanal	Team Leader / Operadores
6			

N.º	Actividade	Freq.	Resp.
7			
8			
9			

Elaborado - Ana Maia / João Pereira	
Data:	13/07/2018
Rubrica:	

6.3 ANNEX 3 – A3 documents of MOD deviation KPI

FICOSA Corporate

A3 (KPI - MOD DEVIATION)

Team Members: Pedro Alexandre (PA); Francisco Ferreira (FF); Rui Dias (RD); Paulo Agostinho (PG); Vítor Pinto (VP) *Coordinator:* Costa Pereira (CP)

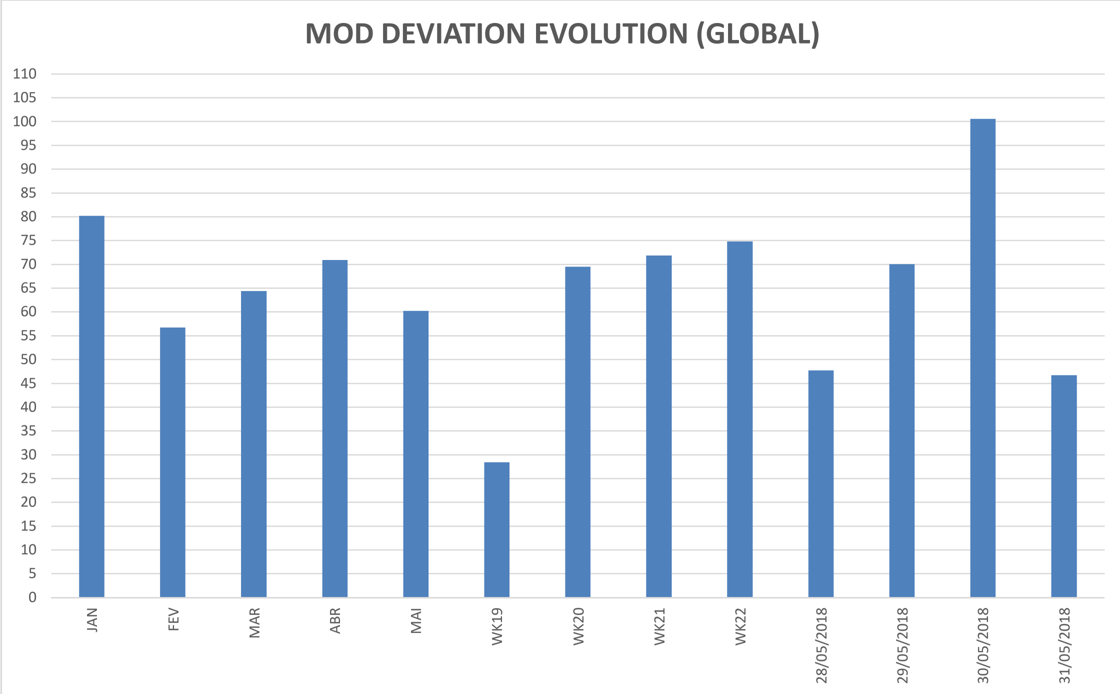
1. DEFINE

MOD deviation (Global)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate OEE/A3 | 3º Refresh Graphs

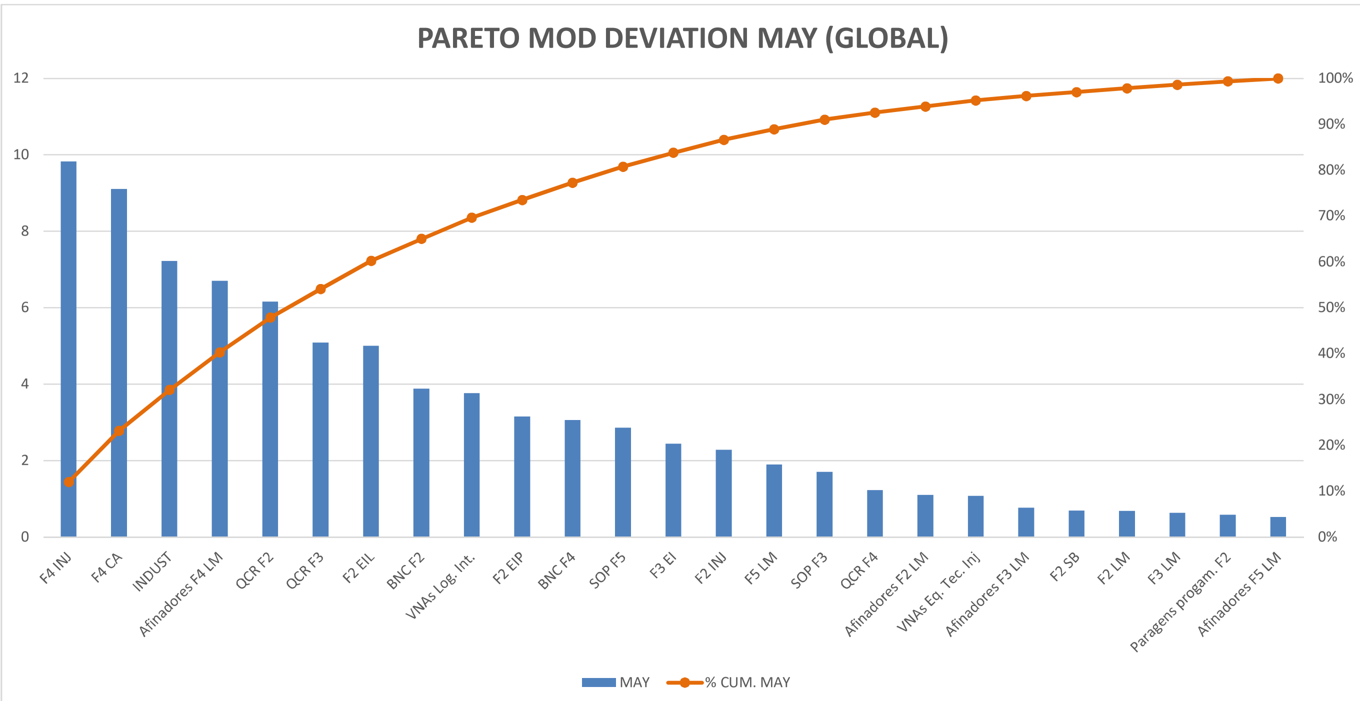


4. IMPROVEMENT ACTIONS

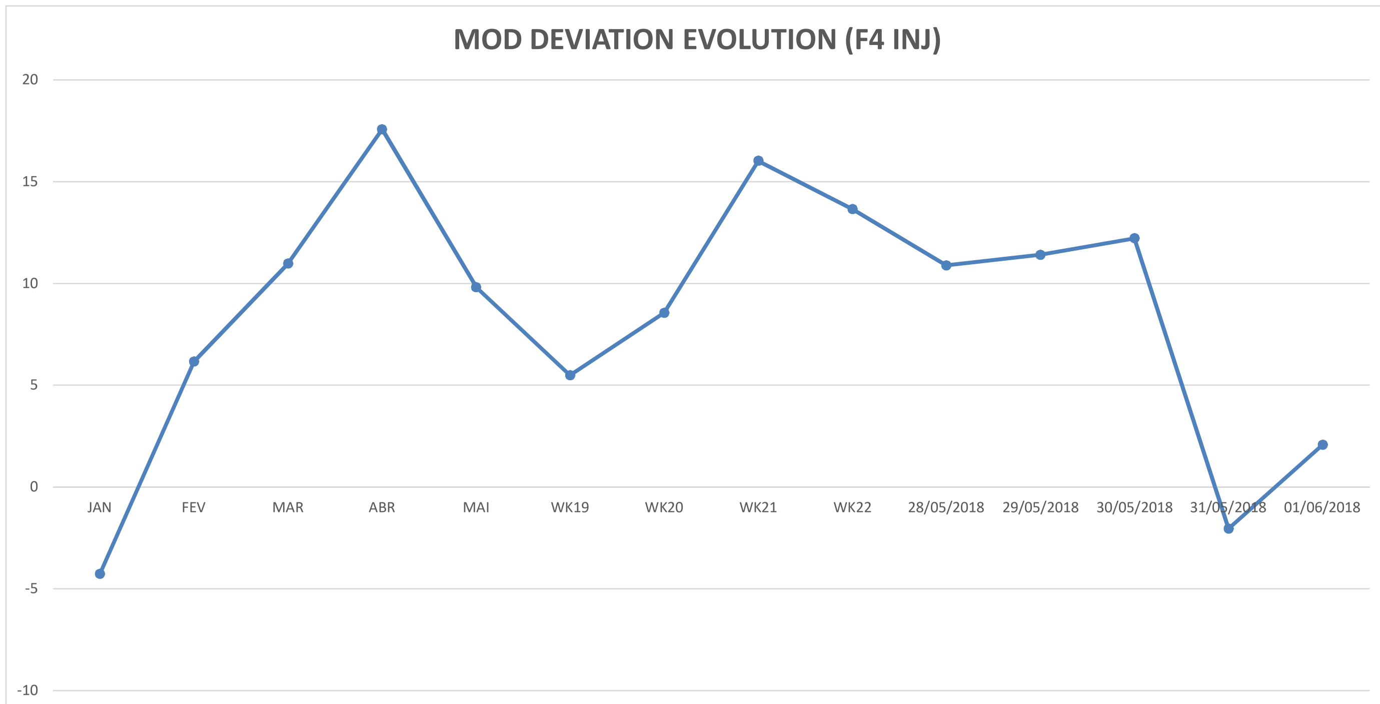
N	ANALYSE: Main Causes/Sources	Module	PLAN: Actions	Resp	Date	MOD Improvement	DO: Date			CHECK: Process	ACT: People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	Nº	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
3	Desvio MOD por QCRs F3	QCR F3	VW Capots Duplos - validar ação no molde para robustez do clip + colocação de PY no posto de dobragem refª 999	PR	25/mai	3.0	25/05/2018	MAI	WK21	Kanboard #14098	OPEN
5	Desvio MOD por afinadores F2	Afinadores F2 LM	Integrar afinador na linha GM auto como op. Especializado.	PA	27/mai	3.0	27/05/2018	MAI	WK22	Kanboard #13076	OPEN
6	Desvio MOD por SOPs F3	SOP F3	Seat Capot G :Novo dispositivo para garantia do posicionamento do tubo exterior;	PR	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #9455	OPEN
3	Desvio MOD F4 CA	F4 CA	Estudar as condições de inj. que permitam anular as ocorrências de peças partidas e queimadas no molde 1 do MVS2 e assim retirar o muro de selecção	EM	31/mai	6.0	31/05/2018	MAI	WK22	Kanboard #11902	OPEN
6	Desvio MOD F4 LM	F4 LM	Propor ao cliente a eliminação da marcação das 13 pinças que estão a ser efetuadas na peça do projeto 005F	FT	24/mai	3.0	24/05/2018	MAI	WK21	Kanboard #10549	OPEN
4	Desvio MOD por Afinadores F4 LM	Afinadores F4 LM	Seat 270_ Rertirar a selecção a 100%, após fiabilização do processo de injecção e operações do posto de pré-montagem.	RD	18/mai	2.0	18/05/2018	MAI	WK20	Kanboard #13298	OPEN
2	Desvio MOD F2 INJ	F2 INJ	Implementação de um sistema de kanban para os fabricos integrados (GM manual)	FF	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #11845	OPEN
1	Desvio MOD F2 INJ	F2 INJ	Formação dos elementos da equipa de moldes, transversalizando a capacidade de resolução de problemas aos 3 turnos	FF	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #10783	OPEN
5	Desvio MOD F2 INJ	F2 INJ	Reorganização do Kanban da injecção de zamak	FF	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #10956	OPEN
4	Desvio MOD F1	F1	Planetárias - Velocidade de produção c/ arame 0,5 - Aplicar anilhas para bobines de chapa	PG	27/mai	1.0	27/05/2018	MAI	WK22	Kanboard #12501	OPEN
2	Desvio MOD por SOP F1	SOP F1	B479 manipulos - Arranque do novo indice (muro de seguimento)	PG	20/mai	1.0	20/05/2018	MAI	WK21	Kanboard #12399	OPEN
3	Desvio MOD por BNC F1		GM travão - aplicar e validar nova ferramenta de dobragem dos Brakets	PO	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #14005	OPEN

1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE



5. CHECK RESULTS



Corporate

A3 (KPI - MOD DEVIATION)

Team Members: Carla Fernandes (CF), Conceição Rosa (CR) ***Coordinator:*** Pedro Alexandre (PA)

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17-May-2018, Ed.6

1. DEFINE

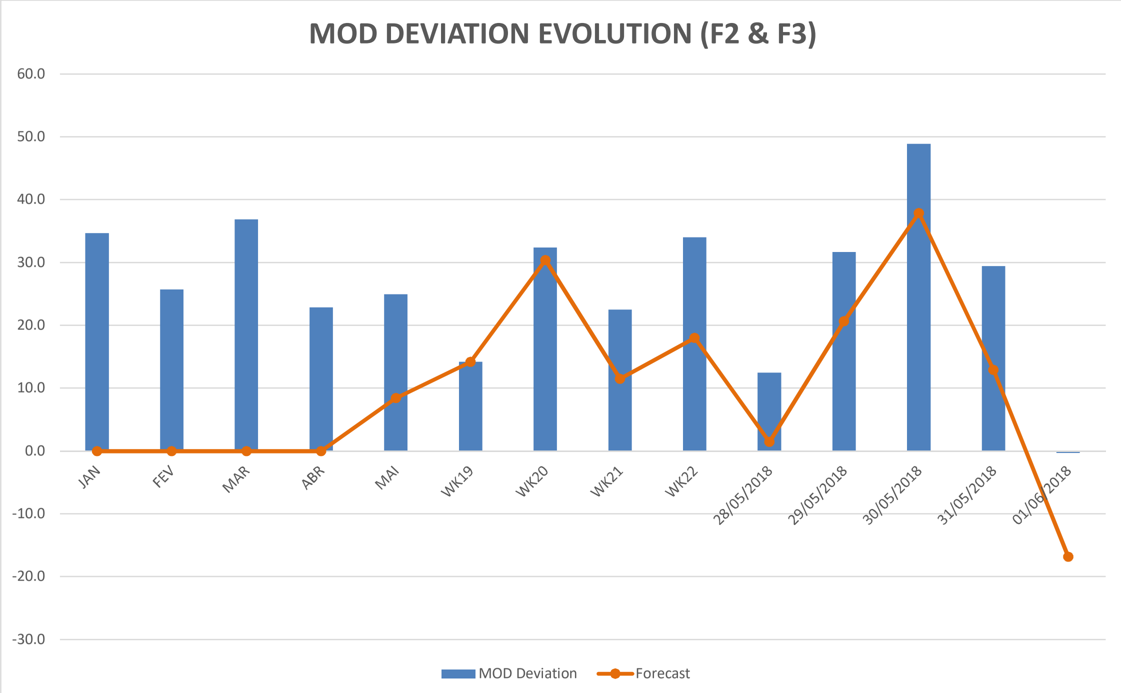
MOD deviation above target (F2&F3)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate OEE/A3 | 3º Refresh Graphs

