Digital transformation: Digital performance assessment approach in the industry

Beatriz Alves Pereira

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Orientador na FEUP: Prof. Dr. António Almeida

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

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Abstract

Recent technological developments have had a significant impact on various aspects of society. In the industrial sector, the advancement of sensor technology, Big Data, and the Internet of Things (IoT) has given rise to the fourth industrial revolution: Industry 4.0. In an increasingly globalized and dynamic environment, companies need to adapt and remain competitive to survive and thrive. Digitalization, in particular, offers a significant competitive advantage, enabling companies to quickly adapt to market changes, efficiently meet customer demands, and become more agile and flexible compared to their competitors.

In this context, this dissertation addresses the digitalization of the shop floor in two different companies. This process was made possible not only through the analysis of existing literature on Industry 4.0 but also by leveraging the experience and knowledge of a technology startup. The theoretical concepts behind the technologies that enable the digital transition to Industry 4.0 are explored, followed by the utilization of a technological platform to assist in controlling information flows in the production sectors of the companies, as well as the monitoring and digitization of performance indicators.

The work carried out throughout this project has both theoretical and practical dimensions. Therefore, this dissertation was developed within the context of a real implementation project for digitalizing the shop floor, with a considerable impact on increasing productivity and reducing costs for the companies. However, the companies are not at the same level regarding the digitalization process. While one focuses solely on digitalizing reports and indicators, the other focuses more on the digitalization of equipment, such as real-time data collection testing. Although the latter is in a more advanced stage of digitalization, there are still improvements that can be made in this regard, as duly identified in this dissertation.

The digitalization process in these two companies aims to reduce the number of non-value-added activities, generate savings related to continuous improvement initiatives, and increase productivity by enhancing operational transparency. This is achieved by leveraging the visibility of collected data and their respective KPIs, as well as the necessary transparency to act upon the gathered data in a collaborative and continuous improvement format.

Transformação digital: Abordagem de avaliação do desempenho digital na indústria

Resumo

Os recentes desenvolvimentos tecnológicos têm tido um impacto significativo em diversos aspetos da sociedade. No setor industrial, o avanço da tecnologia de sensores, *Big Data* e Internet das Coisas (IoT) permitiu o surgimento da quarta revolução industrial: a Indústria 4.0. Nesse sentido e num ambiente cada vez mais globalizado e dinâmico, as empresas precisam de se adaptar e permanecer competitivas para sobreviver e prosperar. A digitalização, em particular, oferece uma vantagem competitiva significativa, permitindo que as empresas se adaptem rapidamente às mudanças do mercado, atendam às demandas dos clientes de forma mais eficiente e se tornem mais ágeis e flexíveis em relação à concorrência.

Neste contexto, a presente dissertação aborda a digitalização do chão de fábrica, em duas empresas distintas, utilizando diferentes abordagens. Este processo foi possível, não só através da análise de literatura existente acerca da Indústria 4.0, mas também aproveitando a experiência e conhecimento de uma startup tecnológica. São explorados os conceitos teóricos subjacentes às tecnologias que possibilitam a transição digital para a indústria 4.0, seguindo-se a utilização de uma plataforma tecnológica para auxílio no controlo de fluxos de informação nos setores produtivos das empresas, bem como a monitorização e digitalização de indicadores de desempenho.

O trabalho desenvolvido ao longo deste projeto possui uma dimensão não apenas teórica, mas também prática. Nesse sentido, a presente dissertação foi desenvolvida no contexto de um projeto de implementação real de digitalização do chão de fábrica, com impacto considerável no aumento da produtividade e na redução de custos das empresas. No entanto, as empresas não se encontram ao mesmo nível no que respeita ao processo de digitalização. Enquanto uma se centra apenas na digitalização de relatórios e indicadores, através de importação manual de ficheiros, a outra incide mais numa vertente de digitalização de um equipamento, resultando num teste à recolha de informação do mesmo em tempo real. Embora esta última se encontre numa fase mais avançada do processo de digitalização, ainda existem progressos que podem ser realizados nesse sentido, conforme devidamente identificados nesta dissertação.

O processo de digitalização nestas duas empresas tem como objetivo reduzir o número de atividades sem valor acrescentado, gerar poupanças relacionadas com iniciativas de melhoria contínua e aumentar a produtividade através do reforço da transparência das operações. Tal é alcançado explorando a visibilidade dos dados recolhidos e os respetivos KPIs e a transparência necessária para agir sobre os mesmos, em formato de colaboração e melhoria contínua.

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This project is the culmination of 5 years of study at FEUP, where I had the opportunity to create countless memories with the people who helped me grow and reach this final stage successfully. It has been years of extensive learning and a lot of mutual support. Therefore, I am pleased to express my gratitude to the key individuals who played a crucial role in the final stretch of my journey.

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Contents

Acronyms and Symbols

API	Application Programming Interface
CC	Cloud Computing
CPS	Cyber-Physical System
ERP	Enterprise Resource Planning
EWM	Extended Warehouse Management
HMI	Human Machine Interface
IoT	Internet of Things
IT	Information Technology
JIT	Just In Time
KPI	Key Performance Indicator
MES	Manufacturing Execution System
MQTT	Message Queuing Telemetry Transport
MTBF	Mean Time Between Failures
MTTA	Mean Time To Assist
MTTR	Mean Time To Repair
OEE	Overall Equipment Effectiveness
OPC	Open Platform Communications
OT	Operational Technology
PDCA	Plan-Do-Check-Act
PLC	Programmable Logical Controller
PO	Production Order
POD	Production Operator Dashboard
RM	Raw Material
RMW	Raw Material Warehouse
SAP	Systems Applications and Products in data processing
SCADA	Supervisory Control and Data Acquisition
TPM	Total Productive Maintenance
TPS	Toyota Production System
VPN	Virtual Private Network

List of Figures

List of Tables

1 Introduction

In this chapter, the contextual background of the dissertation and the project on which it is founded are presented. The companies where the research was conducted are mentioned, along with the methodology employed and the overarching objectives of the study.

1.1 Context

This dissertation was carried out in the scope of the master in Production Management of the Mechanical Engineering course of the Faculty of Engineering of the University of Porto and was realized during 4 months in the company proGrow. The project arose following a need of the client companies in increasing their technological maturity, in order to maximise the potential of its production. To carry out the project successfully, it was essential to understand the different worlds represented by the two companies and their different needs, related with digitization of their processes. The work developed to accomplish the project is mirrored in this dissertation, being presented the main foundations of each of its phases and also part of the acquired knowledge, since not all of it can be transcribed.

The low digital maturity in the industrial sector overall has been a significant limitation in achieving optimized performance indicators. The digitization of production processes emerges as an urgent need to address the challenges of the modern era. The lack of technological integration, absence of automated systems, and excessive reliance on traditional methods have hindered industrial companies' ability to maximize efficiency, reduce costs, and increase productivity. The digitization of production processes not only drives competitiveness but also opens up new business opportunities and strengthens the resilience of the industrial sector in the face of rapid and complex changes in the global landscape. It is imperative that companies invest in modernizing their operations and embrace digital transformation to ensure a strong market position and achieve better results in their performance indicators.

According to Hanley et al. (2018), most organisations still rely on conventional productivity tools, such as spreadsheets, to access, analyse and process the data collected from their assets (approximately 88% of organisations surveyed). In contrast, only 26% of respondents use sensor technologies, while data visualisation technologies are starting to gain traction (around 62%), but are still far from being a ubiquitous practice, especially when combined with reading real-time data through sensors. There is therefore still plenty of work and potential that can add value at this stage of companies' initiation into the digitalisation process.

1.2 Presentation of the companies

This section presents the company where the dissertation was carried out, as well as the client companies where the project was implemented.

1.2.1 proGrow

proGrow, S.A. is a technology startup that was founded in 2014, with the primary objective of expediting the worldwide transition of the industry towards the 21st century. The company's vision is to incorporate the tenets of Industry 4.0 into daily life, thereby advancing the technological landscape of the industry. Its mission, clarified in the slogan "Producing more with less", is to help companies produce more value with fewer resources. To achieve this aim, the entity offers a digital platform, known as proGrow, that empowers organizations to attain sustainable operational excellence.

This platform is tailored to enhance the shop floor experience, and it comes equipped with state-of-the-art connectivity and analytical capabilities. The fundamental principle behind this solution is the digitalization of industrial equipment. The proGrow offers various integration options with IoT Gateways and supported protocols, and it can bring any equipment or workstation online, even through manual interfaces. By leveraging this service, organizations can closely monitor the status of each equipment and manually input additional information. Furthermore, the platform facilitates the sending of alerts and the escalation of deviations, enabling employees to react promptly due to the real-time visibility of results. The platform also provides access to collaboration tools and analysis capabilities to drive continuous improvement efforts. The company works closely with its customers to comprehend their specific requirements and tailors the platform accordingly to meet their needs.

1.2.2 Client Company 1

The client company 1, situated in Oliveira de Azeméis, is, since 2008, the main production unit for a multinational Austrian manufacturer specializing in the production of lighting elements for the automotive sector. This factory invoices around 70 million euros per year and employs 710 employees.

The group, established in 1977, was previously exclusively engaged in the manufacturing of components for heavy vehicles but has been gradually venturing into the competitive market of light vehicles. Notably, the company's major customers include renowned car manufacturers such as Volkswagen AG (Audi, Lamborghini, Volkswagen), PSA Groupe (Peugeot and Citroën), Daimler AG (Mercedes) and Mitsubishi Motors. The group currently employs approximately 1500 individuals.

1.2.3 Client Company 2

The client company 2 was part of a Group established in 1986 in Sinde, located in Tábua. It specializes in the manufacturing of sofas and mattresses. Presently, the Group consists of multiple factories responsible for various aspects of production, such as the manufacturing of sofa frames, fibres, springs, foam, and mattresses. The 7 factories are located in Tábua, Nelas, Carregal do Sal and Auxerre (France). The Group presently employs approximately 3500 individuals and has a production capacity of 2.75 million sofa seats and 1.2 million mattresses per year.

The Group has consistently demonstrated its ability to adapt to market changes, which has contributed significantly to its success since inception. Currently, the company is one of the primary suppliers to prominent international retailers such as Ikea, Conforama, El Corte Inglés, Alinea, Maisons du Monde, and Estrutu-Tube, among others.

The present project was carried out in one of the group's factories, founded in 2010, which is dedicated to the production of mattresses. Its production capacity is 1 million mattresses per year and with an extensive variety of models with various specifications. In mattress manufacturing, the factory operates under vertical integration. Raw materials are supplied and then the transformation of various materials into mattress production takes place.

1.3 Project presentation

The objective of the undertaken project is to facilitate the transition of an automotive company and a mattress manufacturing company towards a smart factory, improving its digital maturity by implementing the proGrow platform. The situation on the shop floor of the companies was that of a traditional production organization with a low level of data acquisition automation and indicator tracking. Additionally, there was a lack of digitization in workflow processes and continuous improvement initiatives. This situation led to the allocation of valuable work time to tasks such as manually inputting data into computer systems, calculating indicators, and filling out continuous improvement charts and action lists.