TARGET = 20

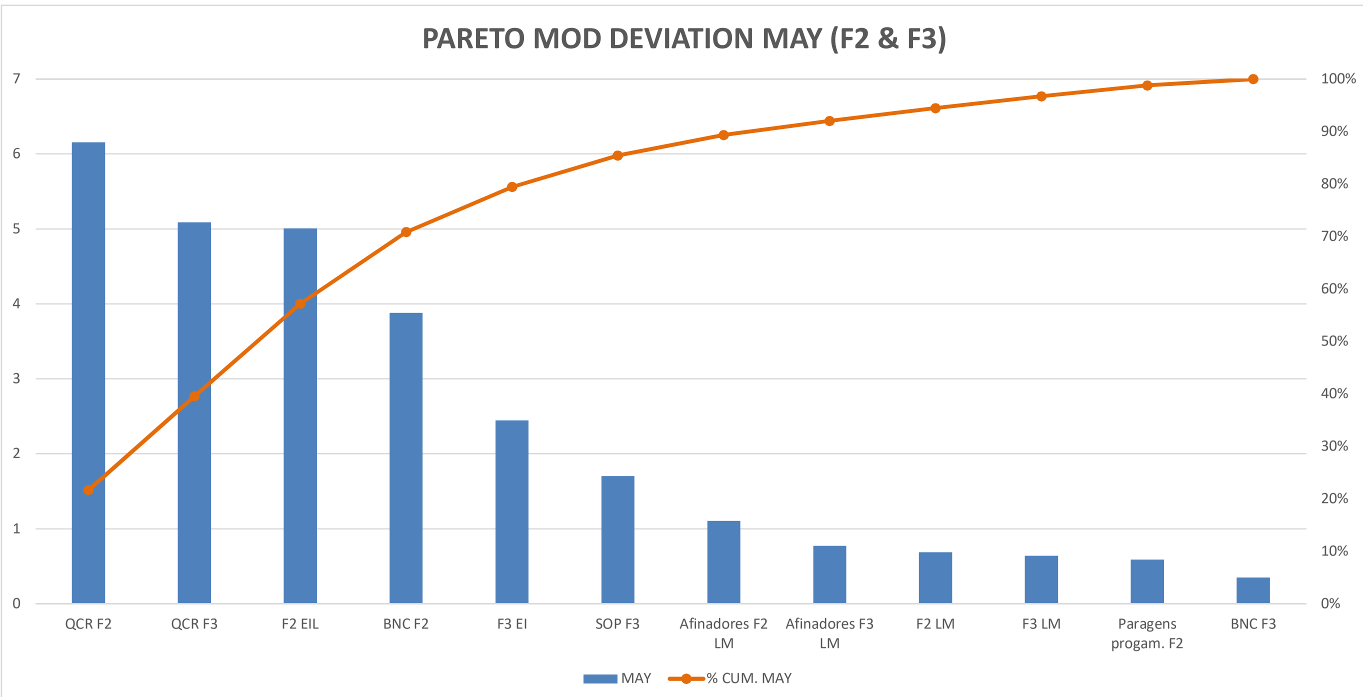


4. IMPROVEMENT ACTIONS

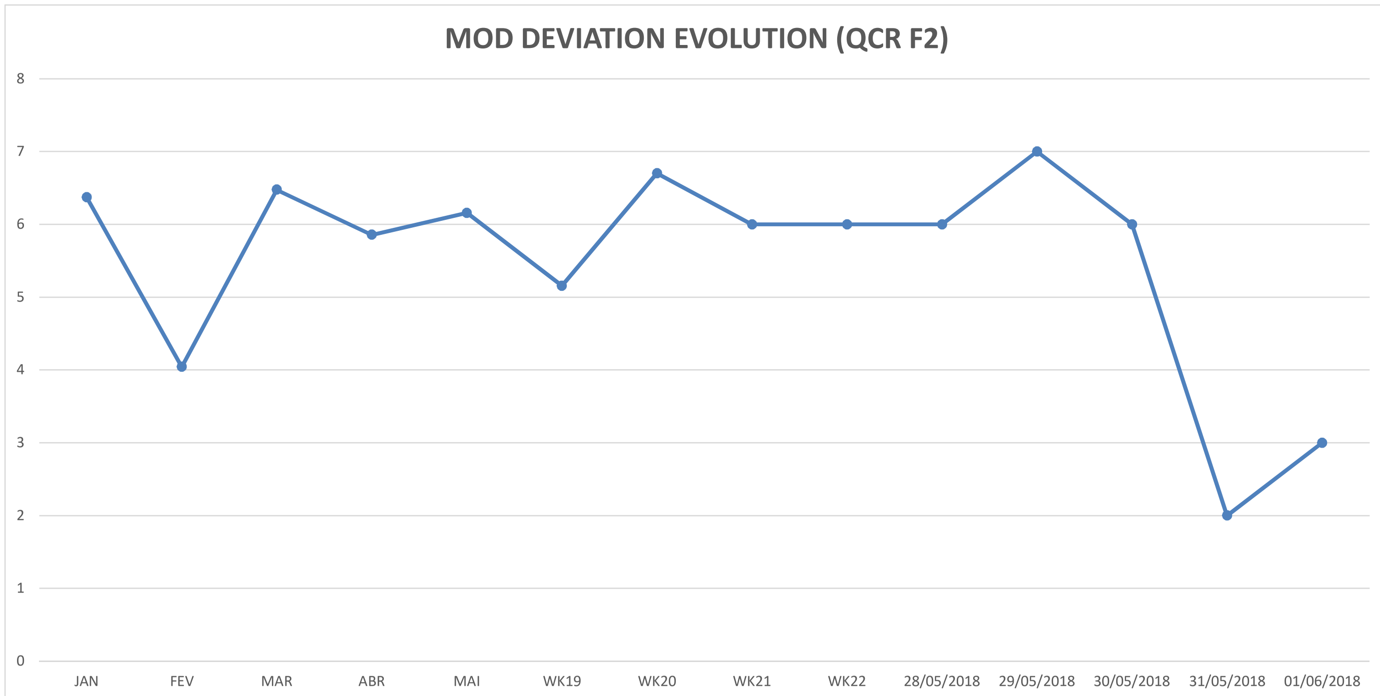
N	ANALYSE: Main Causes/Sources	Module	PLAN: Actions	Resp	Date	MOD Improvement	DO: Date			CHECK: Process	ACT: People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	Nº	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
3	Desvio MOD por QCRs	QCR F3	VW Capots Duplos - validar ação no molde para robustez do clip + colocação de PY no posto de dobragem refª 999	PR	25/mai	3.0	25/05/2018	MAI	WK21	Kanboard #14098	OPEN
5	Desvio MOD por afinadores	Afinadores F2 LM	Integrar afinador na linha GM auto como op. Especializado.	PA	27/mai	3.0	27/05/2018	MAI	WK22	Kanboard #13076	OPEN
6	Desvio MOD por SOPs	SOP F3	Seat Capot G :Novo dispositivo para garantia do posicionamento do tubo exterior;	PR	31/mai	1.0	31/05/2018	MAI	WK22	Kanboard #9455	OPEN
1	Desvio MOD nos EI	F3 EI	Revisão de rutas	IR	31/mai		31/05/2018	MAI	WK22	Kanboard #7837	OPEN
2	Desvio MOD por QCRs	QCR F2	RG3: Fechar ações definidas. Problema filamento de cabo aberto e terminais de espiral partidos	PA	20/mai	6.0	20/05/2018	MAI	WK21	Kanboard #10098	OPEN
4	Desvio MOD por BNCs	BNC F3	2 Ops a escarear espiral armado (Alteração de máq/processo de corte. Passou de cisalha para disco.) - AdquirIR equipamento corte a cisalha.	PO	12/mai	2.0	12/05/2018	MAI	WK20	Kanboard #13598	CLOSED
7	Desvio MOD LMs	F3 LM	Validação Rutas	PO	31/mai	0.5	31/05/2018	MAI	WK22	Kanboard #14001	CLOSED
8	Desvio MOD LMs	F3 LM	Ação alterar posto montagem cabo Volvo Polo Portas	PO	31/mai		31/05/2018	MAI	WK22	Kanboard #13003	CLOSED

1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE



5. CHECK RESULTS



Ficosa Corporate

A3 (KPI - MOD DEVIATION)

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17-May-2018, Ed.6

Team Members: **Carla Fernandes (CF), Conceição Rosa (CR)** ***Coordinator:*** **Pedro Alexandre (PA)**

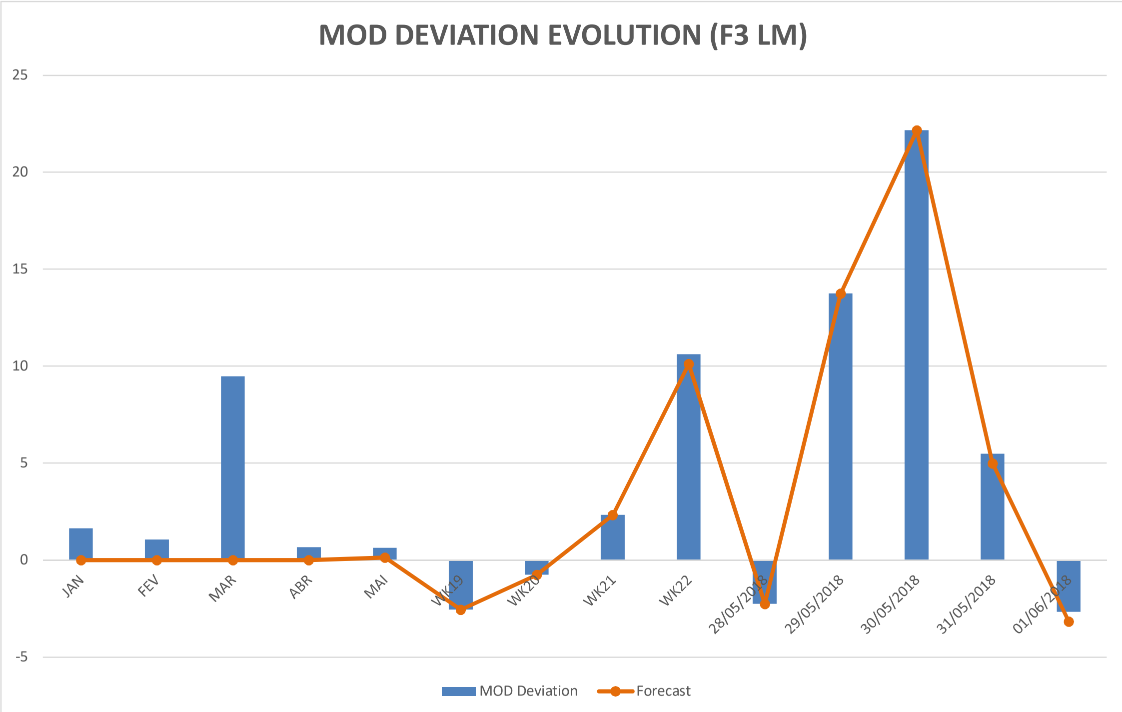
1. DEFINE

MOD deviation (F3 LM)

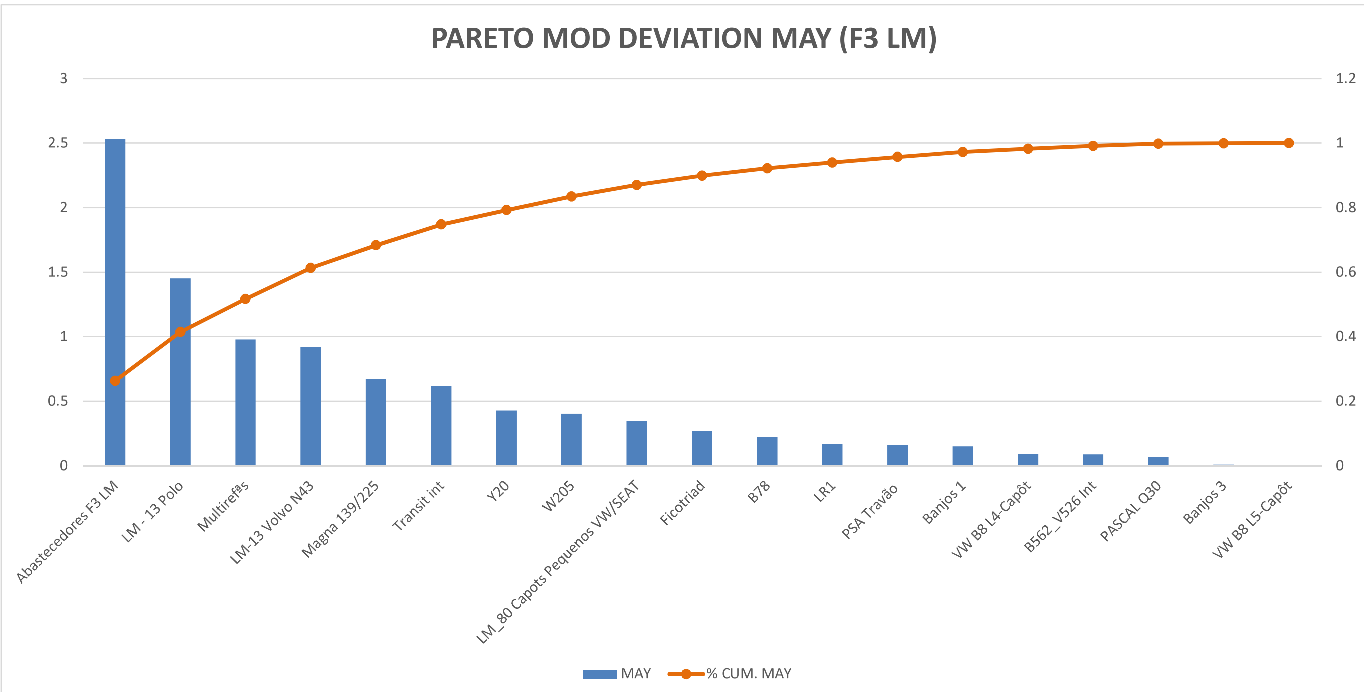
Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate OEE/A3 | 3º Refresh Graphs



3. ANALYSE

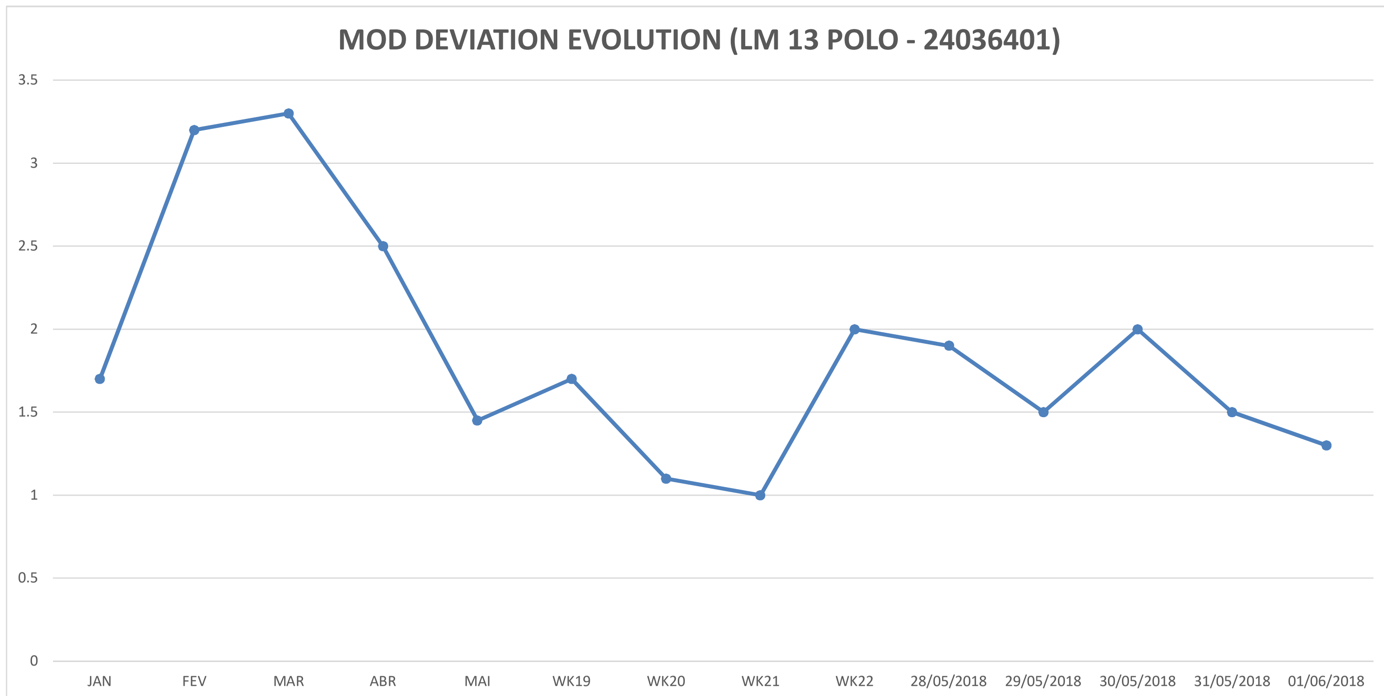


4. IMPROVEMENT ACTIONS

	ANALYSE		PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	MOD Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	Nº	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
7	Desvio MOD LMs	F3 LM	Validação Rutas	PO	31/mai	0.5	31/05/2018	MAI	WK22	Kanboard #14001	CLOSED
8	Desvio MOD LMs	F3 LM	Ação alterar posto montagem cabo Volvo Polo Portas	PO	31/mai		31/05/2018	MAI	WK22	Kanboard #13003	CLOSED

1º Order PDCA actions | 2º Archieve closed PDCA actions

5. CHECK RESULTS



6.4 ANNEX 4 – A3 documents of OEE KPI

FICOSA Corporate

A3 (KPI - OEE)

Team Members: **Pedro Alexandre (PA); Francisco Ferreira (FF); Rui Dias (RD); Paulo Agostinho (PG); Vitor Pinto (VP)** ***Coordinator:*** **Costa Pereira (CP)**

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31-May-2018, Ed.8

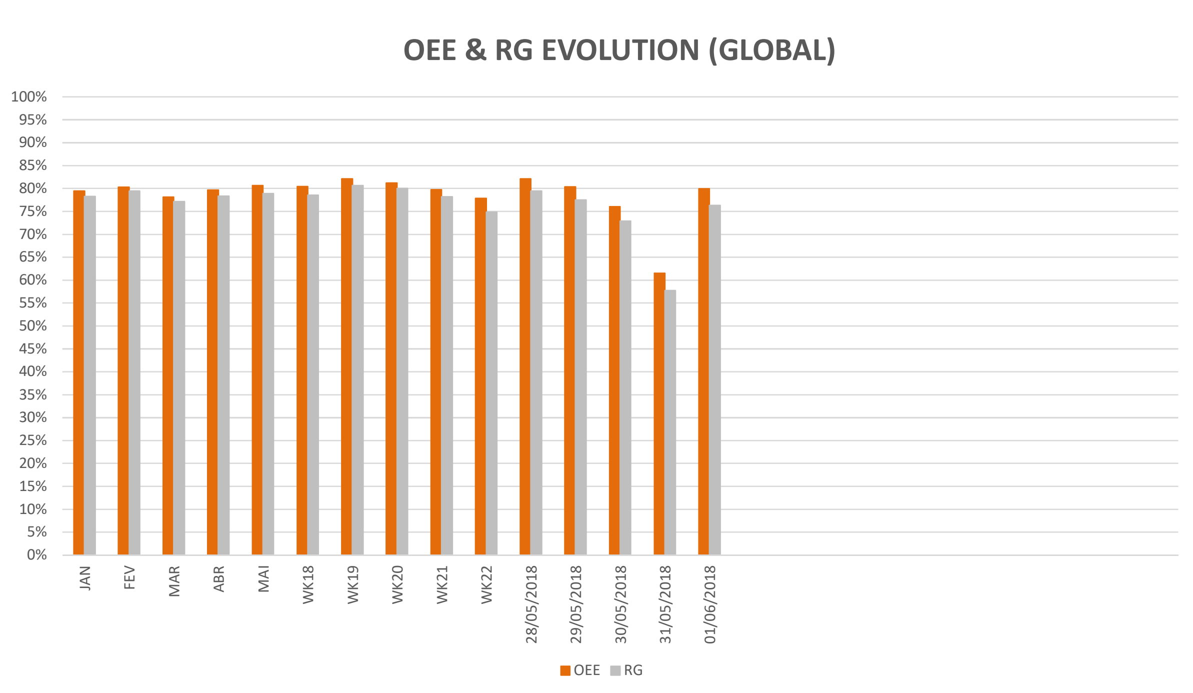
1. DEFINE

OEE (Global)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate OEE/A3 | 3º Refresh Graphs

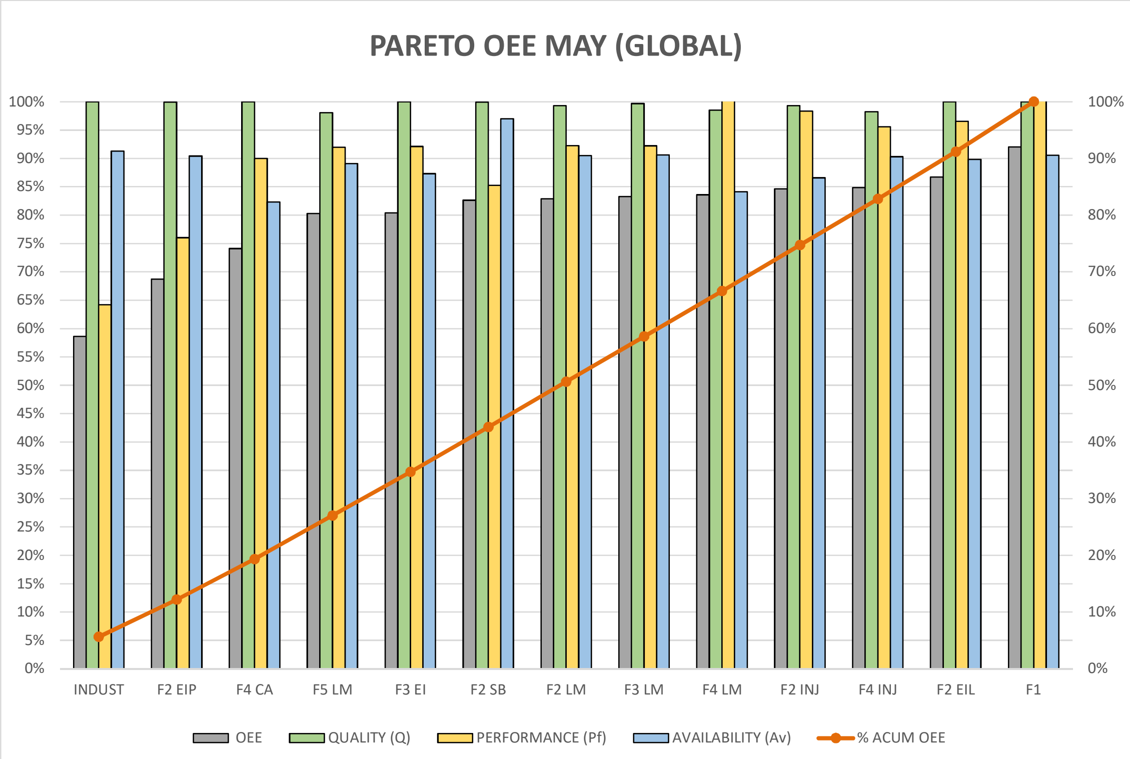


4. IMPROVEMENT ACTIONS

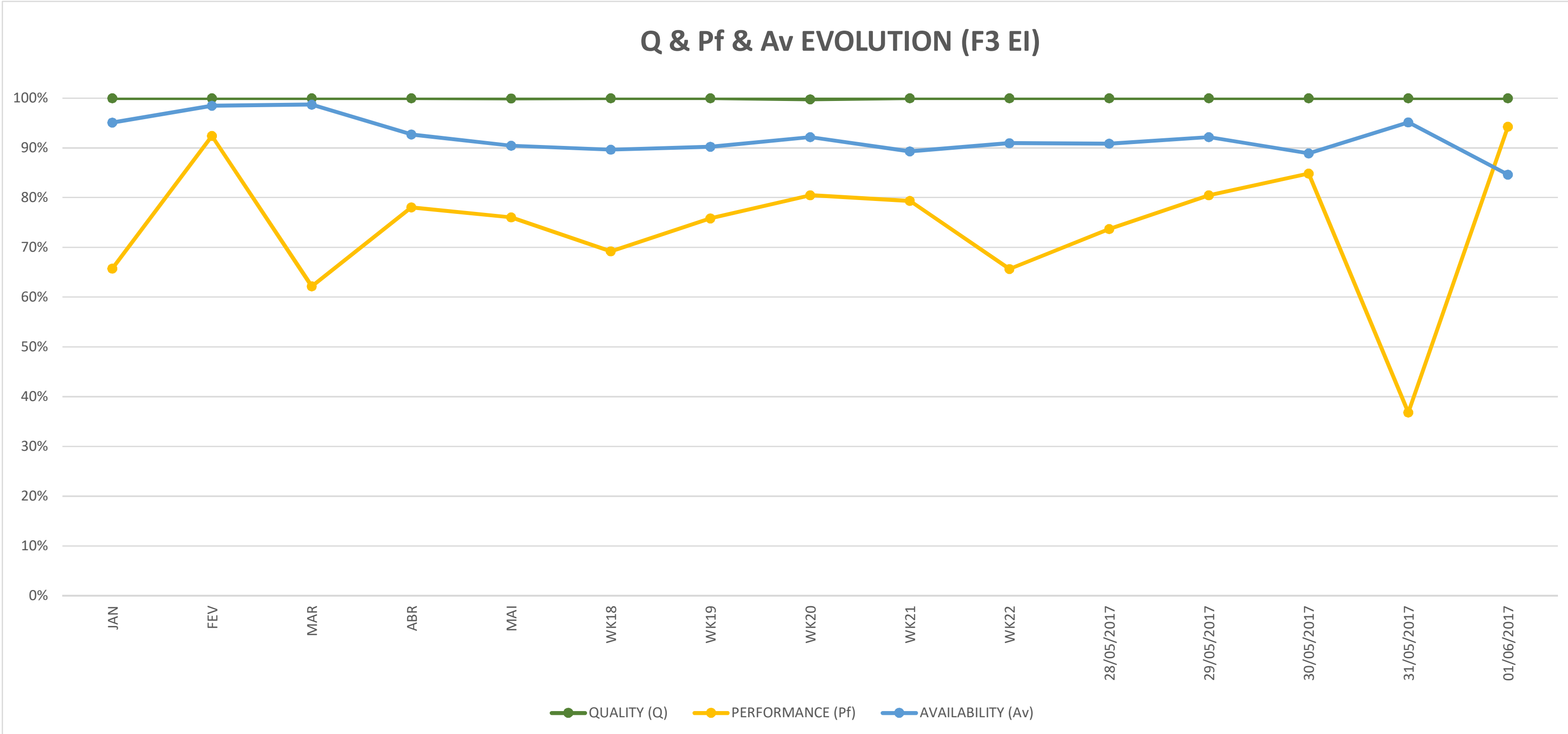
ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	OEE Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
11	Desvios de velocidade (1.8%)	F3 LM	VW Polo portas: Alterar posto de montagem de cabo por forma a incorporar montagem do clip no terminal de cabo no posto de aparar	PO	31/mai	0.70%	31/05/2018	MAI	WK22		OPEN
4	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Plano para redução setups planificados (Lotes económicos, sequência optima de refªs…)	DL	20/mai	0.40%	20/05/2018	MAI	WK20		OPEN
10	Desvios de velocidade (1.8%)	F2 LM	Volvo - Validar rutas, definir ações para desvios	PO	25/mai	0.20%	25/05/2018	MAI	WK21		OPEN
3	Machine downtime=3,2% Process fine tuning =0,7%	F2 INJ	2.c)Improve machine reliability-next machine: nº 15 (preventive maintenence plan)	FH	31/mai	1.70%	31/05/2018	MAI	WK22	Kanboard #14835	OPEN
4	Mold setup=2,2%/14 per day/ Avg=38,4 min	F2 INJ	Aumentar o stock (trabalhar 12 horas ao sábado)	TL	22/mai	0.80%	22/05/2018	MAI	WK21	Kanboard #13931	OPEN
2	Mold repair = 1,1 % (April=1,3%)	F2 INJ	Plano de intervenção nos moldes: RG3 ext (multiplás) e GM CD369	ML	31/mai	0.30%	31/05/2018	MAI	WK22		OPEN
6	OEE (falta de MOD)	F4 INJ	KB - Implementar equipa de substituição de paragens (Ok, Lanche, 5S, etc..)	RD	31/mai	5.57%	31/05/2018	MAI	WK22	Kanboard #12005	OPEN
5	Av) falta de peças de substituição	F4 INJ	Criar stk/peças de substiuição (C1YX); modificar bocas de lobo 1º molde	RD	28/mai	0.30%	28/05/2018	MAI	WK22	Kanboard #13041	OPEN
2	Av/Q fuso mal dimensionado	F4 INJ	KB - Comprar fuso/camisa (peq novo) MQ19 (75%); reparação do da máq 19 (25%)	FT	31/mai	0.27%	31/05/2018	MAI	WK22	Kanboard #14482	OPEN
3	Tachi/B02E - Fiabilidade do equipamento	F1	Recolha das causas/frequência e seguimento das ações para elimição dos dois maiores problemas (posto comum e intr. do tubo)	PA	31/mai	0.50%	31/05/2018	MAI	WK22	Kanboard #10946	OPEN
2	Tachi/B02E - Fiabilidade do equipamento	F1	Fecho das ações no PT dobragem dos arames laranja e fiabilização dos sensores/programação de deteção do tubo nos ganchos	PA	27/mai	0.50%	27/05/2018	MAI	WK22	Kanboard #10112	OPEN
5	Qualidade LR2/C1 - escorrido de ZK no cabo	F5	Testar ação de melhoria (aperto do canal do molde) - validar molde, e maquina	OL	28/mai	0.4%	28/05/2018	MAI	WK22	Kanboard #13956	OPEN

1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE



5. CHECK RESULTS



Ficosa Corporate

A3 (KPI - OEE)

Team Members: Carla Fernandes (CF), Conceição Rosa (CR) *Coordinator:* Pedro Alexandre (PA)

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31-May-2018, Ed.8

1. DEFINE

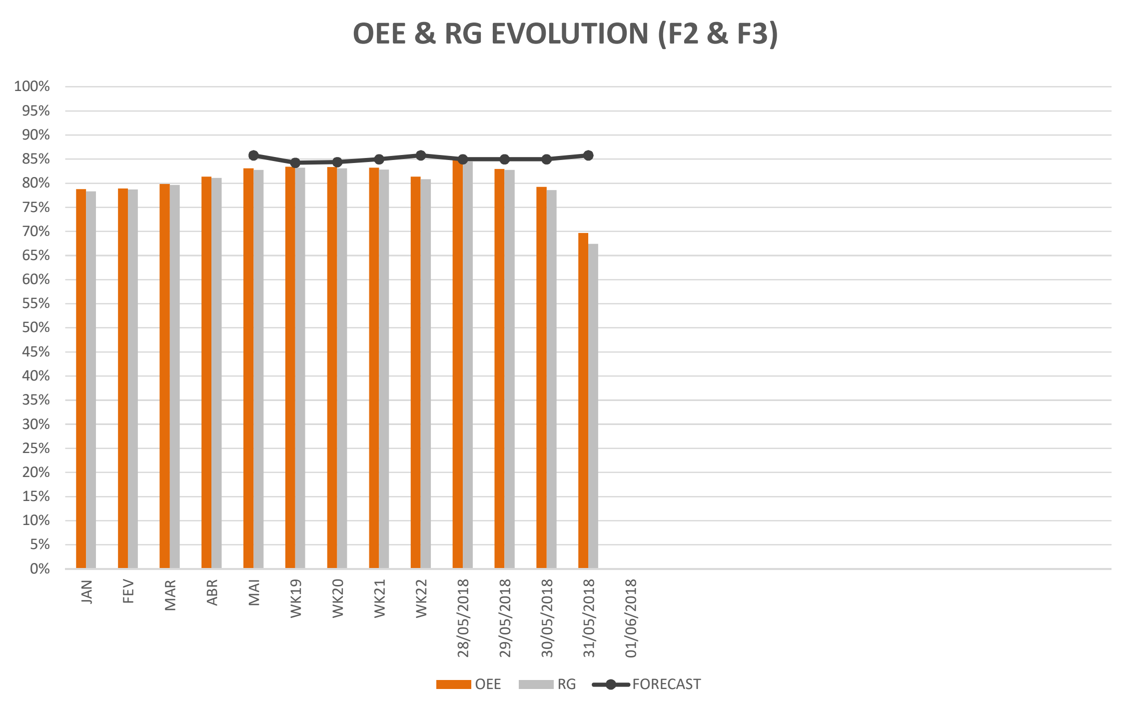
OEE below target (F2 & F3 LM)