Regarding client company 1, in addition to digitizing its reports and continuous improvement initiatives, as a parallel or consequent benefit, the platform will enable the company to enhance its equipment maintenance methods. Given the current state of the company, the digitization project will primarily focus on optimizing machine lifecycles and reducing maintenance costs, with the ultimate goal of improving equipment availability, which is currently the most critical factor. This objective is achieved through the digitization and optimization of workflows. These shortcomings have resulted in the inefficient allocation of valuable work time to tasks such as manual data entry into IT systems, indicator calculations, and filling out continuous improvement charts and action lists. In consultation with management, it has been determined that the focus of this project in the current phase would be on the injection and metallization section.

The project in the mattress manufacturing company includes digitizing indicators on a specific equipment and creating real-time monitoring capabilities for it, aiming to further enhance the overall efficiency and effectiveness of the company's operations. This project will be short-term and limited to a single equipment in assembly section 1, serving as a proof of concept for this digitization method. In the long term, it is expected to be extended to the remaining equipment in the factory.

1.4 Objetives

The objectives of implementing this project in the industrial sector are focused on reducing the effort expended on monitoring indicators and improving the response time of operational teams to maintenance and time management issues, increasing digital maturity of the companies. It is expected that the increased visibility and enhanced collaboration facilitated by the platform will contribute to reducing time spent on activities that do not add value to the company, while also improving the overall efficiency of the factory. This improvement can be assessed through increased visibility and transparency of KPIs, aiding decision-making within the company. The achievement of these objectives will serve to positively assess the impact of digitisation in the industrial sector.

To achieve the described objectives, the project of the client company 1 will focus on the implementation of a new digitalized information flow for quick reaction to values outside the defined limits. In addition, the “Improvement” module of the platform will be made available to centralise all the actions and projects defined, increasing their visibility and the collaboration of all the workers.

The project of the client company 2 will focus on the implementation of a device in the equipment to be digitized and consequent monitoring of the indicators. This device was recently introduced in the solution implemented by proGrow, so the effectiveness of this new method will also be evaluated.

The successful achievement of these objectives would result in significant positive impacts, both for the companies in terms of reduced production costs, as well as for all stakeholders involved in the production process. The utilization of the proGrow platform to enhance production process efficiency would serve as evidence of the positive influence that modern technologies, such as this platform, can have in industrial environments.

1.5 Methodology

The project under consideration involves some companies and stakeholders. Therefore, the initial phase of the project, which lasted for a month and a half, encompassed training sessions at proGrow, the company responsible for project development, as well as familiarization with the client companies. Concurrently, discussions were held with the client companies regarding the dissertation project, and subsequently, an extensive literature review was conducted.

The subsequent phase of the project entailed establishing a baseline of the client companies' initial production process and its monitoring, along with the calculation of shop floor indicators.

Following this, the project specifications were formulated, considering the customer's requirements, and addressing the identified problems and challenges, with the objective of devising a solution that adequately addresses these needs.

Finally, in the last month of the project, the solution was implemented, and the results were thoroughly discussed and estimated. A Gantt chart illustrating the distribution of tasks over the course of the project is presented in figure 1.1.

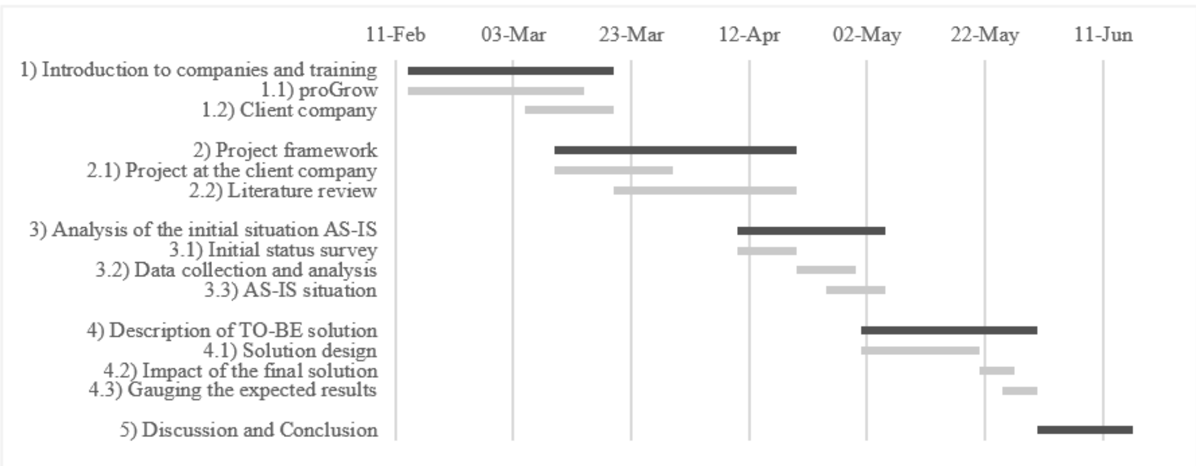

Figure 1.1 - Gantt chart of the project phases.

The methodology adopted to develop the project in both companies falls within the domain of practical investigation, specifically an applied research approach. This approach is problem-oriented and focuses on a specific business problem, aiming to develop practical techniques and solutions (Chawla & Sondhi, 2015). In this case, the problem at hand is to define guidelines for carrying out digital transformation in the industrial sector. The validation of data was conducted using primary and secondary data sources, including information provided by the client company as well as data collected during on-site visits and regular meetings that took place throughout the project's development.

1.6 Dissertation structure

The structure of this dissertation consists of five chapters, including this introductory chapter.

Chapter 2 provides a comprehensive literature review, covering the key topics relevant to this research, which include Industry 4.0, the proGrow, and continuous improvement methods.

Chapters 3 and 4 presents the initial status (AS-IS), implemented solution (TO-BE) and results of client companies 1 and 2, respectively. In these chapters, the problems of each company are identified and the opportunities for improvement are diagnosed. The collected data is analysed in detail, serving as a basis for the presentation of the proposed solution and the methodology used for its conception. Finally, the validation and exploration of the data supporting the solution design are presented, as well as an evaluation of the expected impacts of the suggested measures.

The final chapter entails a discussion of the obtained results, followed by conclusions and future perspectives for the evolution and improvement of this project.

2 Literature Review

This chapter provides an overview of the theoretical foundations that form the basis of the project. First, the Toyota Production System will be introduced, which will then lead to Lean Manufacturing and the Kaizen culture. The next section is dedicated to the framework of the topic of performance indicators applicable in industry. The subchapter concerning Industry 4.0 analyses the functioning of Big Data technology. Furthermore, the concept of digitalisation of the shop floor is analysed, with a constant focus on Change Management throughout the project.

2.1 Toyota Production System

The Toyota Production System (TPS) is a production system developed by Toyota Motor Corporation between 1948 and 1975, and it was invented by Taiichi Ohno and Shigeo Shingo. The fundamental principle underlying the TPS is the complete elimination of waste. To support the system, two pillars are required: *just in time* (JIT) and *jidoka*, as explained by Ohno in 1988.

The concept of *just-in-time* pertains to the practice of ensuring that the required components for a specific assembly process are delivered to the assembly line precisely at the moment they are needed and in the exact quantity required. By implementing this approach throughout the entire production flow, an organization can strive to minimize inventory to the point of achieving almost zero stock (Ohno, 1988).

Jidoka is a manufacturing concept that entails the integration of automation with human intervention to establish high-quality processes. This approach enables production to be carried out by machines that halt operation in the event of any abnormalities. Subsequently, human supervision takes over to conduct quality control and, if necessary, stop the production line. The fundamental objective of *Jidoka* is to prevent defective parts from progressing down the production line. This is not only crucial for safeguarding customer interests and reducing scrap costs but also serves as a continuous improvement tool that plays a pivotal role in making Kanban work effectively. Deviation from *Jidoka* principles by allowing defective parts to proceed along the production line constitutes a violation of Kanban rules, thereby impeding the process of identifying and addressing the root causes of problems (Wilson, 2009).

2.1.1 Lean Manufacturing

Toyota developed a production method known as “Lean Manufacturing”, which is centred on the elimination of waste and aims to make the two pillars of the Toyota Production System more effective. Unlike traditional process improvement approaches that primarily focus on enhancing activities that add value to the process, Lean Manufacturing, on the other hand, emphasizes identifying and eliminating activities that do not add value, with the goal of reducing or eliminating waste in the process. This approach acts as a remedy to any form of waste, as described by Womack and Jones in 1996.

The identification of activities that do not add value in Lean Manufacturing involves a search for existing waste, which can typically be categorized into eight defined forms: overproduction, waiting times, transport, excessive processing, inventories, movements, defective products, and misuse of human resources creativity. The process of identifying these wastes requires a comprehensive analysis of the flow of material and labour, encompassing activities at both the strategic level, which should align with the principles of lean thinking, and the operational level, also known as gemba, where lean process tools should be applied (Gao & Low, 2014).

Lean Maintenance is a management strategy that aims to apply lean principles and goals to physical asset management. The goal of Lean Maintenance is to improve the overall effectiveness and efficiency of maintenance processes while minimizing downtime, reducing costs, and improving the quality of the final product or service. This process is presented in figure 2.1. By applying lean principles to maintenance operations, organizations can streamline their processes, eliminate waste, and reduce the risk of breakdowns and downtime (Christiansen, 2021).

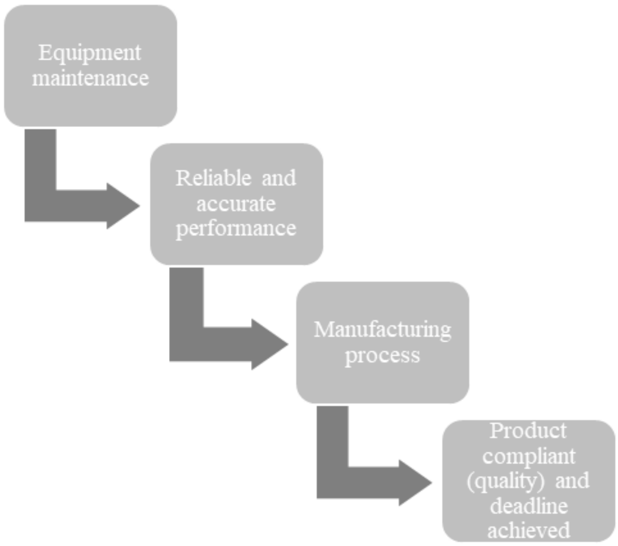

Figure 2.1 - Lean Maintenance.

By implementing preventive and predictive maintenance strategies, it is conceivable to avert unscheduled downtime, and these techniques are more efficacious than the reactive maintenance approach, which follows a "wait and see" philosophy. Preventive maintenance is a proactive strategy that aims to prevent equipment and system failures and issues before they materialize, by executing a series of pre-planned tasks. In contrast, corrective maintenance is a reactive approach that is enacted only after the detection of a problem or failure, and its objective is to restore the normal functioning of the equipment or system. While preventive maintenance is generally viewed as a superior approach compared to corrective maintenance, the combination of both strategies can be implemented in order to optimize the efficiency and availability of equipment and systems. Nevertheless, undertaking an analysis of breakdown data to identify the underlying causes of each unplanned stoppage and subsequently eliminating these root causes represents a more effective methodology for continuous improvement.

In the realm of management tools and practices that are employed to achieve and sustain a lean posture, several notable techniques can be identified. These include the Ishikawa diagram, the value stream mapping process, the 5S and 5 Whys methodologies, the Kanban system, the PDCA cycle, production in cells, and the SMED methodology, among others.

2.1.2 Continuous Improvement

The concept of continuous improvement, originating from the Japanese term "Kaizen", encompasses a continuous and innovative improvement process that aims to involve all levels of an organization (Caffyn, 1999). Among the tools employed to support this process and facilitate problem-solving, the PDCA (Plan-Do-Check-Act) cycle holds significant prominence in this project.

PDCA cycle

The PDCA cycle, which was popularized by Dr. W. Edwards Deming, a renowned figure in modern quality control (Chakraborty, 2016), provides a systematic approach to problem-solving. It emphasizes that problems should be addressed through a series of phases, namely Plan, Do, Check, and Act. When confronted with a problem viewed as an opportunity for improvement, the initial phase involves studying and analysing the situation to collect crucial data that will serve as the foundation for the improvement plan (Plan). Subsequently, the plan is executed (Do) in accordance with the established course of action. The Check phase follows, wherein the outcomes of the implementation are assessed to identify successes and any discrepancies. In the fourth phase of the cycle, the information collected in the previous phases is used to understand the errors and identify the root causes behind them (Gao & Low, 2014). Lastly, once successful implementation is achieved, standardization of the new process should be carried out. It is essential to allocate adequate time to each phase of the PDCA cycle to ensure a smooth and effective quality improvement process (Chakraborty, 2016).

2.2 Key Performance Indicators

Key Performance Indicators (KPI) are quantitative measures that evaluate the performance of a company, team, or process against a specific objective. They are essential for effective business management because they provide objective, data-based information for making informed decisions and monitoring progress toward goals (Parmenter, 2007).

However, performance measurements continue to pose a challenge for operations managers, as indicators are often misinterpreted and instructions for their use are unclear. To effectively translate an organization's strategy, it is essential to choose the right indicators. Strategies and indicators are closely related and interdependent. KPI should have four main characteristics, according to Franceschini et al. (2007): they must be simple to understand for managers and other stakeholders, traceable and verifiable, related to defined objectives, and representative of the process as much as possible.

After selecting KPI, defining the target values for each of them is important, taking into account that these values may need to change over time, as well as the KPI themselves, which are periodically reassessed (Heini, 2007). Merging important KPI to create a core system may reduce the risk of information loss, misinterpretation, and poor significance of individual KPI. In this regard, Overall Equipment Effectiveness (OEE) is a very important, popular and essential indicator for measuring industrial productivity.

OEE is the primary measure of production effectiveness. It can be used for value stream or individual workstation performance evaluation. Good value stream OEE is one of the key precursors to the implementation of Lean and is the product of three important operational parameters (Wilson, 2009):

$$OEE = Availability * Quality * Performance$$

Where,

$$Availability = \frac{Operation\ Time}{Net\ Available\ Time}$$

$$Quality = \frac{Total\ Production - Defect\ Amount}{Total\ Production}$$

$$Performance = \frac{Total\ Production}{Planned\ Production}$$

Table 2.1 depicts a diagram illustrating the components of OEE and their respective representations in terms of time.

Table 2.1 - OEE parameters. Source: Elevli & Elevli (2010).

<table>
<tr><th colspan="5">Total Time</th></tr>
<tr><th colspan="4">Net Available Time</th><th>Scheduled Downtime</th></tr>
<tr><th colspan="3">Operating Time</th><td>Downtime Losses</td><td></td></tr>
<tr><th colspan="2">Net Operating Time</th><td>Speed Losses</td><td colspan="2"></td></tr>
<tr><th>Fully Productive Time</th><td>Defect Losses</td><td colspan="3"></td></tr>
</table>

Table 2.2 categorises the Six Big Losses and how they are accounted for in the OEE calculation (Elevli & Elevli, 2010).

Table 2.2 - Categorisation of Losses in OEE. Source: Elevli & Elevli (2010).

Six Big Losses Category	OEE Loss Category	OEE Factor
Equipment failure	Unplanned Stoppages	Availability
Setup and Adjustment	Planned Stoppages	
Shutdowns and Short Breaks	Short Stops	Performance
Reduced Speed	Slow Cycles	
Reduced Yield	Start Rejections	Quality
Quality Defects	Production Rejections	

Within the context of the project in company 1, it is acknowledged that not all aspects of OEE have been fully addressed. The immediate focus will be solely on the availability component in the near term.

The availability parameter of OEE represents the proportion of the actual operating time of a machine to the planned production time. Any incidents that impede the scheduled production for a substantial duration (sufficient time for an operator to record a reason) result in a decrease in availability, and consequently, a decline in the OEE. Instances that result in a reduction in availability encompass unscheduled stoppages (for instance, equipment malfunctions and deficits in raw materials) and anticipated halts (such as the time required for changing over equipment). The analysis of OEE includes the evaluation of changeover time as it is duration that could have otherwise been utilized for production purposes. Although it may not be entirely feasible to eradicate changeover time, in most circumstances, it can be curtailed to a significant extent.

To quantify the effectiveness of maintenance activities, it is essential to establish a comprehensive set of performance indicators that facilitate the monitoring and control of these activities. Reliable indicators, such as Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR), can be employed to mitigate reliability issues, and improving the accuracy of their measurement can positively impact equipment availability (Sohn et al, 2006).

The Mean Time Between Failures (MTBF) is a measure of reliability, representing the ability of this to function for a given period of time in good conditions. It is calculated as follows (Smith, 2011):

$$MTBF = \frac{available\ time - planned\ downtime}{number\ of\ stoppages}$$

Mean Time to Repair (MTTR), expresses the average time required to repair a malfunction, i.e., the average time required to restore the equipment to its normal operating conditions and is calculated using the following equation (Smith, 2011):

$$MTTR = \frac{time\ to\ repair}{number\ of\ stoppages}$$

This indicator considers the time from problem diagnosis, repair, testing and, finally, delivering the equipment to the operator.

2.3 Total Productive Maintenance

Total Productive Maintenance (TPM) can be delineated as a strategic initiative aimed at enhancing the operational efficiency of the production system through a comprehensive array of maintenance activities. This approach entails a novel perspective towards industrial predicaments within the Maintenance/Production interface, encompassing the exchange of competencies across distinct levels within an organizational framework. Typically, most industries adopt an organizational structure wherein maintenance and production departments are situated separately, despite both departments being fundamentally aligned in their pursuit of constituting a cohesive and productive unit for the company. TPM serves as a mechanism fostering cooperation and collaboration between these departments, with the overarching objective of eradicating inefficiencies, elevating product quality, augmenting equipment availability, and bolstering reliability (Ngoy & Israel, 2021).

As the implementation of TPM produces a profound change in culture at all levels of the organisation, it is essential that it is very well outlined and takes into consideration all the people affected, giving them the opportunity to be part of the implementation process in order to feel encouraged. The benefits are remarkable:

- Improvement of product quality (reduction of rework and scrap);
- Decrease of setup and process stabilization times;
- Reduction of production cost;
- Improvement of equipment reliability and availability;
- Work in polyvalent teams of operators and technicians;
- Increased quality of maintenance service;
- Reduction in the number of breakdowns.

This methodology is based on 8 pillars: autonomous maintenance, planned maintenance, training and coaching, anticipated management, quality maintenance, TPM Office (linked to the elimination of waste) and safety and environment (Ngoy & Israel, 2021).

2.4 Industry 4.0

The term "Industrial Revolution" is frequently utilized by scholars, historians, and economists to describe epochs of technological transformation that have had a significant impact on both the economy and society (Klingenberg et al., 2017).

The first significant landmark in the history of industry is acknowledged as the First Industrial Revolution, which was initiated through the advent of steam engines towards the conclusion of the 18th century. The fundamental principle of steam engine operation is the conversion of steam's internal energy into mechanical energy. Subsequently, the Second Industrial Revolution marked a crucial turning point, wherein electricity was harnessed in industrial settings, enabling the creation of the production line in 1870 (Marr, 2018). Information technology and electronics, responsible for the Third Industrial Revolution in the 1970s, introduced automation into the factory setting (Klingenberg et al., 2017). Currently, the world is experiencing the Fourth Industrial Revolution, which stems from the concept of the Internet of Things (IoT) with the aim of facilitating the seamless communication between machines and systems. This transformation seeks to achieve a higher degree of automation and operational independence while reducing the necessity of human intervention. It is noteworthy, however, that the primary objective of this shift is not to supplant human labour with machines but rather to enhance human productivity and efficiency by automating repetitive tasks, thereby enabling individuals to concentrate on more intricate and intellectually demanding endeavours that necessitate human ingenuity and innovation.

Industry 4.0 is described by the German Federal Government as an emerging structure in which production and business processes are integrated. Manufacturing and logistics systems, in the form of Cyber Physical Production Systems (CPPS), heavily utilize the network of information and communications resources that are readily available on a global scale (Bahrin et al., 2016). The imperative of Industry 4.0 is the transformation of conventional machinery into autonomous and adaptive machines, resulting in enhanced operational efficiency and maintenance management through seamless interaction with the environment (Lee et al., 2014). The primary objective is to establish an intelligent and connected manufacturing ecosystem for the deployment of networked information systems (Bahrin et al., 2016). The core requirements of Industry 4.0 include real-time data monitoring, tracking of product status and location, and provision of production process control instructions. It consists of nine prospective pillars: Internet of Things (IoT), Big Data, Cloud Computing (CC), additive manufacturing, autonomous robots, simulation, horizontal and vertical system integration, cybersecurity, and augmented reality and can be further enhanced by artificial intelligence solutions (Rüßmann et al., 2015). Cloud Computing, in particular, a paradigm that provides simple, immediate and ubiquitous access to a variety of customisable and shareable computing media that can be rapidly provisioned and launched with minimal effort or interaction with the provider of such service, enabling centralised sharing of IT resources as well as flexible expansion of computing resources. As a preliminary stage towards the adoption of the Industry 4.0 framework, this subchapter aims to delve deeper into the matter of Big Data as means of gathering information regarding production processes and their subsequent monitoring.

Changes in production can be divided into different stages of development through digitalization, shown in figure 2.2. Computerization and connectivity are regarded as the preliminary stages or the foundations of Industry 4.0. The development stages of Industry 4.0 are divided into the phases visibility, transparency, forecasting ability and adaptability. A foresight and self optimization are thus based on an understanding of the processes and an analysis of these. Key Performance Indicators, presented before, are of central importance and an important controlling instrument.

Figure 2.2 - Industry 4.0 development stages. Source: Joppen et al. (2019).