Photos of the team members

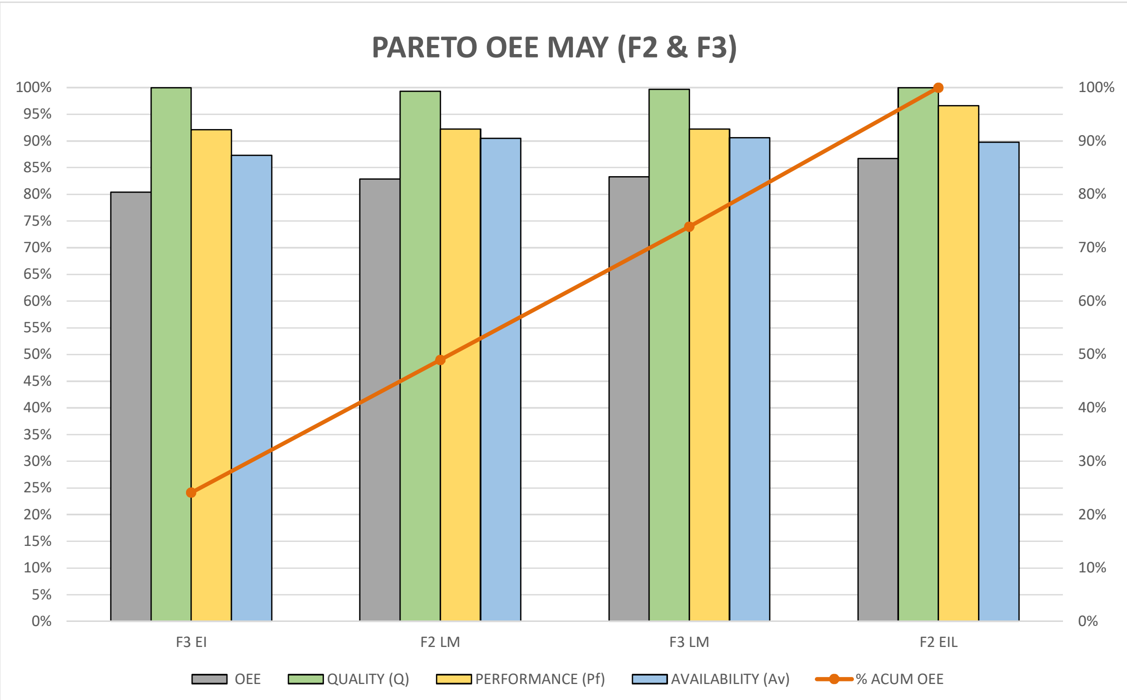
2. MEASURE

1º Update CP | 2º Calculate OEE/A3 | 3º Refresh Graphs

TARGET = 83%



3. ANALYSE

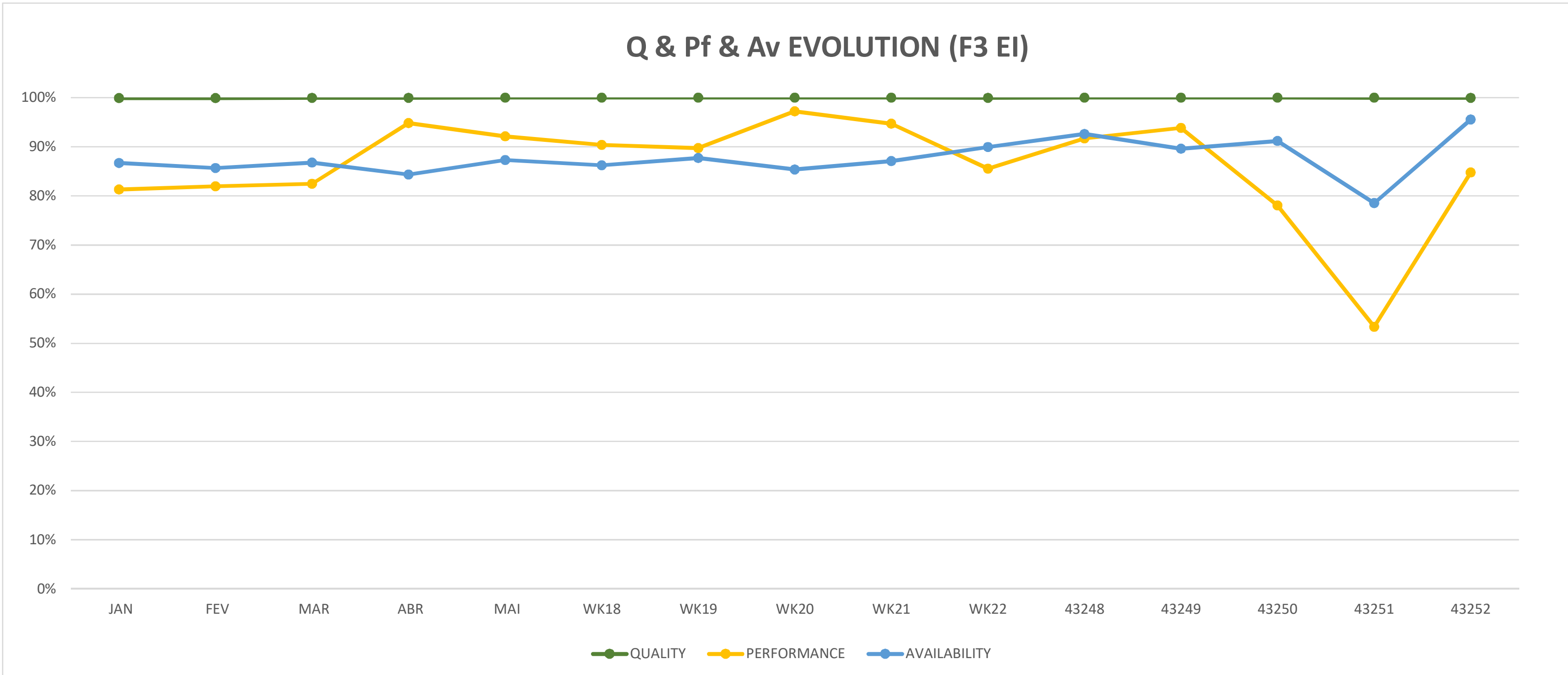


4. IMPROVEMENT ACTIONS

ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	OEE Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
11	Desvios de velocidade (1.8%)	F3 LM	VW Polo portas: Alterar posto de montagem de cabo por forma a incorporar montagem do clip no terminal de cabo no posto de aparar	PO	31/mai	0.70%	31/05/2018	MAI	WK22		OPEN
4	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Plano para redução setups planificados (Lotes económicos, sequência optima de refªs…)	DL	20/mai	0.40%	20/05/2018	MAI	WK20		OPEN
10	Desvios de velocidade (1.8%)	F2 LM	Volvo - Validar rutas, definir ações para desvios	PO	25/mai	0.20%	25/05/2018	MAI	WK21		OPEN
7	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Volvo_ Alterar geometria do porta pinos. Objetivo: reduzir 90% paragens por pinos partidos. Actual = 45,9h_0,07%.	BP	31/mai	0.06%	31/05/2018	MAI	WK22	Kanboard #7677	OPEN
6	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 EIL	Volvo_Melhorar disponibilidade equipamento zamak; _ Total impacto Zamak = 59h_0,07%.	FH	31/mai	0.05%	31/05/2018	MAI	WK22	Kanboard #9331	OPEN
3	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Plano de redução de MOD tendo em atenção a ocupação das linha, deslocando equipas nas paragens para linhas disponíveis.	PA	06/mai	0.80%	06/05/2018	MAI	WK18		CLOSED
5	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	RG3 A - plano de melhoria de disponibilidade = 0,28%.	FT/PR	14/mai	0.14%	14/05/2018	MAI	WK20	Kanboard #9605 Kanboard #9925	CLOSED
8	Disponibilidade (Av 6.9% + Setups 2.8%)	F2 LM	Inteva_ Plano de melhoria problemas sistémicos . 202 h_0,27%.	FH	10/mai	0.13%	10/05/2018	MAI	WK19	Kanboard #7671	CLOSED
1	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	PSA Travão - Dar maior robustez ao guiamento da gaveta coletora de cabos OK (51 horas de paragem)	FH	06/mai	0.10%	06/05/2018	MAI	WK18	Kanboard #11233	CLOSED
9	Desvios de velocidade (1.8%)	F3 LM	PSA Travão _ Desvio na ruta/plano de ações refª 695	LN	05/mai	0.06%	05/05/2018	MAI	WK18	Kanboard #9140	CLOSED
2	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	PSA travão - Plano de constituição de 3,5 dias de stock. Objetivo redução 30% # setups. Impacto actual = 89,7h	PA	11/mai	0.04%	11/05/2018	MAI	WK19		CLOSED

1º Order PDCA actions | 2º Archieve closed PDCA actions

5. CHECK RESULTS



FICOSA Corporate	**A3** (KPI - OEE)	P-QA-XX/XX-09-H Page 1/1 Edited by: J. Pereira 31-May-2018, Ed.8
	Team Members: **Carla Fernandes (CF), Conceição Rosa (CR)** ***Coordinator:*** **Pedro Alexandre (PA)**	

1. DEFINE

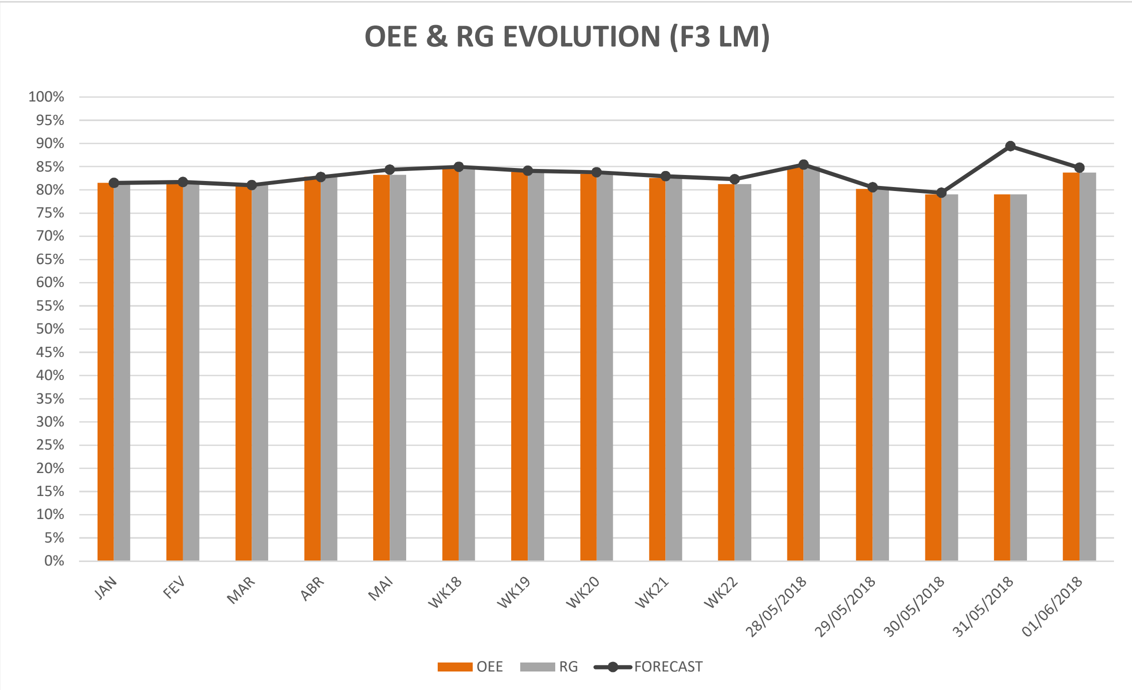
OEE below target (F3 LM)

Photos of the team members

2. MEASURE

1º Update CP **2º Calculate OEE/A3** **3º Refresh Graphs**

TARGET = 83%

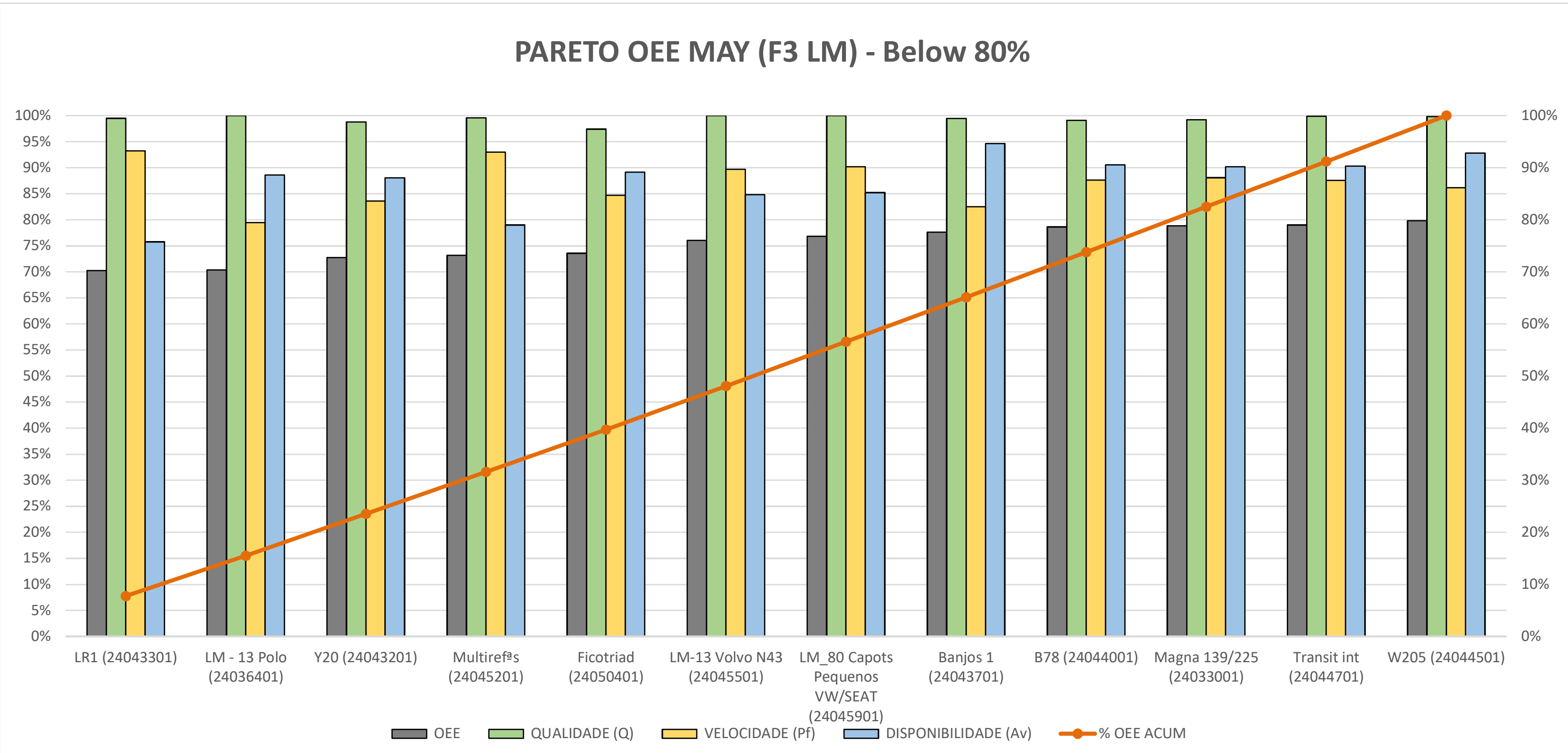


4. IMPROVEMENT ACTIONS

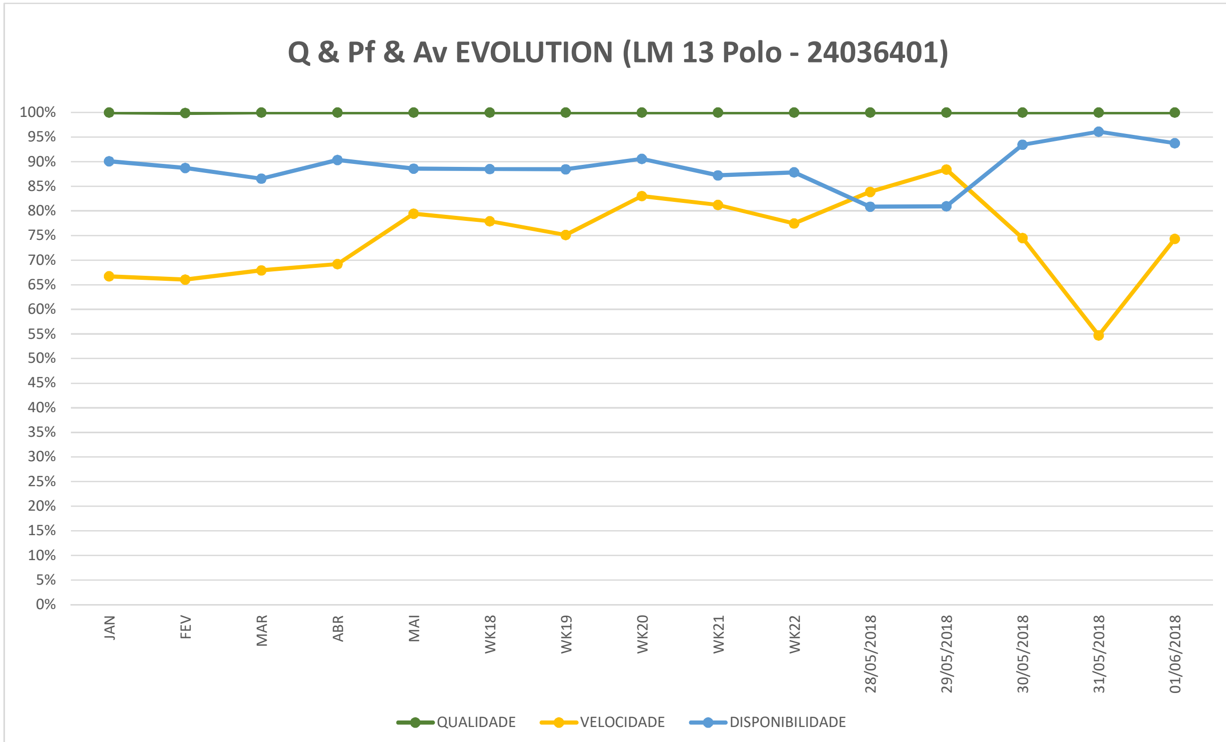
ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	OEE Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
11	Desvios de velocidade (1.8%)	F3 LM	VW Polo portas: Alterar posto de montagem de cabo por forma a incorporar montagem do clip no terminal de cabo no posto de aparar	PO	31/mai	0.70%	31/05/2018	MAI	WK22		OPEN
5	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	RG3 A - plano de melhoria de disponibilidade = 0,28%.	FT/PR	14/mai	0.14%	14/05/2018	MAI	WK20	Kanboard #9605 Kanboard #9925	CLOSED
1	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	PSA Travão - Dar maior robustez ao guiamento da gaveta coletora de cabos OK (51 horas de paragem)	FH	06/mai	0.10%	06/05/2018	MAI	WK18	Kanboard #11233	CLOSED
9	Desvios de velocidade (1.8%)	F3 LM	PSA Travão _ Desvio na ruta/plano de ações refª 695	LN	05/mai	0.06%	05/05/2018	MAI	WK18	Kanboard #9140	CLOSED
2	Disponibilidade (Av 6.9% + Setups 2.8%)	F3 LM	PSA travão - Plano de constituição de 3,5 dias de stock. Objetivo redução 30% # setups. Impacto actual = 89,7h	PA	11/mai	0.04%	11/05/2018	MAI	WK19		CLOSED

1º Order PDCA actions **2º Archieve closed PDCA actions**

3. ANALYSE



5. CHECK RESULTS



6.5 ANNEX 5 – A3 documents of Scrap KPI

FICOSA Corporate

A3 (KPI - SCRAP)

P-QA-XX/XX-10-H
Page 1/1
Edited by: J. Pereira
17-May-2018, Ed.6

Team Members: **Pedro Alexandre (PA); Francisco Ferreira (FF); Rui Dias (RD); Paulo Agostinho (PG); Vítor Pinto (VP)** ***Coordinator:*** **Costa Pereira (CP)**