The quality and competitive performance of an Industry 4.0 solution depend, among various factors, on its ability to facilitate vertical OT/IT (Operational Technology/Information Technology) connectivity, as well as horizontal OT/OT and IT/IT connectivity among components and systems implemented in the company (Wermann et al., 2019). Industrial networks are crucial components for data acquisition, communicating with each other through different protocols.

The visibility phase is based on the importance of visualizing the information obtained from the data. Collecting data and extracting information by itself does not add any value to the industrial process. It is necessary to visualize the information in order to address inefficiencies, reduce costs, and improve productivity.

The transparency stage emphasizes the relevance of understanding the production processes so that value can be derived from the obtained and exposed information through the stages of connectivity and visibility.

While technological advancements offer significant benefits, they also present certain reservations and limitations that must be considered and explored. One of the most significant challenges is the management and storage of vast amounts of data generated by the integration of machines and systems. Ensuring data security and privacy is also a crucial concern. The massive volume of data generated and collected necessitates appropriate storage mechanisms to ensure ease of access and processing, and the issue of data and system security is of utmost importance in Industry 4.0 (Kingsbury, 2020). Given that processes and systems are virtually integrated and connected over a network, there is a risk of data leaks and security breaches. However, security concerns extend beyond cyber-attacks and encompass the need to uphold ethical, social, and legal aspects relating to data treatment policy and privacy (Rüßmann et al., 2015).

Another significant challenge is related to the financial investment required for Industry 4.0 implementation. The size of a company is a critical factor in adopting these technologies, with small or medium-sized companies at a disadvantage in comparison to larger companies with greater investment potential. Furthermore, the new technological reality of Industry 4.0 requires employees to adapt to changing design, manufacturing, and operational practices, posing additional challenges for companies (Valdez et al., 2015).

2.4.1 Big Data

Big data refers to the vast amount of structured, semi-structured, and unstructured data generated by organizations, individuals, and machines. According to Forrester’s definition, Big Data consists of four dimensions: Volume of Data, Variety of Data, Velocity of generation of new data and analysis and Value of Data. With the rise of digital technology and the internet, the amount of data being generated has grown exponentially, and it continues to increase at an unprecedented rate (Witkowski, 2017). Manyika et al. (2011) assume that as technology advances, so will the amount of data that constitutes Big Data. The size and composition of datasets may also vary depending on the specific industry, including the type of software available and the typical volume of data generated in that particular business. However, it can currently be stated that Big Data sets in most industrial sectors can range anywhere from tens of terabytes to multiple petabytes in size (Manyika et al., 2011).

According to Manyika et al. (2011), Big Data enables value creation in five distinct ways: (1) creating transparency by making data more easily and quickly accessible; (2) the possibility of performing variance analysis of performance and understanding root causes of problems; (3) segmenting populations and targets in order to customize action plans; (4) the possibility of supporting or replacing human decision-making with automated algorithms; (5) innovating with new business models, products and services.

Notwithstanding the potential benefits described earlier, the management of large volumes of data inevitably presents challenges and limitations. It is understandable that increased investment and attention in this area translate into an increase in legal issues that may restrict the use of this data. One of the limitations is the set of data processing policies, specifically on subjects such as privacy, data security, intellectual property, and the responsibility to manage such data. Another challenge associated with handling Big Data is the requirement to adopt innovative technologies capable of capturing and storing data. Additionally, a third challenge arises with regards to talent acquisition in organizations, as they must be capable of utilizing these new technologies effectively. Other limitations include difficulties in obtaining information from disparate sources and changes in the industrial sector's structure, particularly in sectors where transparency and competitiveness are uncommon (Manyika et al., 2011).

2.5 Cyber-physical production systems

Digitalization is seen as a solution and the next step in manufacturing development as a way to address the growing issues in production. Connecting all systems and technologies involved in the process of creating value is the main goal, and productivity will be improved by using the data collected (Joppen et al., 2019).

The term cyber-physical system (CPS) refers to systems of collaborative computational elements that control physical entities, usually using feedback from the sensors that these systems monitor. Monostori (2014) characterizes these systems as those in which virtual entities, i.e., computers, are continuously linked to the physical environment, receiving, processing, and transmitting information. This conception implies a "union" between the physical and virtual realms, where sensors are utilized to transmit data to the virtual system, which processes them and determines the optimal course of action. The actual worth of IoT in industry is evidently derived from the data produced by the machines' cyber-physical systems (Bagheri & Lee, 2015).

2.5.1 Digitisation architecture

In order to enable an intelligent operation of a factory in accordance with the principles of Industry 4.0, the utilization of software to facilitate information technologies is indispensable. The graphical representation, denoted as figure 2.3, illustrates the pyramid structure that delineates the hierarchical arrangement of diverse types of software within modern production systems, as per the ISA-95 model/architecture. This model has been universally acknowledged as the international standard for facilitating the integration of control systems and companies, as established by the International Society of Automation. Its implementation can be characterised into 5 levels (from 0 to 4): (Jiang, 2018)

- **Level 0:** in the context of the physical production process, the collection of machine signals is accomplished through the utilization of devices, specifically sensors, which facilitate the acquisition of relevant data;
- **Level 1:** relating to the management of production activities at the equipment level, the control is facilitated through the utilization of controllers, specifically Programmable Logic Controllers (PLC), along with the associated sensors that enable the manipulation of the collected data;
- **Level 2:** represents the oversight of production processes. The control is achieved through the employment of tools such as SCADA (Supervisory Control and Data Acquisition) and HMI (Human Machine Interface);
- **Level 3:** in the context of managing shop floor operations, which entails tasks such as generating production schedules, regulating the flow of production through manufacturing orders and optimizing the entire manufacturing process, the presence of Manufacturing Execution System (MES) is indicative of this level;
- **Level 4:** the interconnectivity of production operations with other functional areas within the organization, such as logistics, distribution, delivery, and inventory control, is facilitated through the integration with Enterprise Resource Planning (ERP) systems. These ERP systems serve as a centralized hub for decision-making processes, enabling seamless coordination and communication among different departments of the company.

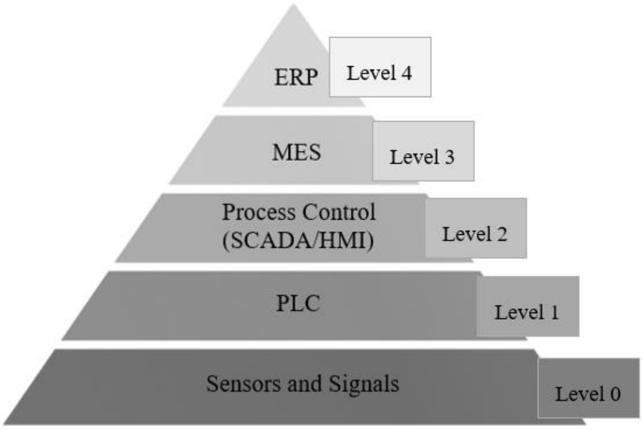

Figure 2.3 - Structure of the ISA-95 standard. Source: Jian (2018).

2.5.2 proGrow

The information presented in this sub-chapter is sourced from internal proGrow documentation.

proGrow is a data company focused on the digitalization of operations that occur in the companies, bringing together their data and centralizing operational knowledge. The various stages of digitisation are set out in figure 2.4. The digitalisation proposed by this company involves:

- the collection and correlation of data by integrating information from different sources;
- the definition and digitalisation of operational performance indicators that have an impact on the profitability of the business, enabling the monitoring of equipment efficiency;
- the definition, digitalization, and automation of management dashboards to aid in decision-making. They enable simple visualisation of the company's key performance indicators and real-time factory floor monitoring;
- management of continuous improvement initiatives (e.g., projects, actions);
- centralised promotion of an interdepartmental collaboration platform with the goal of fostering communication and efficient problem solving.

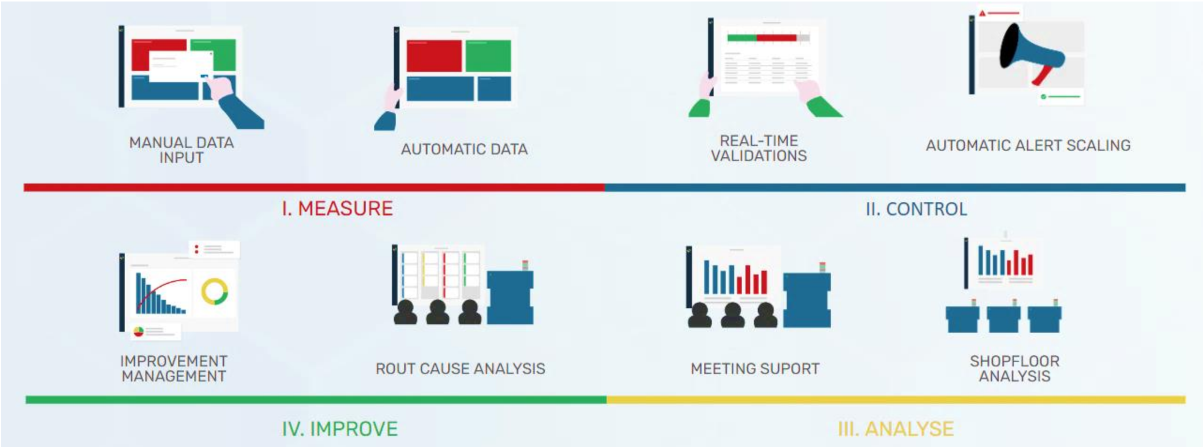

Figure 2.4 - Digital transformation at shop floor. Source: proGrow.

The platform integration mode is summarised in figure 2.5. The equipment present on the factory floor of a company generates data and these are exposed on the platform through various types of information sources: IoT devices and information systems (files, databases, web service).

Devices considered IoTs such as sensors and PLCs, must be connected to an organisation's internal network to access the data they store. In order to achieve this access, the use of a communication protocol characteristic of the IoT is required.

Databases allow the storage of data in tables that are related to each other, requiring permission from the owner of the database to access the information.

A web service is an application programming interface (API) that allows the system to ask a set of questions and transmit the respective answers to a primitive data source, such as a database or an IoT, ensuring the reliability of the integration between systems. This data accessibility is possible through permissions by the web service holder.

The files can be generated and updated automatically or manually and are accessible through their availability on a server.

The aforementioned data accesses are facilitated by the organization granting proGrow authorization to access its virtual private network (VPN) or a virtual machine that is managed by the platform.