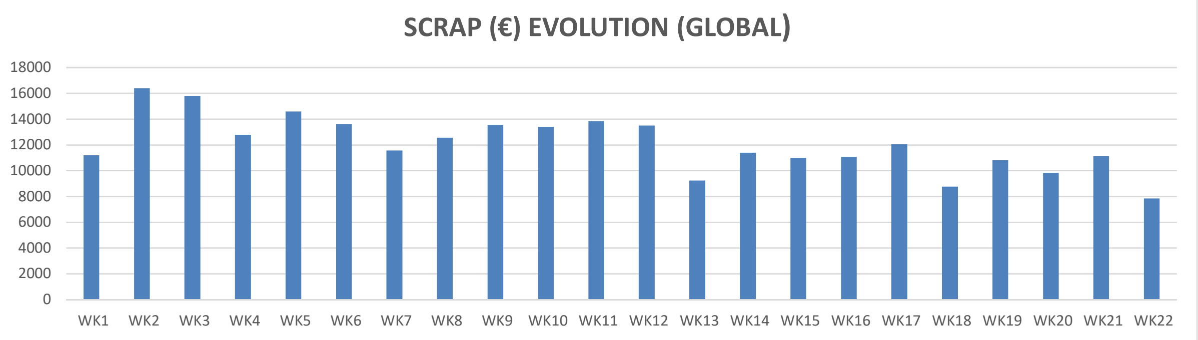
1. DEFINE

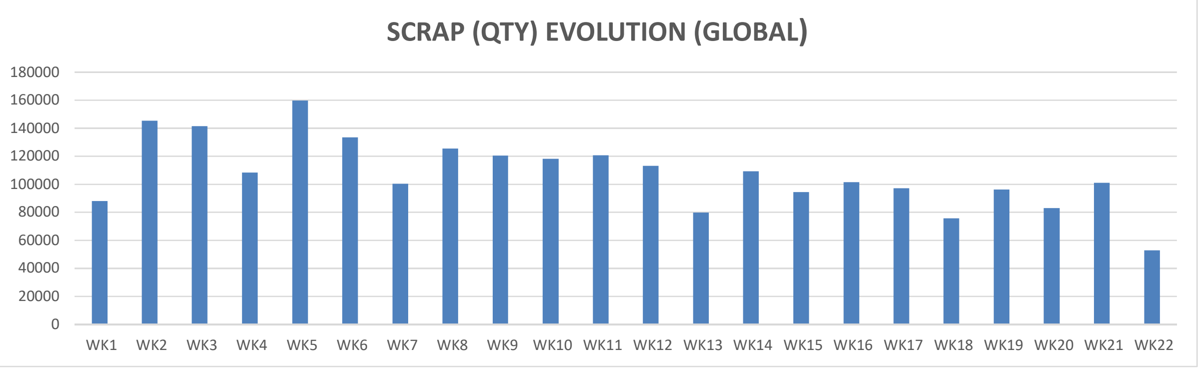
SCRAP Quantity and Cost (Global)

Photos of the team members

2. MEASURE

1º Update BPCS | 2º Calculate SCRAP/A3 | 3º Refresh Graphs



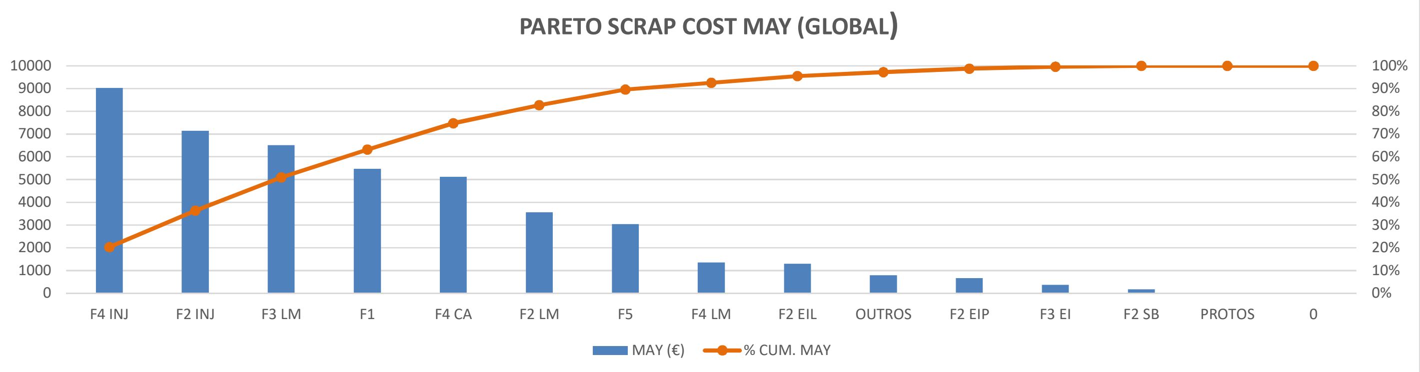


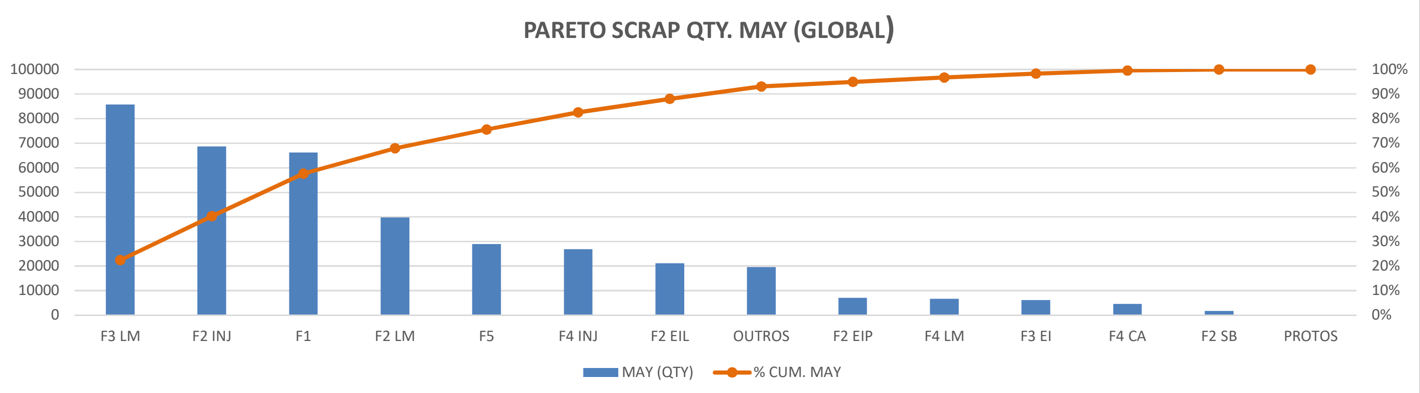
4. IMPROVEMENT ACTIONS

N	ANALYSE		PLAN				DO			CHECK	ACT
	Main Causes/Sources	Module	Actions	Resp	Date	SCRAP reduction	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	EUROS	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
2	Scrap ES11VP0600 F3 _ 1100€	F3 EI	Alterar processo de fabrico tradicional para máquinas "Chinesas"	PG	25/mai	960.0	25/05/2018	MAI	WK21	Kanboard #13055	OPEN
1	Scrap associado a ppm's GM	F3 LM	Aplicar cortante com movimento de fixação e corte independentes	PR	31/mai		31/05/2018	MAI	WK22	Kanboard #13045	OPEN
4	Scrap associado a ppm's GM	F3 LM	Rever condição pressão pneumática para condição ideal de trabalho das linhas_ação	VB	14/mai		14/05/2018	MAI	WK20	Kanboard #9452	OPEN
3	Sucata arame AR13200E00A	F4 LM	Recolher no final de cada turno de todas as linhas S.Mat e pesar o mesmo , para fazer RH .	RD	26/mai		26/05/2018	MAI	WK21	Kanboard #10949	OPEN
2	xvs3 Sucata	F4 INJ	Problemas com bicos de injeção	ML	22/mai		22/05/2018	MAI	WK21	Kanboard #10095	OPEN
4	Sucata de afinação(Dorcas)	F4 CA	Validar correcta conformação na TEC .	GF	31/mai		31/05/2018	MAI	WK22	Kanboard #13001	OPEN
6	Elevado valor de sucata de POM Kepital	F2 INJ	Fixar o maior nº possivel de moldes a máquinas (atualmente 6 máquinas).	FF	31/mai		31/05/2018	MAI	WK22	Kanboard #12077	OPEN
2	Purgas de PA preto sucatadas como POM	F2 INJ	Separar e reportar sucata com a referencia correcta	CR	27/mai		31/05/2018	MAI	WK21	Kanboard #14405	OPEN
5	Sucata na afinação do terminal vermelho L405	F2 INJ	Procurar no mercado amostra e testar outro fornecedor e tipo de pigmento	ML	31/mai		31/05/2018	MAI	WK22	Kanboard #11099	OPEN
3	Falhas no revestimento espiral	F1	Criar emenda em plastico com rosca um novo desenho para resistir ao processo de revestimento de espiral	AP	20/mai	600.0	20/05/2018	MAI	WK20	Kanboard #12501	OPEN
2	Problemas desbobinagem c/ nova bem.	F1	Montagem de roldanas para facilitar a saída do tubo das caixa e que tambem irão garantir a sua existencia no interior do espiral	PR	18/mai	600.0	18/05/2018	MAI	WK20	Kanboard #12399	OPEN
1	AR1201A5 - Valor mais alto de Scrap	F1	Melhoria do processo de distribuição e garantia "exata" da quantidade de arame durante o processo da pré-laminagem	DF	10/mai	400.0	10/05/2018	MAI	WK19	Kanboard #14005	OPEN

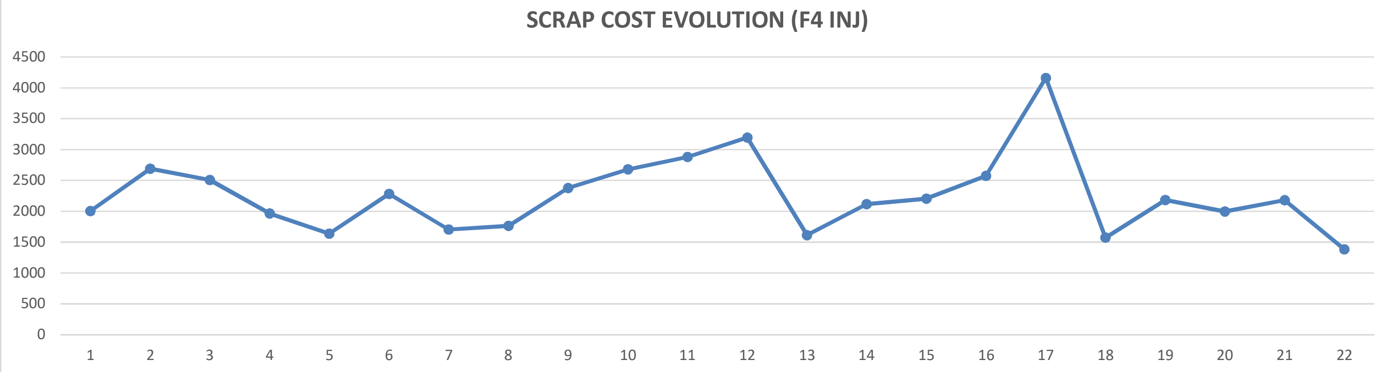
1º Order PDCA actions | 2º Archieve closed PDCA actions

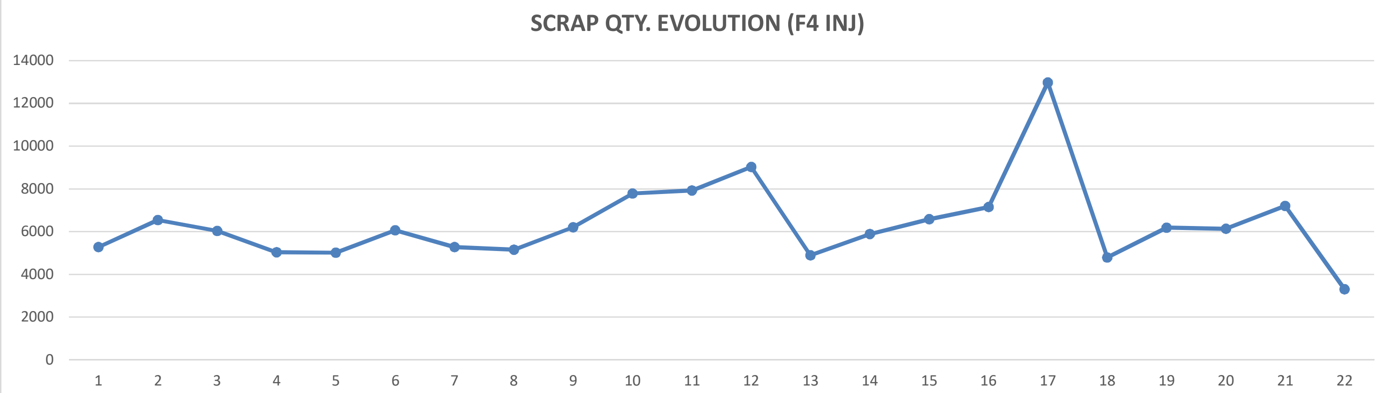
3. ANALYSE





5. CHECK RESULTS





FICOSA
Corporate

A3 (KPI - SCRAP)

P-QA-XX/XX-11-H
Page 1/1
Edited by: J. Pereira
20-May-2018, Ed.4

Team Members: **Filipe Teixeira (FT); Andreia Pereira (AP); Susana Costa (SC)** ***Coordinator:*** **Rui Dias (RD)**

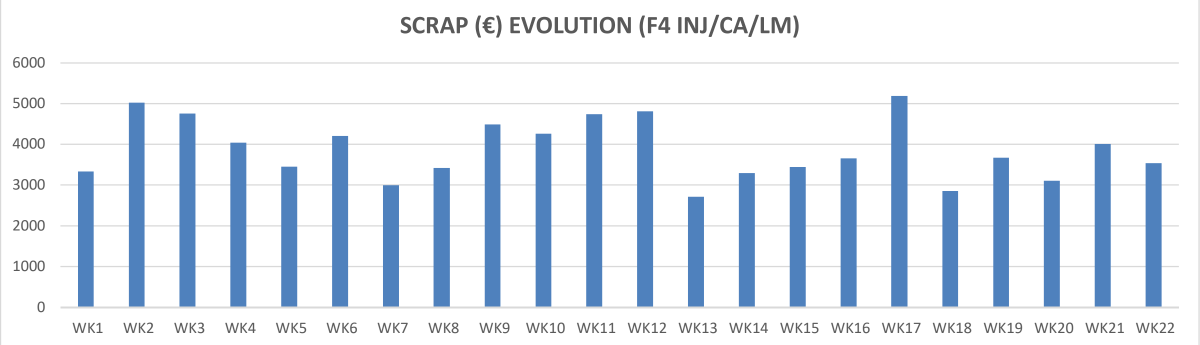
1. DEFINE

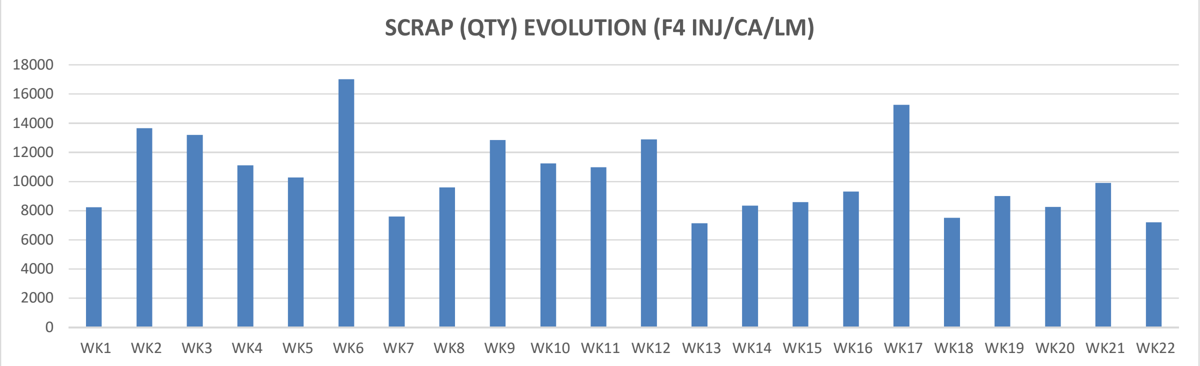
SCRAP Quantity and Cost (F4)

Photos of the team members

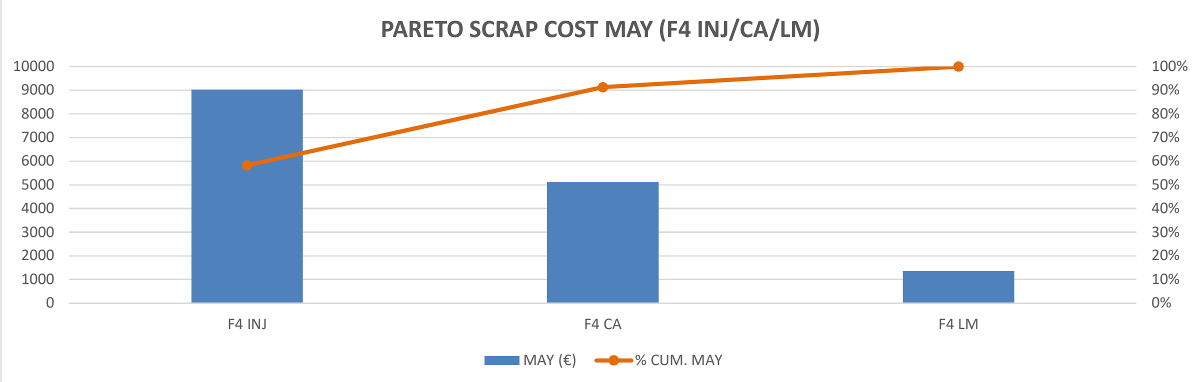
2. MEASURE

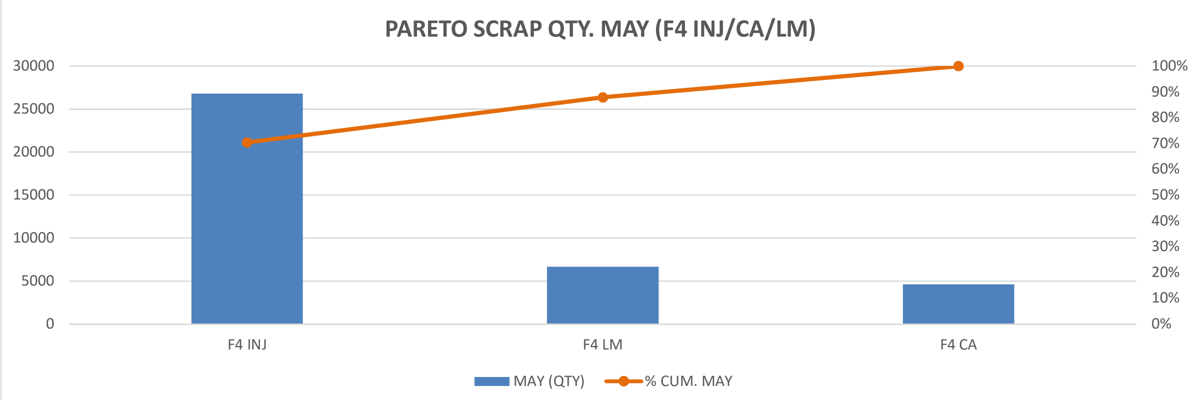
1º Update BPCS | 2º Calculate SCRAP/A3 | 3º Refresh Graphs