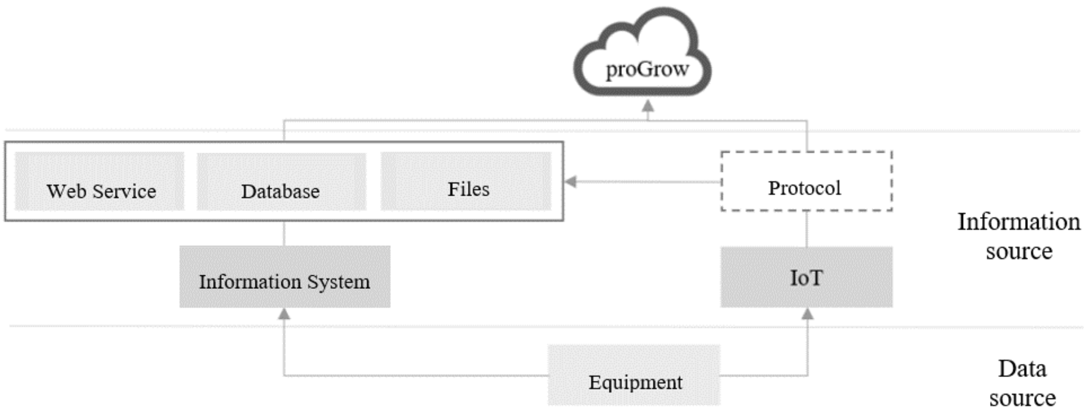

Figure 2.5 - Platform integration mode. Source: proGrow.

The platform features six distinct modules for different analyses.

The first module, entitled "Shopfloor", allows the user to monitor in real time what is happening on the shop floor, as shown in figure 2.6. The proGrow platform divides the equipment, according to the degree of integration, into manual stations (manual status and quantity produced), semi-automatic stations (automatic status and quantities produced manually) and automatic stations (automatic status and quantity produced).

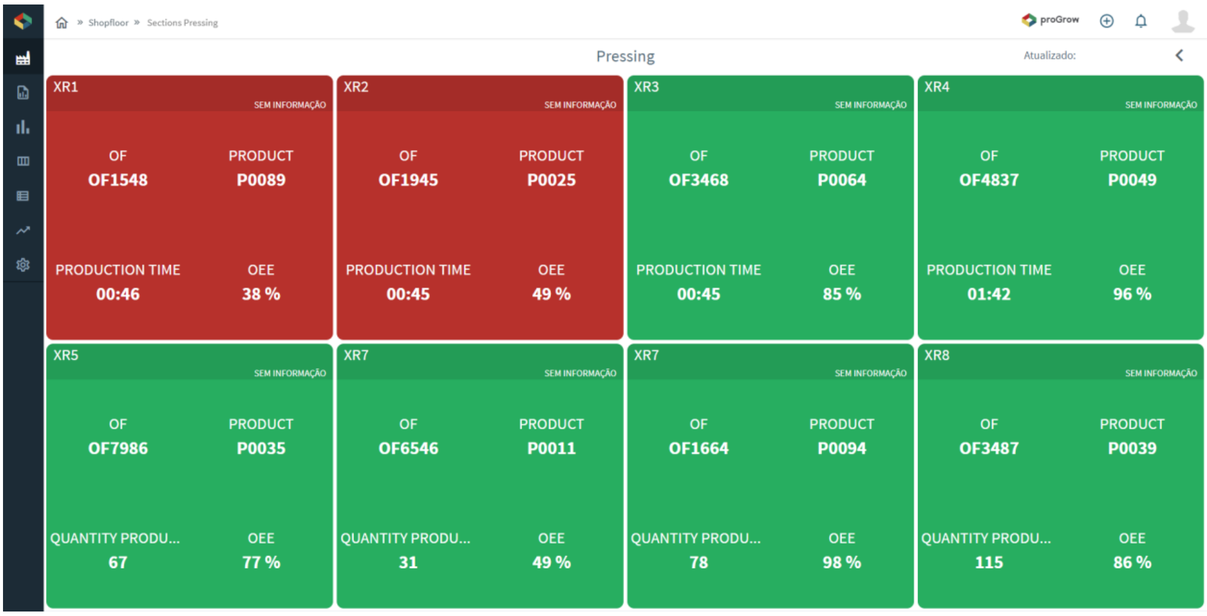

Figure 2.6 - "Shopfloor" interface example. Source: proGrow.

The second module is the “Report” module. In this area it is possible to generate management dashboards that automatically monitor the evolution of an indicator, as shown in figure 2.7. The update frequency of these reports may vary between monthly and per shift reports. This module also allows, in a collaborative view, comments or notes to be left on the analysis of a certain indicator. This function allows communication between employees, promoting the centralisation of all information.

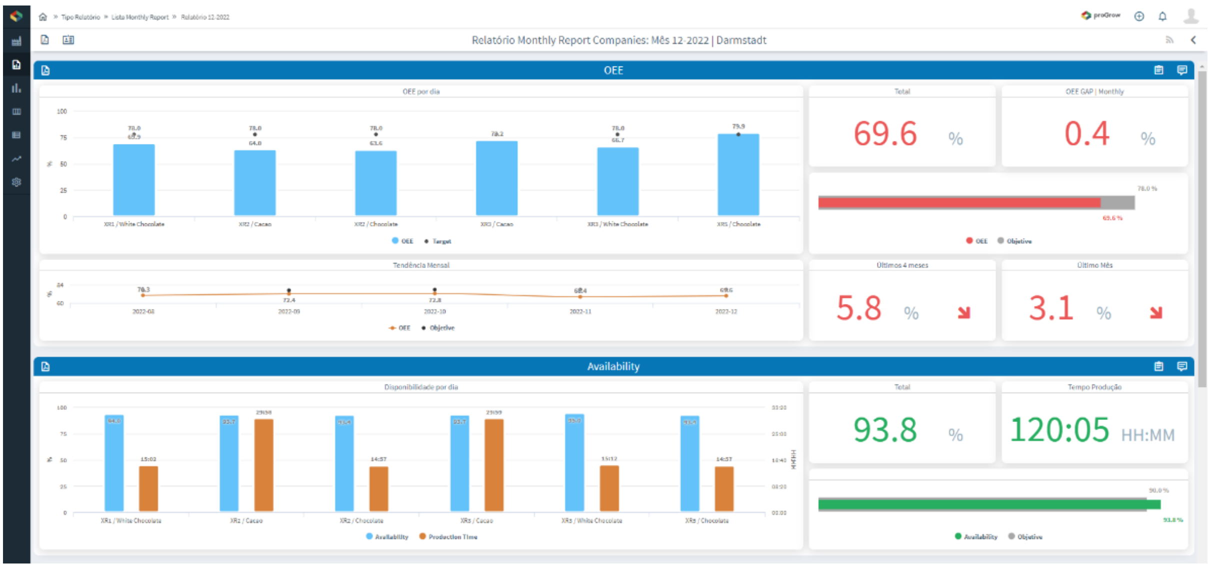

Figure 2.7 - "Report" interface example. Source: proGrow.

The "KPIs" module, depicted in figure 2.8, constitutes the third component of the platform. Within this section, users can access a range of performance indicators, and have the option to filter or view them from diverse perspectives. These indicators can be inputted manually or obtained automatically.

Figure 2.8 - "KPIs" interface example. Source: proGrow.

The platform also encompasses a "Kanban" module, as illustrated in figure 2.9. Within this module, users can access a table that presents the four phases of the PDCA cycle, along with the corresponding actions, tasks or projects associated with each phase.

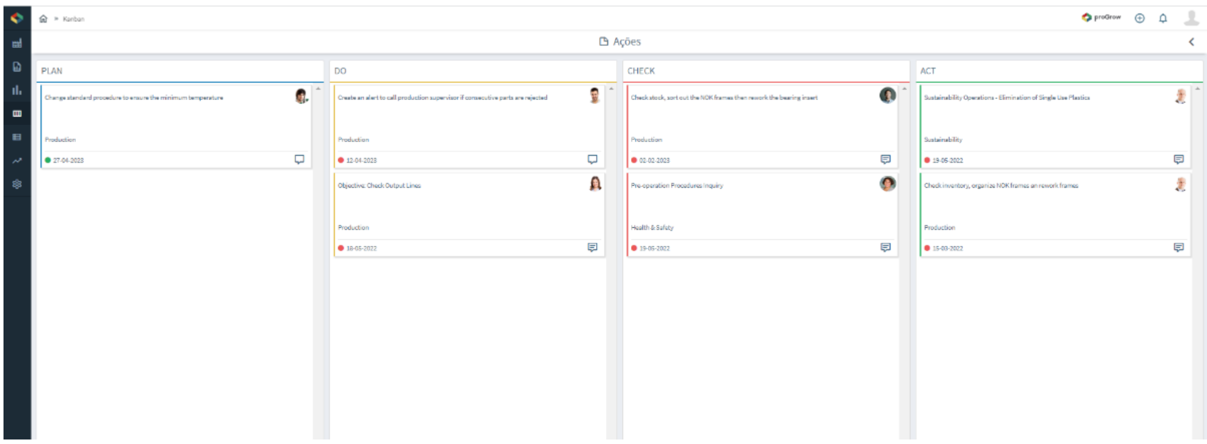

Figure 2.9 - "Kanban" interface example. Source: proGrow.

The "Tasks" module, which constitutes the fifth component of proGrow, facilitates the management of standard activities within a company, following the PDCA cycle. Tasks are defined by their associated context, responsible individuals and involved departments. Figure 2.10 presents an example of a checklist used for conducting a weekly 5S audit within this module.

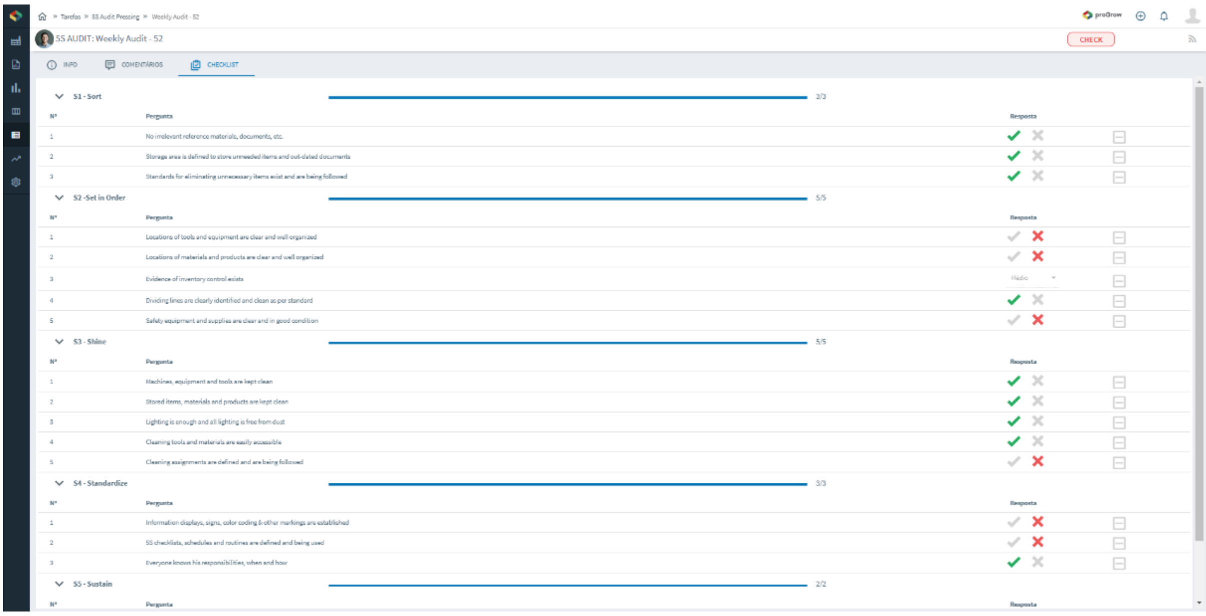

Figure 2.10 - "Tasks" interface example. Source: proGrow.

The "Improvement" module, which constitutes the final module of proGrow, is aligned with the philosophy of continuous improvement. Within this module, operators can suggest improvement opportunities, which are subsequently reviewed by responsible employees. Based on the review, the suggestions may be promoted to action or deemed not applicable if deemed unsuitable for implementation at that time. Actions and projects (which consist of a series of coordinated actions aimed at a common objective), are managed in accordance with the PDCA cycle. It is also possible to associate performance indicators, whether entered manually or automatically, with each action or project, enabling monitoring of their progress and evaluation of their impact. An example of KPI monitoring is illustrated in figure 2.11.

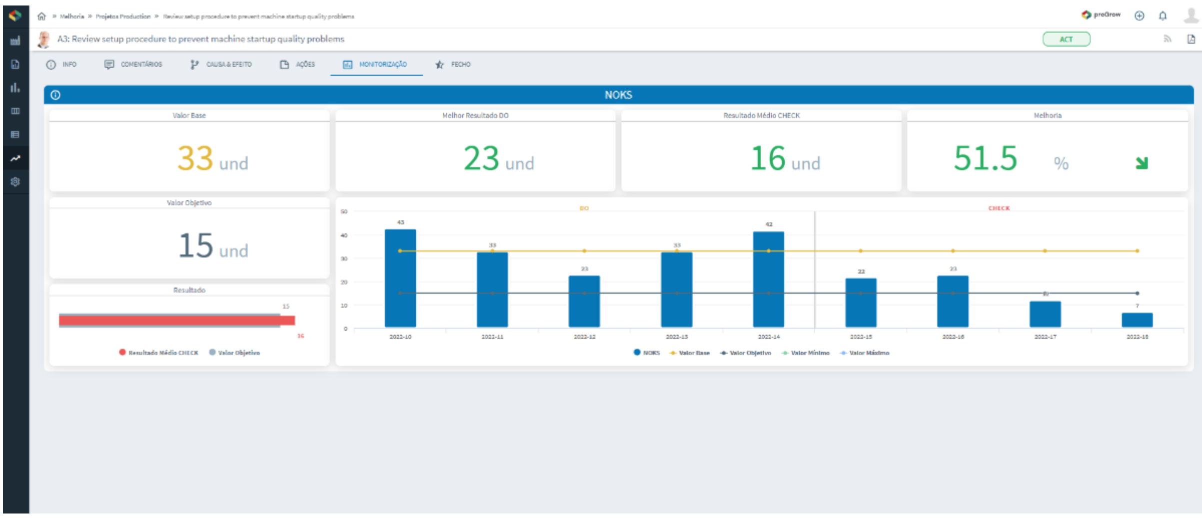

Figure 2.11 - "Improvement" interface example. Source: proGrow.

The adoption of a platform with the aforementioned characteristics can yield significant benefits across various areas. In the administrative domain, it has been demonstrated in proGrow's history that human labour can be reduced by 50% to 100% through the generation of performance indicator reports and streamlined management of continuous improvement initiatives, resulting in tangible savings. Additionally, the digitalization of continuous improvement processes facilitates an increase in the number of improvement projects and actions within the company, leading to qualitative and quantitative gains ranging from 50% to 100% according to proGrow's historical data. Furthermore, in terms of operational efficiency, the implementation of real-time performance indicators, as demonstrated by proGrow's history, can result in an anticipated increase in operational efficiency ranging from 15% to 30%. These performance indicators enable more informed decision-making, thereby contributing to improved operational performance.

2.6 Change Management

Inevitably, change is an essential component for an organization to evolve. Embracing change enables a company to confront the competitiveness of the market, adapt to external factors, and persevere during an economic recession. According to Abudi (2017), change is a constant element among the most successful companies globally. In today's global economic climate, where consumers demand more, competition is fierce, and regulations are increasing, it is critical that organizations integrate a culture of change into their daily routines. This implementation of change, when executed correctly, should be accompanied by a forward-looking vision rather than just a present perspective (Abudi, 2017). Thus, the ability of an organization to remain open to change and implement improvements is a significant determinant of its success in both the short and long term. Similarly, individual change projects' success is determined by their short and long-term outcomes. Therefore, the subject of change management plays a critical role in a digital transition project, such as the research presented in this dissertation.

In light of research indicating that approximately 66% to 80% of organizational change efforts fail (Appelbaum et al., 2012), substantial endeavours have been undertaken to devise effective guidelines for change management. Despite the extensive body of literature on the subject, the eight-step model advanced by Kotter (1996) remains one of the most prominent and prosperous guides to organizational change. These eight steps are as follows:

1. Establish a sense of urgency;
2. Create a guiding coalition;
3. Develop a vision and strategy;
4. Communicate the change vision;
5. Empower broad-based action;
6. Generate short-term wins;
7. Consolidate gains and produce more change;
8. Anchor new approaches in the corporate culture.

To start the change process, the initial step is to cultivate a sense of urgency via communication and backing from upper management (Kotter, 1996). Organizations may adopt various techniques to achieve this, including enlisting external sources such as consultants (Armenakis et al., 1993) or relying on an in-house project team. Oakland and Tanner (2007) have identified several drivers for change, which can be categorized into external and internal factors. External drivers comprise customer requirements, market competition, and regulatory demands, whereas internal drivers include enhancing efficiency and improving product and service quality. Nonetheless, Oakland and Tanner (2007) contend that internal drivers are often an offshoot of external drivers.

The second step in the change process acknowledges the inadequacy of an individual in single-handedly leading and managing a company's transformation (Armenakis et al., 1993). Thus, Kotter (1996) regards the creation of a guiding coalition as a critical step in which individuals possessing power, influence, and energy are willing to spearhead the change initiative. According to Kotter (1996), this coalition should encompass individuals with hierarchical authority within the organization, so those who oppose the initiatives cannot obstruct them; individuals with credibility and experience within the company, ensuring that all viewpoints are substantiated and represented, and the resulting actions are respected by all stakeholders; and individuals with leadership skills who can effectively oversee the change process. In line with Kotter's third and fourth steps, this team is accountable for developing a "clear and appropriate vision" and devising a strategy that caters to the organization's requirements and constraints, while effectively communicating it to other stakeholders. Without a far-sighted vision, change goals may easily translate into an incoherent list of projects that are incompatible and confusing, ultimately steering the organization towards unfavourable outcomes (Kotter, 1996).

The fifth step is crucial because it extends beyond communication, which cannot address all of the issues and challenges the team will experience during the process. Structures, skills, systems, and supervisors are the four main roadblocks listed by Kotter (1996). In order to help the work groups managing the ongoing change process deal with some of the difficulties they may face, some autonomy and decision-making power should be given to them in this step.

Kotter (1996) posited that the final two stages of the change management process necessitate the establishment of a more adaptable organizational culture, which is oriented towards the future and aimed at mitigating the occurrence of setbacks in the implementation of changes while instilling a culture of change within the organization. The integration of sustainable practices into an organization's modus operandi requires their assimilation by all individuals who occupy leadership positions throughout and following the change. It is crucial that these individuals comprehend and adhere to the cultural norms and practices underlying the change in order to ensure its continuity, while simultaneously demonstrating to those involved the performance enhancements resulting from the implementation of the change.

3 Case Study at Automotive Industry

In this case study, the digitization project of the shop floor is developed in client company 1. Chapter 3 first explores the company's initial situation, particularly focusing on its digital maturity, which is intended to be the main focus of the case study. After identifying the problem, the proGrow platform is implemented, along with a new digital information flow, in addition to digitized continuous improvement initiatives. At the end of the chapter, the impact caused by the solution is addressed in relation to the previously reported problem.

3.1 Current situation AS-IS

In this sub-chapter, a brief presentation of the organisational reality of the client company 1 is made, in order to allow an understanding of the procedures, processes and respective equipment used in the company's production cycle, as well as to appreciate the company's technological maturity. As such, the productive flow of the factory is presented, as well as the production data collection process, namely the production register and performance indicators. Additionally, the identification of the problems present on the shop floor and the recognition of the needs regarding their digitalisation is carried out, for which a solution is to be presented and implemented. It should be noted that the company has other sectors and equipment not referenced in this dissertation since only those that are relevant to the scope of the project presented are mentioned.

3.1.1 Production workflow

The client company subdivides its production activity into three distinct areas: the plastic injection area (42 machines), the metallisation area (4 machines) and the assembly area (53 production lines). The production process is divided into 3 shifts per day, 5 days a week. Figure 3.1 illustrate the sequence of the production process in the client company.

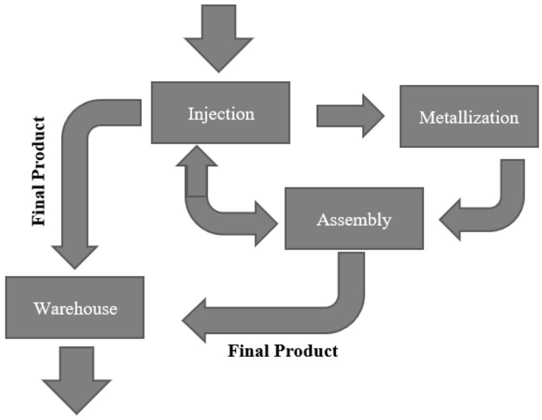

Figure 3.1 - Sequence of the production process in the client company.

The plastic injection area, metallisation area, mould maintenance area, and raw materials warehouse are situated in the same factory unit. From here, all the necessary components (already injected plastic materials, metallised materials, screws, washers, circuits, among others) are forwarded to factory unit number 2, as well as some orders that have been fulfilled directly to the finished product warehouse.

The raw material of the client company is based on thermoplastic synthetic polymers. The supply of polymers to the machines is ensured through a vacuum granulate transportation system complemented by 54 greenhouses, which heat and humidity the material prior to injection. Subsequently, it is forced under pressure to flow into the mould that will be filled, cooling the material due to heat exchanges with the moulding surfaces. Finally, and after the complete cooling period, the moulding process is concluded with the extraction of the moulding. After injection, the parts to be metallised are introduced into a vacuum chamber to receive the discharge of aluminium vapour on the surface. If they do not undergo the metallisation process, the parts are sent to the assembly section or directly to the finished product warehouse.

Factory unit number 2 is composed by the assembly sector, mould sector and a small material supply warehouse. This unit manufactures the final product for the customer, assembling the parts so that they can later be sent to the injection sector to be finished or, if finished, they are sent directly to the finished product warehouse. The layout of the injection/metallisation area is shown in figure A-1 of appendix A.

In addition to these areas, there is also the logistics and administrative area, making a total of 3000 m^2.

For the initial stage of this project, the focus will be exclusively on the production processes of injection and metallisation. Consequently, this thesis will solely cover these area.