3. ANALYSE



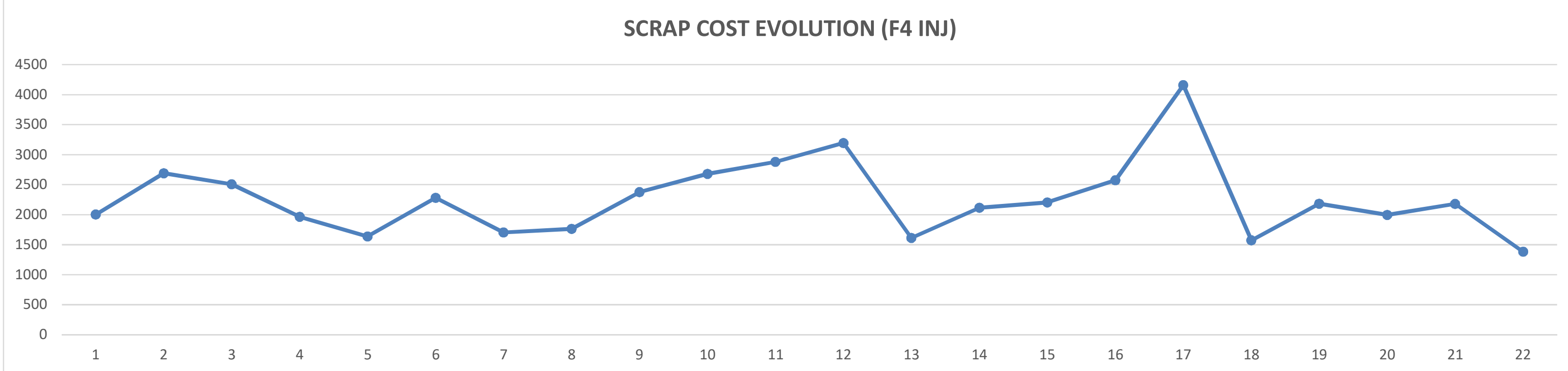


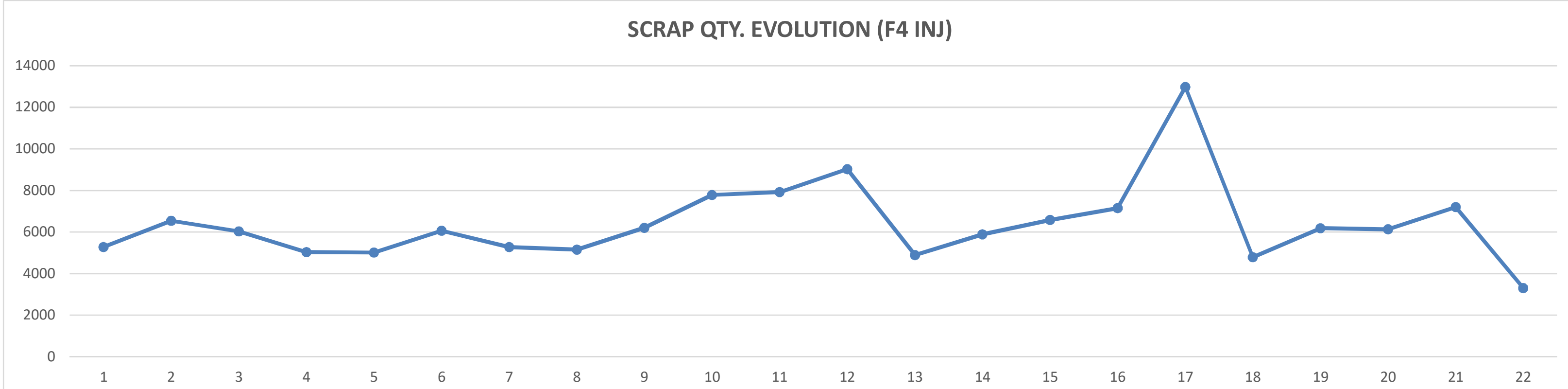
4. IMPROVEMENT ACTIONS

	ANALYSE		PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	SCRAP reduction	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	EUROS	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
3	Sucata arame AR13200E00A	F4 LM	Recolher no final de cada turno de todas as linhas S.Mat e pesar o mesmo , para fazer RH .	RD	26/mai		26/05/2018	MAI	WK21	Kanboard #10949	OPEN
2	xvs3 Sucata	F4 INJ	Problemas com bicos de injeção	ML	22/mai		22/05/2018	MAI	WK21	Kanboard #10095	OPEN
4	Sucata de afinação(Dorcas)	F4 CA	Validar correcta conformação na TEC .	GF	31/mai		31/05/2018	MAI	WK22	Kanboard #13001	OPEN
1	Top 3 sucata	F4	Analise diária 1º D. Produção e R. Técnico e em seguida na Rip	RD	18/mai		18/05/2018	MAI	WK20	Kanboard #11840	OPEN
7	Moldes criticos	F4 INJ	Afinação por gabarit + molde	GF	14/mai		14/05/2018	MAI	WK20	Kanboard #10000	CLOSED
5	Arame á vista apos injeção .MVS2	F4 INJ	Rever bocas de lobo e fixador do arame no molde 2 , deforma a absorver o arame nos dois moldes .	J.S	10/mai		10/05/2018	MAI	WK19	Kanboard #13003	CLOSED
6	Molde danificado , HAB01 .	F4 INJ	Confirmar e validar que todas as máquinas estão a fazer o teste de gito e o fecho do molde com a presão inferior a (30 kg).	M.L	31/mai		31/05/2018	MAI	WK22	Kanboard #13040	CLOSED

1º Order PDCA actions | 2º Archieve closed PDCA actions

5. CHECK RESULTS





A3 (KPI - SCRAP)

Team Members: Filipe Teixeira (FT); Andreia Pereira (AP); Susana Costa (SC) *Coordinator:* Rui Dias (RD)

P-QA-XX/XX-11-H
Page 1/1
Edited by: J. Pereira
20-May-2018, Ed.4

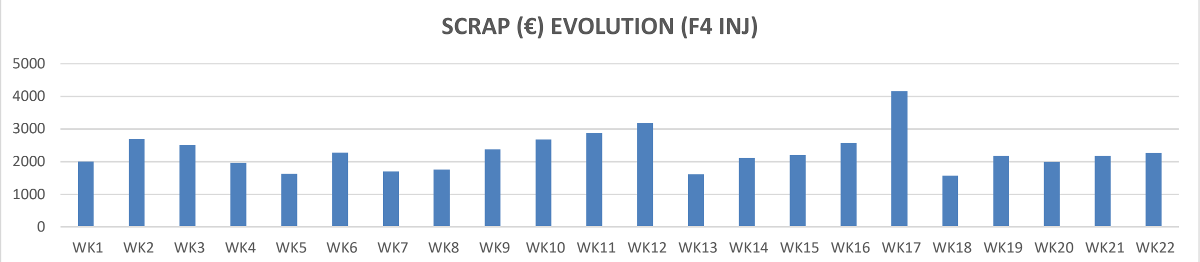
1. DEFINE

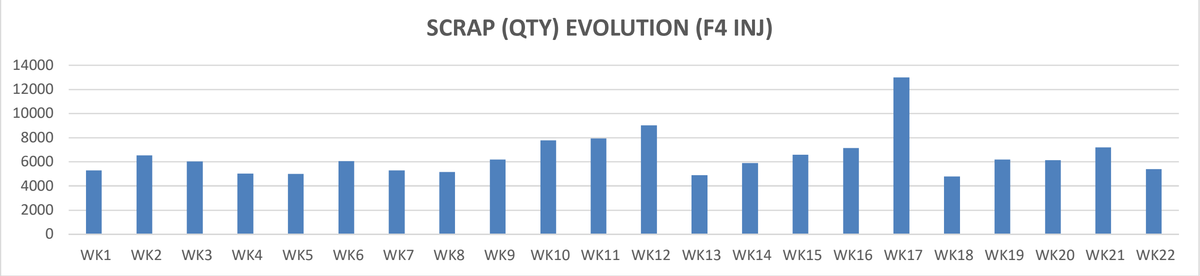
SCRAP Quantity and Cost (F4 INJ)

Photos of the team members

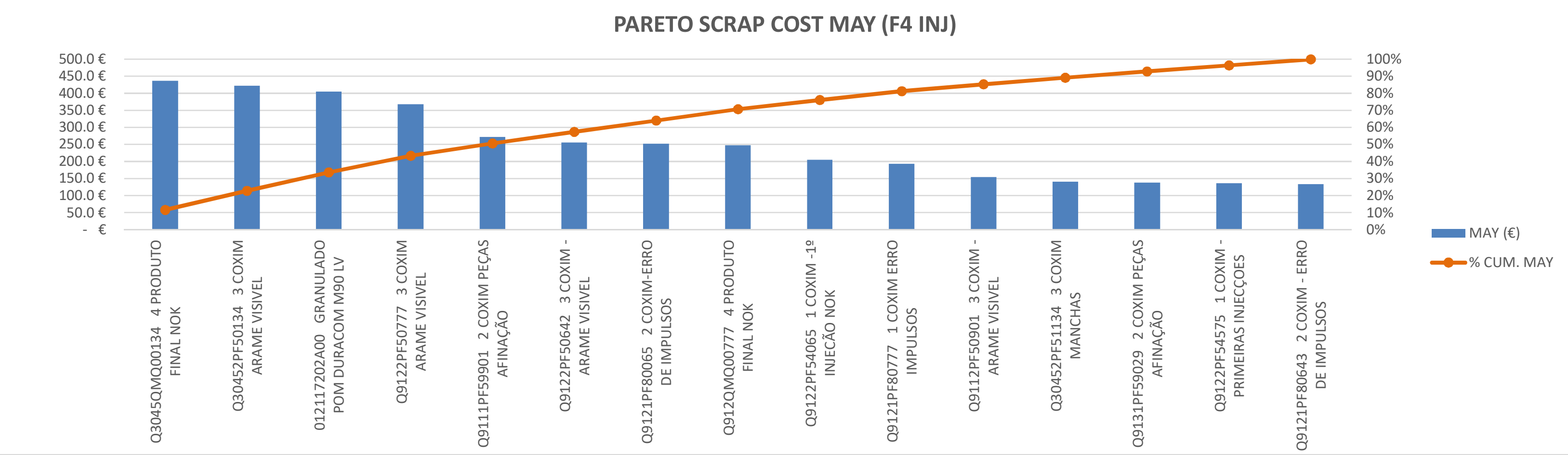
2. MEASURE

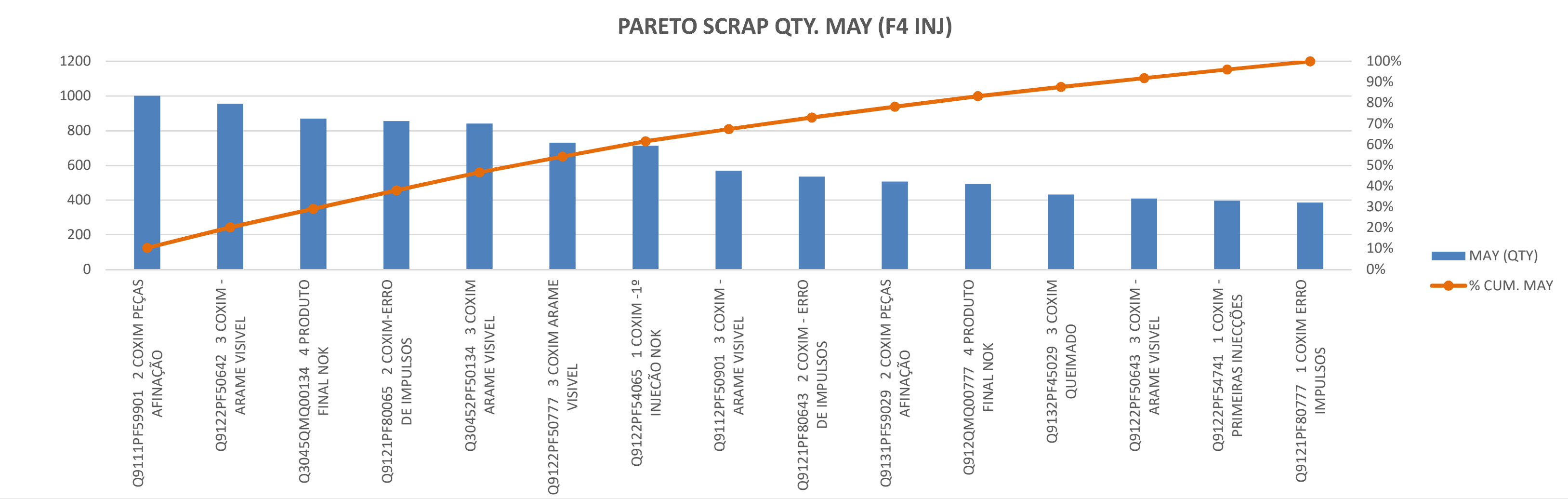
1º Update BPCS | 2º Calculate SCRAP/A3 | 3º Refresh Graphs





3. ANALYSE



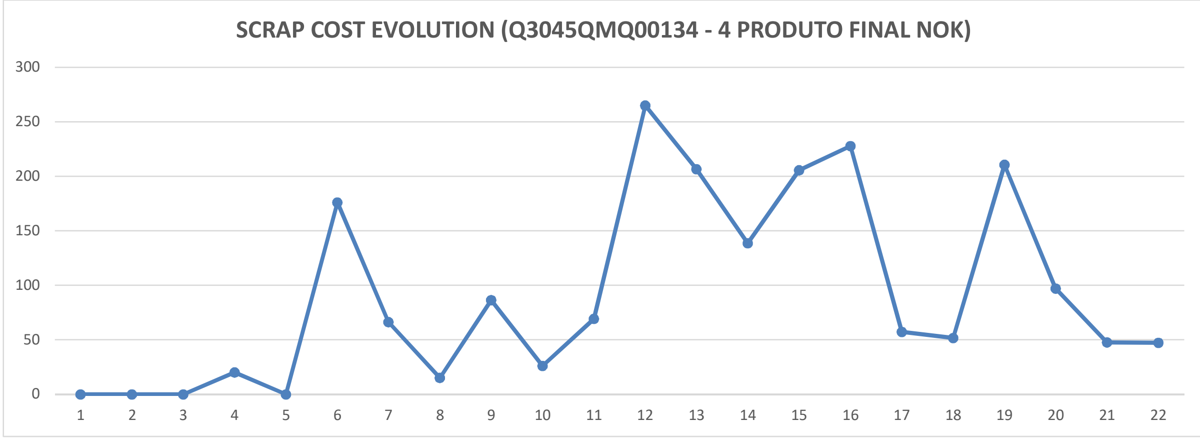


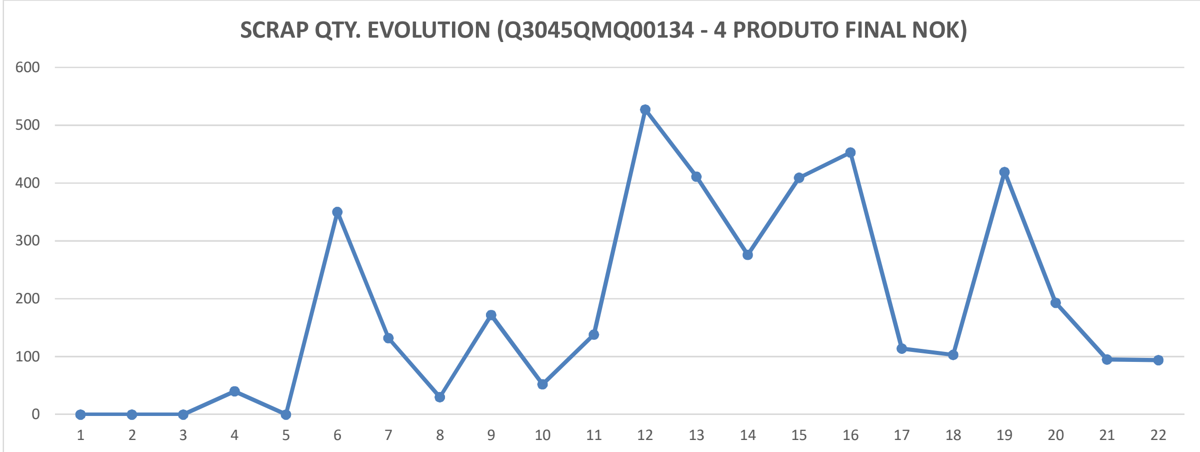
4. IMPROVEMENT ACTIONS

ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	SCRAP reduction	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	EUROS	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
2	xvs3 Sucata	F4 INJ	Problemas com bicos de injeção	ML	22/mai		22/05/2018	MAI	WK21	Kanboard #10095	OPEN
1	Top 3 sucata	F4	Analise diária 1º D. Produção e R. Técnico e em seguida na Rip	RD	18/mai		18/05/2018	MAI	WK20	Kanboard #11840	OPEN
7	Moldes criticos	F4 INJ	Afinação por gabarit + molde	GF	14/mai		14/05/2018	MAI	WK20	Kanboard #10000	CLOSED
5	Arame á vista apos injeção .MVS2	F4 INJ	Rever bocas de lobo e fixador do arame no molde 2 , deforma a absorver o arame nos dois moldes .	J.S	10/mai		10/05/2018	MAI	WK19	Kanboard #13003	CLOSED
6	Molde danificado , HAB01 .	F4 INJ	Confirmar e validar que todas as máquinas estão a fazer o teste de gito e o fecho do molde com a presão inferior a (30 kg).	M.L	31/mai		31/05/2018	MAI	WK22	Kanboard #13040	CLOSED