3.1.2 Collecting/recording data on the shop floor

- **Shop Floor Management Systems**

For the entire production and logistics process, the client company uses systems such as SAP MES (Manufacturing Execution System) and SAP EWM (Extended Warehouse Management), integrated into the company's SAP ERP (Enterprise Resource Planning) software.

Traditionally the ERP can share production orders to the MES, as well as manufacturing and packaging instructions. On the other hand, the MES shares with the ERP the data about the production on the shop floor. The EWM, in turn, processes the entire movement of products and manages the warehouse stock. The online feedback about the respective production status of an order takes place from SAP MES and SAP EWM in the SAP ERP system. For this purpose, all operational data is recorded directly at the employee terminals and fed online into the SAP systems. Via the SAP standard interface, stocks are kept in the current state.

On the shop floor, operators manage production via POD (Production Operator Dashboard), an MES interface that allows them to control and enter data on manufacturing orders, as well as justify equipment stoppages. Figure B-1 in appendix B illustrates the POD interface.

Regarding equipment stoppages, these can be of 14 types: 5 planned stoppages and 9 unplanned stoppages, as shown in table 3.1.

Table 3.1 - List of reasons for stoppage, recorded at the client company.

Unplanned Stoppages	Planned Stoppages
Breakdown analysis	Setup
Settings	Planned maintenance
Machine/peripherals breakdown	Tests
Mould maintenance	Break
Industrial maintenance	No order
Operator shortage	
Lack of packaging	
Material shortage	
Raw material shortage	

When an equipment suffers an unplanned stop, it is declared in the POD by the operator. The equipment and consequently the line that is stopped (if this is the case, the alert will be red) or that is not stopped but needs intervention (the alert will be yellow) is identified on a TV set on the shop floor. This television is shown in figure 3.2.

Figure 3.2 - TV that indicates the state of the equipment.

After going to the line, the shift manager identifies the type of intervention needed and alerts the respective technical area. There are a combined total of 6 mould maintenance technicians, 9 industrial maintenance technicians, and 27 technicians dedicated to continuous production monitoring (robotics and peripherals, process parameter adjustments, mould changes), evenly distributed across the three shifts.

- **KPIs and continuous improvement initiatives**

Until earlier this year, the shop floor had no visibility over the data that was recorded about downtimes. This data served no purpose within the digital system other than to be queried. In this way, the client company was making the mistake of recording and capturing data as an end that serves no clear purpose. However, at the beginning of this year, a new KPI tracking methodology was defined and thus data from the company's information systems became visible on the factory dashboards (traditional method), in the form of weekly reports that include analyses of downtime by type of stop, related to indicators such as the percentage of downtime, MTBF and MTTR, as shown in figures 3.3 and 3.4. This process is still quite time consuming and subject to errors related to data processing. The process of distinguishing weeks in excel to generate reports per week is quite manual. On the other hand, these tools compromise the centralisation, flow and transparency of information, making it difficult to monitor processes. The way the indicators are presented include little information regarding each piece of equipment, shifts or maintenance costs. Despite this advance in data transparency, the TPM tool exercised still needs to be developed to raise the level of results and involvement of those responsible for the different areas.

Figure 3.3 - Shop floor control panel.

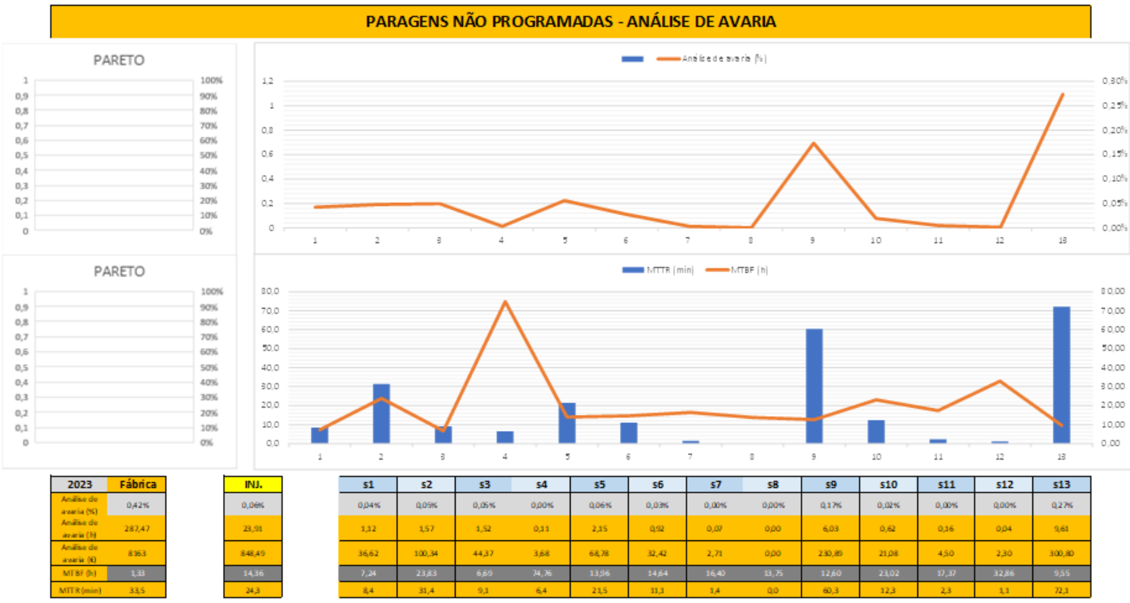

Figure 3.4 - Example of the analysis of indicators used on the shop floor.

The label management reinforces the communication method between production and maintenance, where equipment failures are identified by technicians or shift supervisors, and the subsequent handling of these failures is overseen by the maintenance department (red label) or production department (blue label), depending on the type of intervention required. Once assigned to the respective area, the issue is then resolved and retained for one week to verify and ensure effective problem resolution. The method of labels can be seen in figure C-1 of appendix C. Despite the visibility of this process, there is no alert system in place for label management (depending heavily on individual responsibility).

Also included in this dashboard are labels and records of corrective/preventive actions. Regarding these records, these are recorded on paper, by any employee and the general intention is to reduce unplanned downtime. In this sheet, the problem to be treated is presented, possible causes and actions that should be implemented, as well as a PDCA cycle to monitor the treatment of the respective action. As can be seen in figure 3.5, it is not a very intuitive record, as there are missing fields, and employees have no control over the dates of the respective PDCA cycle. On the other hand, this presentation of the actions can get quite confusing and take much longer to fill in than if it were a digital process.

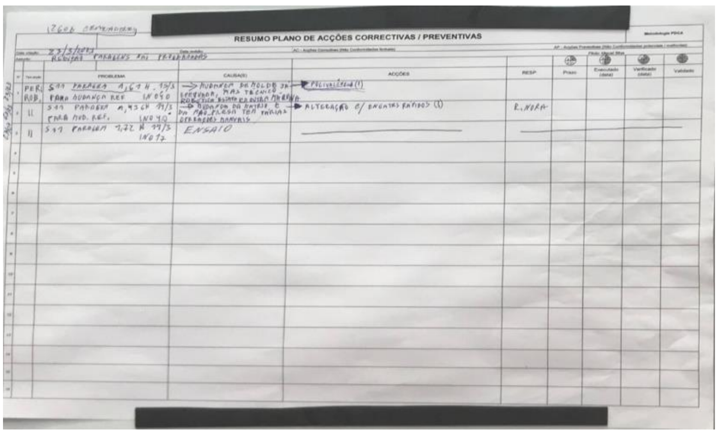

Figure 3.5 - Corrective/preventive action plan in the dashboard.

These traceability methods described above are rather rudimentary and manual, which highlights the lack of digitalisation of most of the documents essential to the aforementioned production, contributing to the low level of digital maturity of the organisation.

Regarding plans for continuous improvement meetings, they are currently being scheduled to take place on a weekly basis. These meetings will involve the production manager responsible for each process, the manager of the area experiencing the most impactful stoppages, and one maintenance technician. However, only 2 meetings have been held yet due to the limited availability of detailed data. Efforts are being made to implement a more intuitive problem monitoring system.

3.1.3 Problem presentation

Through a detailed analysis of the operations performed in the production and information recording area, several problems were identified and consequently, opportunities for improvement were gathered.

Initially, it was identified that communication between the production and maintenance departments was still inefficient despite the implemented measures. As such, it is recommended to establish a process that aims to reduce the response time from the moment a problem is detected to when it is reported and subsequently resolved. Furthermore, it should be noted that the client company has only recently begun schedule weekly meetings with maintenance, production, and continuous improvement personnel to analyse collected data and develop plans and actions for improvement.

Despite the efforts made, not all the necessary information to establish a comprehensive history of breakdowns and enable effective preventive maintenance planning has been made available, thus impacting the visibility of the collected downtime data. It is imperative to include data regarding each machine, shift, and the respective downtime costs in the control panels, and establish a standard analysis of the relevant indicators. On the other hand, it is expected that greater visibility of the indicators would promote greater dedication to the process of reducing downtime on the part of employees, as they would have a more delineated goal to achieve and also a little more control over their work.

Regarding collaboration and continuous improvement initiatives, the dashboard provides a manually recorded action plan which results in a lack of consistency in evaluation across sectors and initiatives. In general, the evaluation of a process is only done according to the production fulfilment plans, not paying much attention to the availability parameter.

3.2 Description of the TO-BE solution

After presenting the initial AS-IS state of the client company's factory floor, this subchapter aims to present the designed and implemented solution based on the previously gathered information.

The proGrow platform will provide modules for Reports, KPIs and Continuous Improvement. Platform users will have the opportunity to access and analyse reports and KPIs, and if necessary, implement an action/improvement project related to them. All these steps will be performed within the platform, making it a highly useful collaboration tool. The combination of KPIs and improvement actions will enable monitoring the impact of each improvement action. The solution is presented in the form of a diagram in figure 3.6.

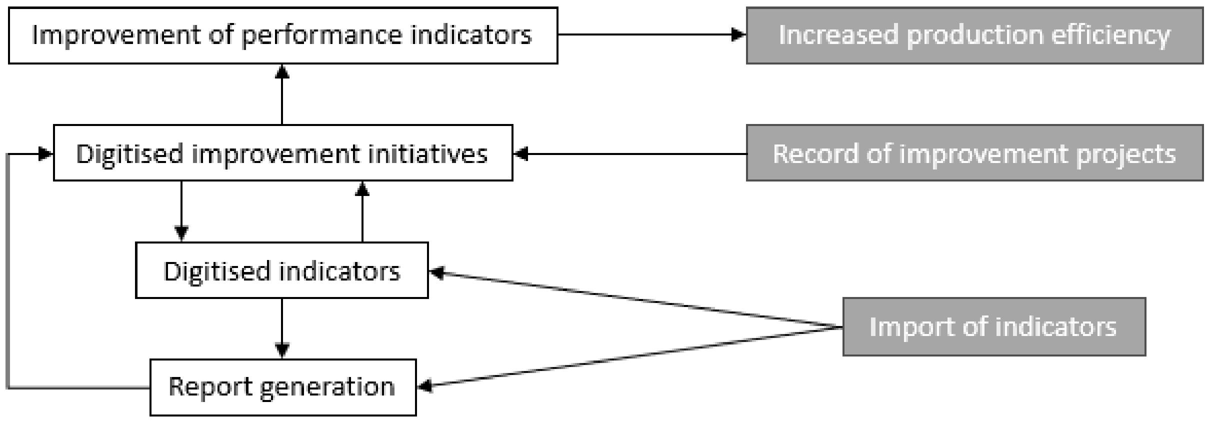

Figure 3.6 - Flow of the proposed solution, with the implementation of proGrow.