1º Order PDCA actions | 2º Archieve closed PDCA actions

5. CHECK RESULTS





6.6 ANNEX 6 – A3 documents of Availability KPI

FICOSA Corporate

A3 (KPI - AVAILABILITY)

Team Members: **Pedro Alexandre (PA); Francisco Ferreira (FF); Rui Dias (RD); Paulo Agostinho (PG); Vítor Pinto (VP)** ***Coordinator:*** **Costa Pereira (CP)**

P-QA-XX/XX-11-H
Page 1/1
Edited by: J. Pereira
09-May-2018, Ed.7

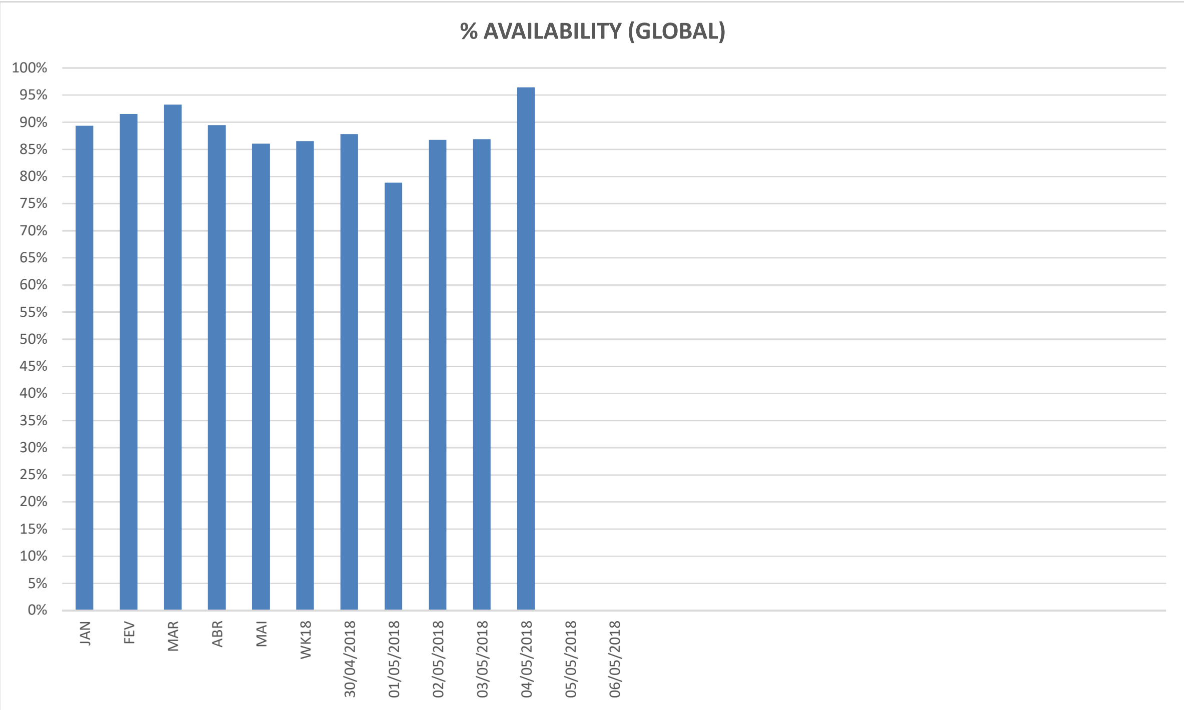
1. DEFINE

Availability (Global)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate Availability/A3 | 3º Refresh Graphs

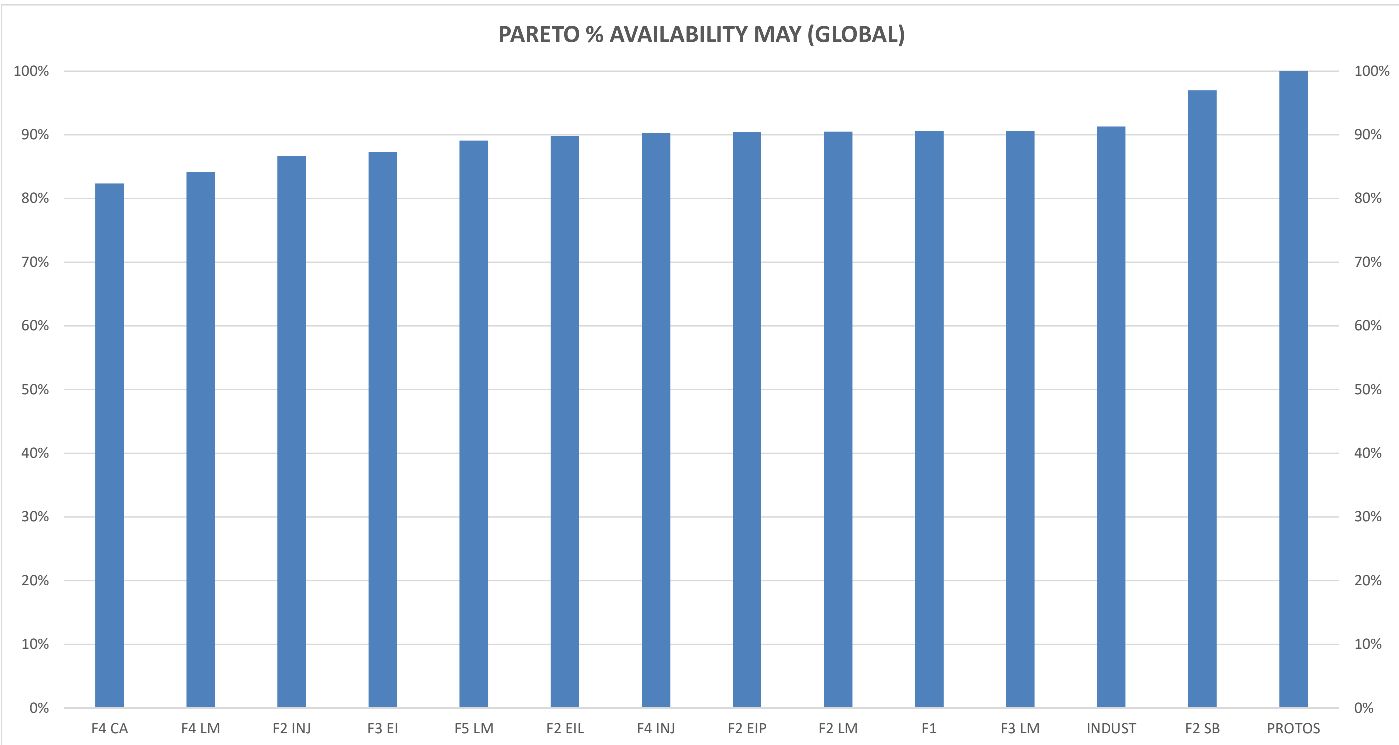


4. IMPROVEMENT ACTIONS

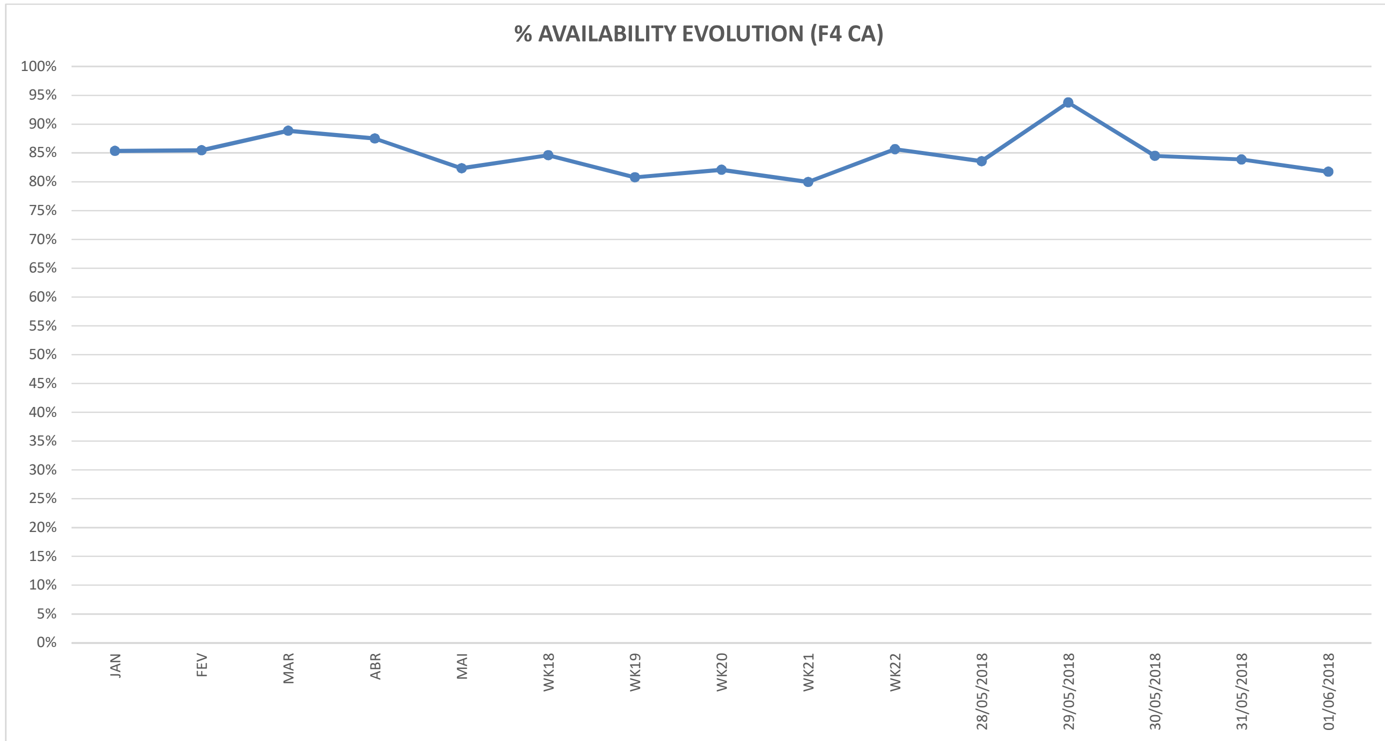
ANALYSE			PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	Availability improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
3	GM Auto V	F2 LM	Solicitar plano de melhoria de disponibilidade à equipa de processos	PA	08/mai		08/05/2018	MAI	WK19	Kanboard #14305	OPEN
1	GM Auto IV	F2 LM	Implementar metodologia de análise e resolução de problemas no formato digital. Objetivo : Standardizar as intervenções e por consequência aumentar a disponibilidade	BP	08/mai		08/05/2018	MAI	WK19	Kanboard #12910	OPEN
2	B562/V526	F3 LM	Melhoria na disponibilidade da linha (foco no posto de introduzir e aparar cabo)	VB	31/mai		31/05/2018	MAI	WK22	Kanboard #14006	OPEN
3	Avaria Maq.	F4 INJ	Antecipar revisão anual aos sistemas com > impacto	RD	31/mai		31/05/2018	MAI	WK22	Kanboard #13029	OPEN
2	Avaria maquina de injecção nº7 (3Sem)	F4 INJ	Substituição do cilindro	VB	20/mai		20/05/2018	MAI	WK20	Kanboard #12670	OPEN
4	Falta manipulador na maquina 2	F4 INJ	Colocação de manipulador	PO	12/mai		12/05/2018	MAI	WK19	Kanboard #11000	OPEN
5	IPF_06: falta de subconj montado	F2 INJ	Ajustar estrutura de operadores ao nível das pré-montagens	FF	31/mai		31/05/2018	MAI	WK22	Kanboard #13047	OPEN
7	IPM_14: falta de subconjunto montado	F2 INJ	Ajustar estrutura de operadores ao nível das pré-montagens	FF	31/mai		31/05/2018	MAI	WK22	Kanboard #14789	OPEN
3	IPM_14 : Molde danificado	F2 INJ	Dimensionar estrutura de suporte para reparações internas à necessidade.	PO	31/mai		31/05/2018	MAI	WK22	Kanboard #12099	OPEN
4	Set-ups constantes MAGNA 198	F1	Planificar a produção das ref.ª 005/006 para mais de uma semana	DL	10/mai		10/05/2018	MAI	WK19	Kanboard #11102	OPEN
2	Limitador terminal cabo FICOTRIAD constantemente a partir	F1	Verificar se é possível alterar o limitador	LN	20/mai		20/05/2018	MAI	WK20	Kanboard #14076	OPEN
1	Tempo de espera da Manutenção para substituiçaõ de peças	F1	Aguarda plano de ações da Manutenção	VB	08/mai		08/05/2018	MAI	WK19	Kanboard #13985	OPEN

1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE



5. CHECK RESULTS



FICOSA Corporate

A3 (KPI - AVAILABILITY)

Team Members: Conceição Rosa (CR) ***Coordinator:*** Francisco Ferreira (FF)

P-QA-XX/XX-11-H
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Edited by: J. Pereira
09-May-2018, Ed.7

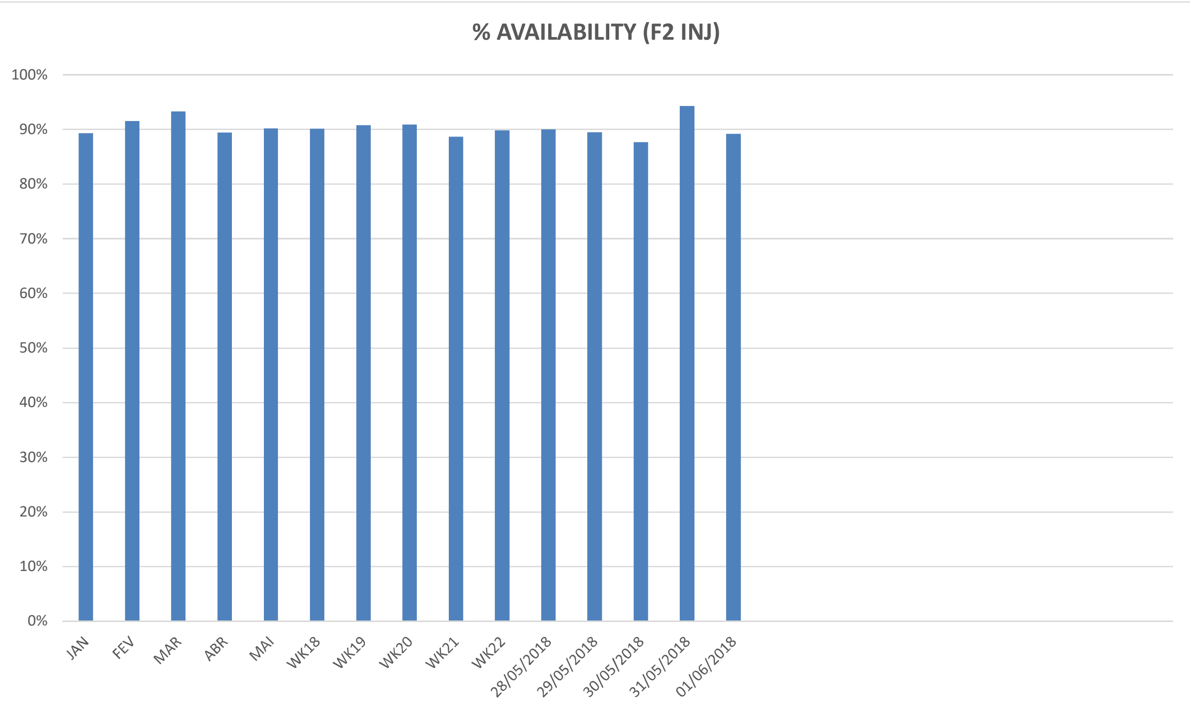
1. DEFINE

Availability (F2 INJ)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate Availability/A3 | 3º Refresh Graphs

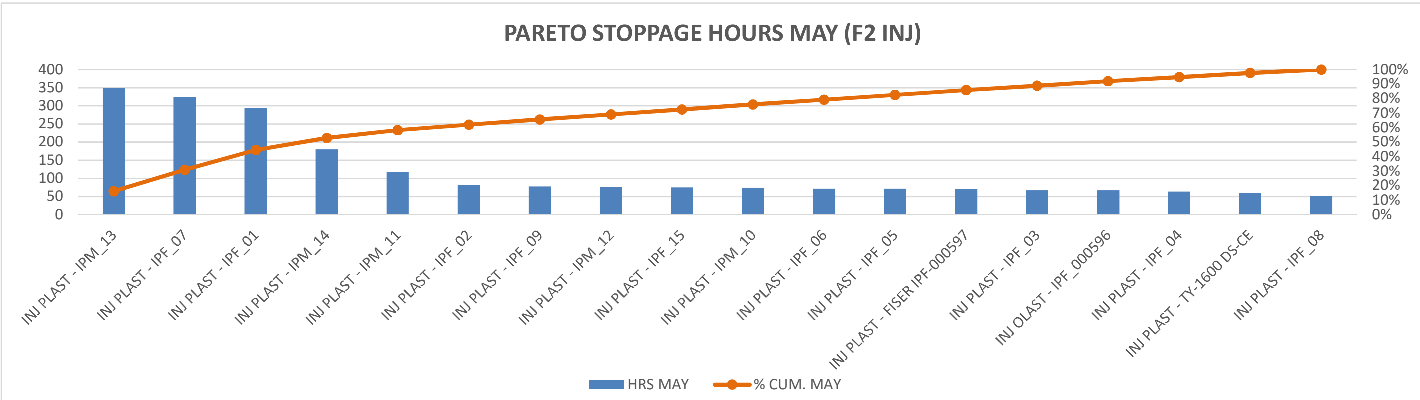


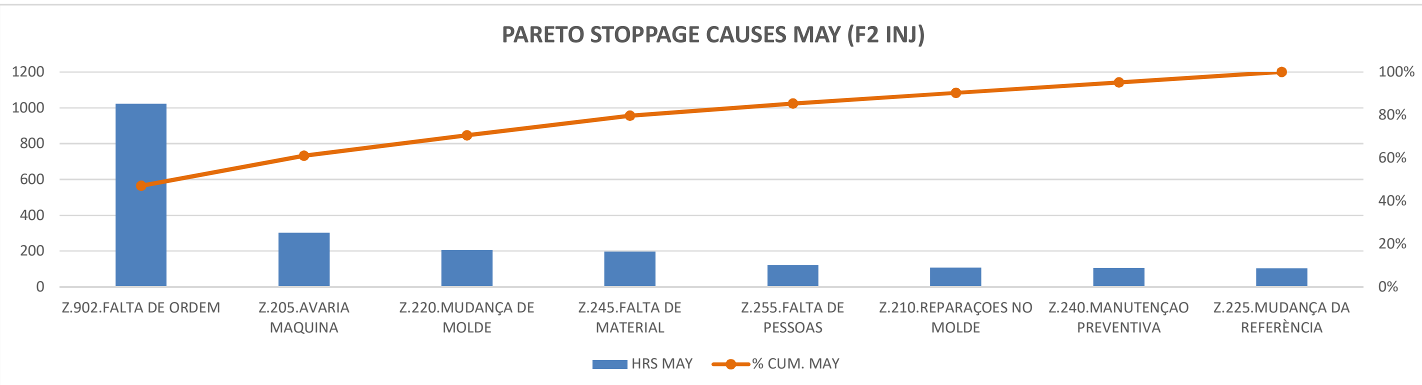
4. IMPROVEMENT ACTIONS

N	ANALYSE		PLAN				DO			CHECK	ACT
	Main Causes/Sources	Module	Actions	Resp	Date	Availability Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
5	IPF_06: falta de subconj montado	F2 INJ	Ajustar estrutura de operadores ao nível das pré-montagens	FF	31/mai		31/05/2018	MAI	WK22	Kanboard #12056	OPEN
7	IPM_14: falta de subconjunto montado	F2 INJ	Ajustar estrutura de operadores ao nível das pré-montagens	FF	31/mai		31/05/2018	MAI	WK22	Kanboard #13045	OPEN
3	IPM_14 : Molde danificado	F2 INJ	Dimensionar estrutura de suporte para reparações internas à necessidade.	PO	31/mai		31/05/2018	MAI	WK22	Kanboard #11098	OPEN
2	Falta de espiral cortada	F2 INJ	Implementar modelo de gestão para stock de espiral revestida e cortes da GM	DL	14/mai		14/05/2018	MAI	WK20	Kanboard #14007	OPEN
6	IPM_13 : Molde MQB1 c/ bastante tempo de indisp.	F2 INJ	Passar sensibilização com registo acerca dos procedimentos para operar com o molde (utilização da chapa)	CR	25/mai		25/05/2018	MAI	WK21	Kanboard #14000	OPEN
8	IPM_13 : Molde MQB1 c/ bastante tempo de indisp.	F2 INJ	Melhorar a configuração da chapa por forma a eliminar a possibilidade de mau posicionamento da espiral	HF	02/mai		02/05/2018	MAI	WK18	Kanboard 13465	OPEN
1	IPM_11 : Avarias	F2 INJ	Definir stock de réguas analógicas na Manutenção (Fiser)	VB	13/mai		13/05/2018	MAI	WK19	Kanboard #11673	OPEN
4	IPM_11 : Avarias	F2 INJ	Verificar altura do bico em relação à mesa (desgaste precoce do bico de injeção).	VB	13/mai		13/05/2018	MAI	WK19	Kanboard #12446	OPEN

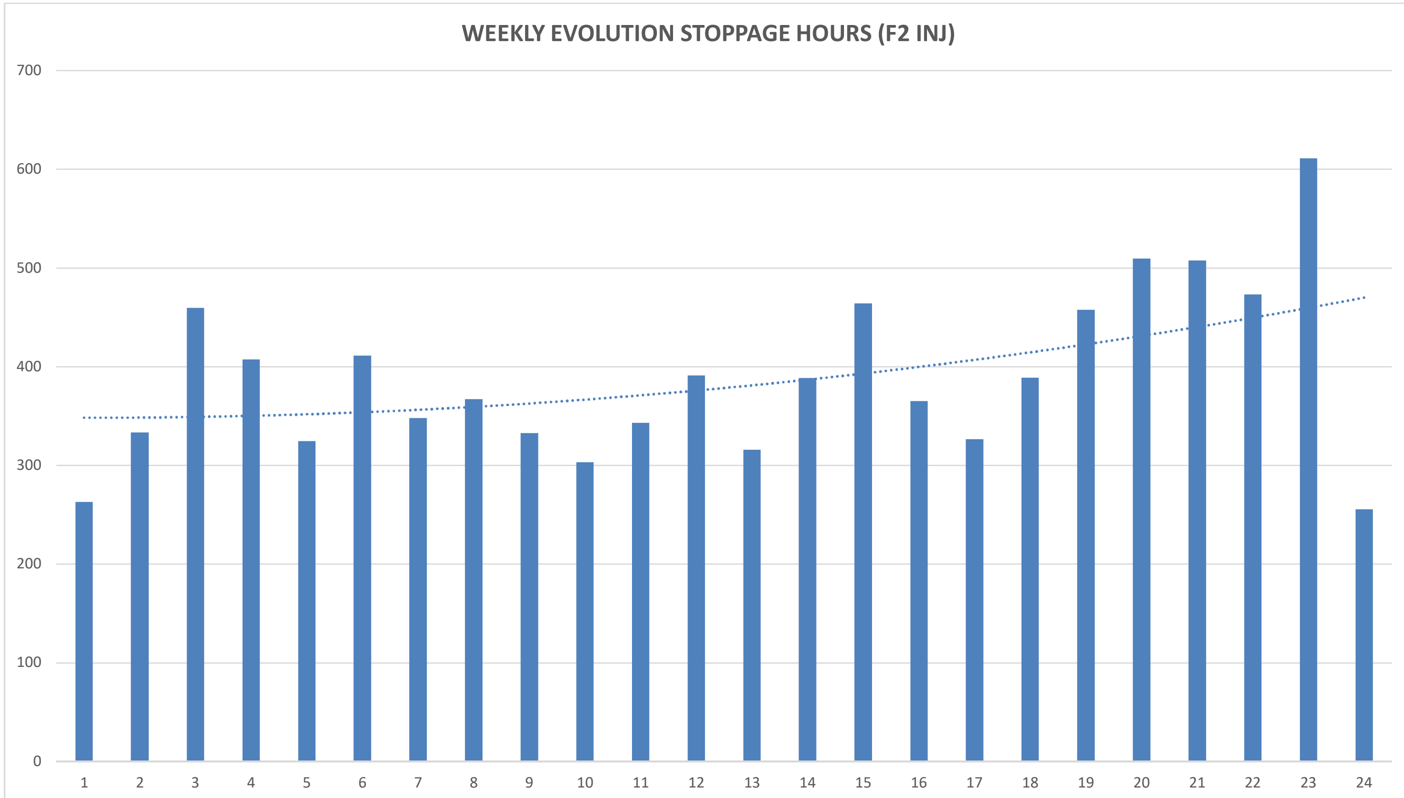
1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE





5. CHECK RESULTS



FICOSA Corporate	A3 (KPI - AVAILABILITY)	P-QA-XX/XX-11-H Page 1/1 Edited by: J. Pereira 09-May-2018, Ed.7
	Team Members: **Conceição Rosa (CR)** ***Coordinator:*** **Francisco Ferreira (FF)**	

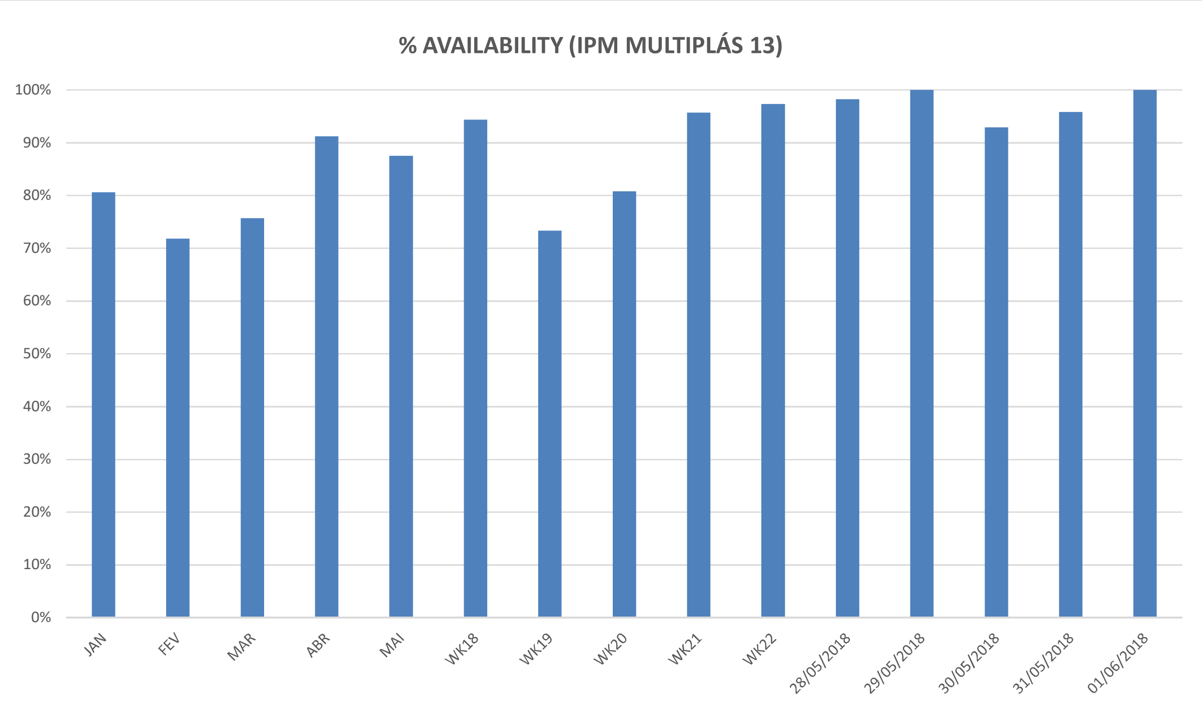
1. DEFINE

Availability (IPM MULTIPLÁS 13)

Photos of the team members

2. MEASURE

1º Update CP | 2º Calculate Availability/A3 | 3º Refresh Graphs

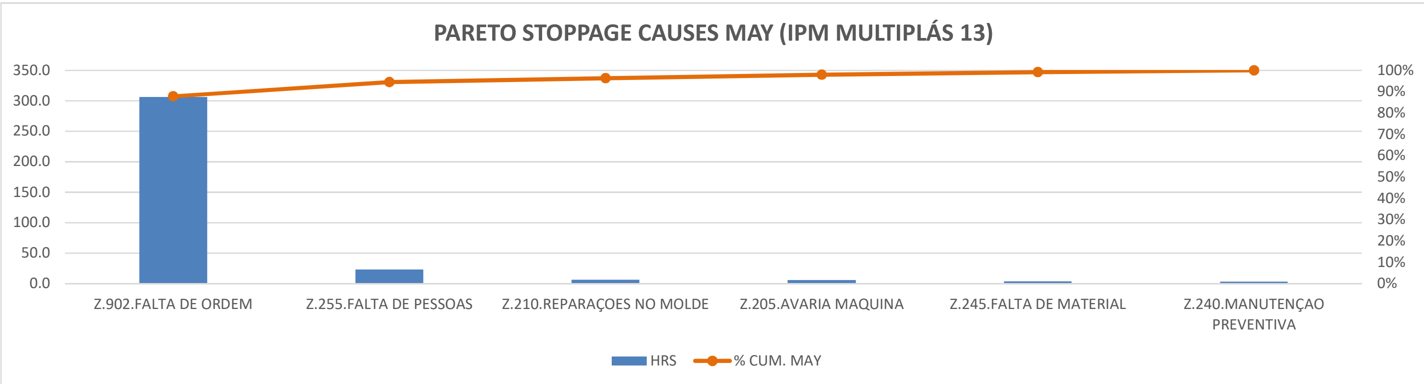


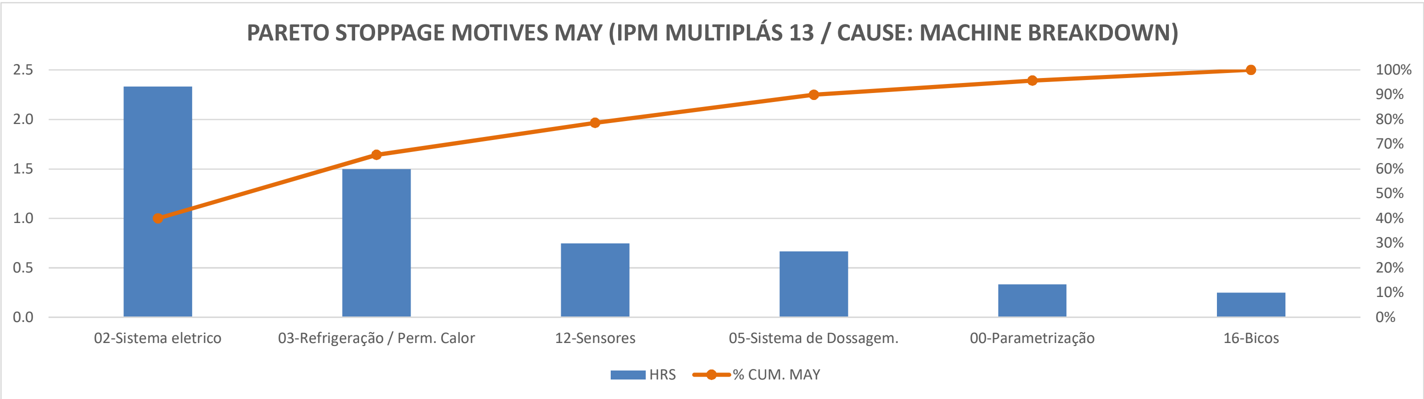
4. IMPROVEMENT ACTIONS

	ANALYSE		PLAN				DO			CHECK	ACT
N	Main Causes/Sources	Module	Actions	Resp	Date	Availability Improvement	Date			Process	People
	(5 Why/Ishikawa, DOE)		(Use short sentences in the active form, e.g: "prepare this", "make that", ...)	(AA)	(dd/mmm)	%	(dd-Mmm)	(MMM)	(WK)	(I-AA-XX/XX-999)	(audit)
6	IPM_13 : Molde MQB1 c/ bastante tempo de indisp.	F2 INJ	Passar sensibilização com registo acerca dos procedimentos para operar com o molde (utilização da chapa)	CR	25/mai		25/05/2018	MAI	WK21	Kanboard #14000	OPEN
8	IPM_13 : Molde MQB1 c/ bastante tempo de indisp.	F2 INJ	Melhorar a configuração da chapa por forma a eliminar a possibilidade de mau posicionamento da espiral	HF	02/mai		02/05/2018	MAI	WK18	Kanboard 13465	OPEN

1º Order PDCA actions | 2º Archieve closed PDCA actions

3. ANALYSE





5. CHECK RESULTS