With the import of indicators into the platform (in this case, through manual importation), proGrow automatically generates the desired reports with the intended analyses. The next step is to examine these reports in order to gather relevant information for implementing an improvement action. This action, also entered into the platform, will have a positive effect on production indicators and, consequently, on production efficiency.

3.2.1 Data validation

The importance of validating acquired information and data lies in the fact that, before envisioning, designing, and implementing a solution, it is necessary to understand the company's objectives and the desired outcomes expected from the project, as well as the concerns, requirements, and needs for designing the solution. Therefore, the purpose of data validation was to validate the project's objectives and progress so that, in collaboration with the continuous improvement manager, we could arrive at the optimal and intended solution desired by the company. The validation of the data took various forms throughout the project, including:

- Visits to the client company's factory floor;
- Project kick-off meeting with the project manager;
- Weekly project status meetings conducted with the project manager until the delivery of the fully implemented final solution.

The scope of the project was defined from its inception, establishing clear stages and milestones to be delivered throughout the project timeline. These pillars contributed to the elimination of future obstacles through the proactive assignment of responsibilities and incremental milestones.

In order to facilitate the initiation of platform usage, training sessions were planned and documentation was created containing procedural instructions for importing improvement initiatives into the platform.

3.2.2 New Information Flow

In order to implement a TPM strategy on the factory floor, it was necessary to establish an information flow capable of quickly alerting to the most critical issues within the factory at any given moment and making them visible to all operators. To achieve this, the "Reports" and "KPIs" modules of proGrow were utilized.

By utilizing production data from the company's management systems, it is possible to create a manual import file with a predefined structure to be submitted on the platform, as depicted in figure 3.7. With each update of the manual indicators, the reports will be automatically refreshed.

G	H	I	J	K	L	M	N	O	P	Q	R
ressource	shift	Data	reason_code_Des	scheduled_downtime	unscheduled_downtim	setup	area	cw	rate_cc_paragem	custos_paragem_nao ogramada	dia_da_semana
PT_ME001	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	MET	1	36.70	0.00	7
PT_IN001	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	3	INJ	1	40.55	0.00	7
PT_IN002	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	3	INJ	1	38.65	0.00	7
PT_IN003	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	59.30	0.00	7
PT_IN004	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	34.43	0.00	7
PT_IN005	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	3	INJ	1	63.30	0.00	7
PT_IN007	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	26.33	0.00	7
PT_IN008	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	3	INJ	1	64.96	0.00	7
PT_IN009	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	25.28	0.00	7
PT_IN010	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	49.34	0.00	7
PT_IN011	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	49.34	0.00	7
PT_IN012	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	117.15	0.00	7
PT_IN015	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	117.15	0.00	7
PT_IN016	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	26.05	0.00	7
PT_IN017	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	26.05	0.00	7
PT_IN018	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	89.54	0.00	7
PT_IN019	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	89.54	0.00	7
PT_IN021	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	29.44	0.00	7
PT_IN022	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	26.19	0.00	7
PT_IN024	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	3	INJ	1	27.96	0.00	7
PT_IN025	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN026	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN027	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN028	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN029	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN030	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_IN033	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	30.68	0.00	7
PT_IN034	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	32.44	0.00	7
PT_IN037	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	33.67	0.00	7
PT_IN038	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	26.97	0.00	7
PT_IN039	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	38.35	0.00	7
PT_IN040	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.37	0.00	7
PT_IN041	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	34.84	0.00	7
PT_IN043	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	25.28	0.00	7
PT_IN044	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	27.96	0.00	7
PT_ME004	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	MET	1	36.70	0.00	7
PT_ME003	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	MET	1	43.30	0.00	7
PT_ME002	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	MET	1	36.70	0.00	7
PT_AS052	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	0	INJ-AS	1	26.22	0.00	7
PT_IN045	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	25.28	0.00	7
PT_AS054	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	0	INJ-AS	1	26.22	0.00	7
PT_IN046	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	38.35	0.00	7
PT_IN047	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	2	INJ	1	35.22	0.00	7
PT_IN048	Shift 1	2023-01-01	Sem encomendas	28800.00	0.00	1	INJ	1	26.98	0.00	7

Figure 3.7 - File for manual data import.

After submitting the data on the platform, proGrow is configured to automatically perform calculations for the indicators that we want to monitor. The most relevant indicators for this project are: unplanned downtime, costs associated with unplanned downtime, MTTR, MTBF, and the percentage of unplanned downtime, which is calculated by dividing the unplanned downtime by the net available time. The table D-1 in appendix D presents a document drafted during the project development, which gathers the client company's specifications regarding KPIs, their respective data sources and their aggregating calculation formulas.

However, as previously concluded, the way the reports were presented only showed how failures progressed over weeks, without focusing on or alerting to any specific issues. The information served only for reference and did not generate any value. This project includes a new, much more intuitive and efficient analysis methodology by utilizing the "Reports" and "KPIs" modules of proGrow. The "Reports" module also enables collaboration among users, as they can comment on the report, linking these comments to the reports for future reference. An overview of the proposed weekly reports can be seen in figure 3.8, providing an example of the section on unplanned downtime related to breakdown analyses, specifically for week 6 of the current year.

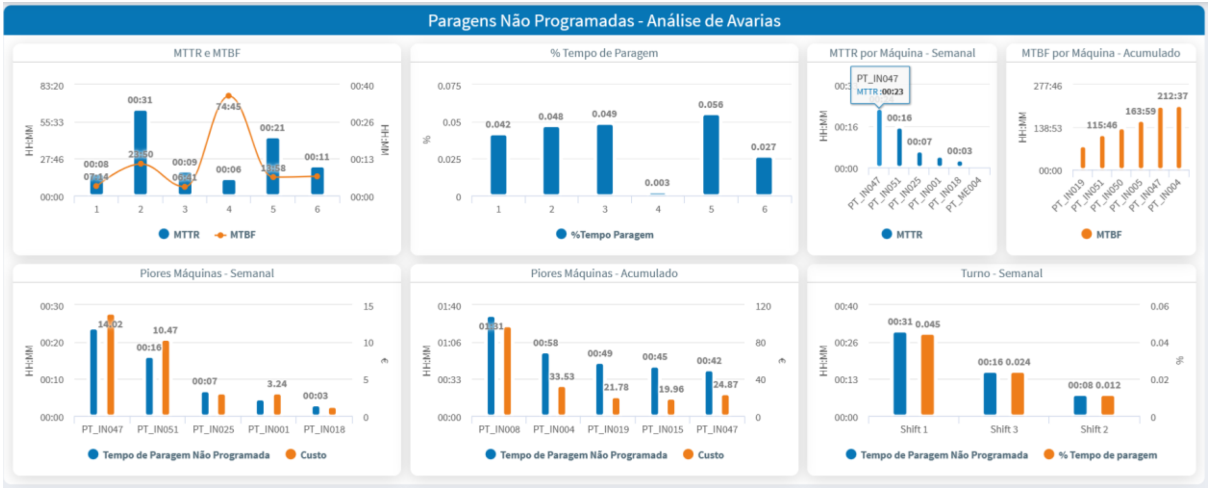

Figure 3.8 - Proposed analyses to be included in the reports.

These reports include five additional analyses compared to the previous ones. For each type of downtime, it is important to analyse the worst-performing machines in terms of downtime cost and duration, both for the current week and the cumulative period since the beginning of the year. Additionally, analysis of downtime by shift and MTTR/MTBF by machine has been included. With this template, it is possible to have a broader view of the most urgent issues to address and explore potential preventive actions to reduce future corrective measures, which incur higher costs and may jeopardize customer deliveries. It is important to consider the costs associated with the worst-performing machines when deciding on a solution. When the delivery of the final product can be affected by equipment downtime, and consequently, the production line, downtime duration should be the sole indicator monitored. However, when delivery is not affected, it is not advisable to rely solely on downtime duration. The relationship between this indicator and the cost of downtime is not always directly proportional; it depends on factors such as the number of personnel operating on the equipment stop line or the monitoring cost of each machine.

As the project progresses, it is expected that various indicators will be analysed to draw conclusions. For this dissertation project, the focus was on the MTTR indicator. In the client company, the MTTR of an equipment is calculated by dividing the unplanned downtime by the number of interventions performed on it for each type of downtime. The unplanned downtime is measured from the moment the machine fails until it resumes its normal operation. However, not all of this time is utilized for repairing the equipment. The average time it takes from the equipment stoppage until the repair process begins, known as Mean Time to Assist (MTTA), is often "hidden" within the MTTR. This indicator assesses the responsiveness of support teams to downtime on the factory floor. Specifically, in the analysis of MTTR per week for each type of downtime, some spikes were observed that should capture the attention of continuous improvement managers, as depicted in figure 3.9. We will examine the case of "machine/peripheral breakdown" downtime type in week 9 in more detail.

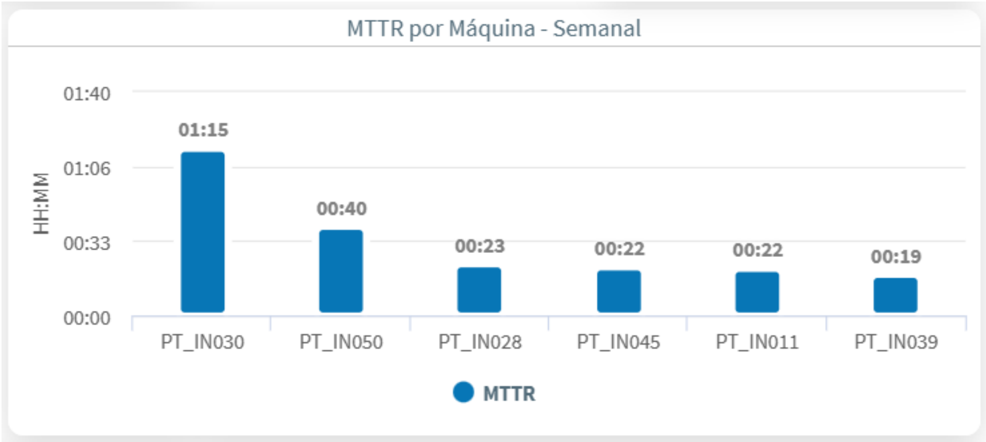

Figure 3.9 - MTTR per machine (week 9 and type of stop "machine/peripheral breakdown").

For the same type of downtime, it should not be very common to observe so many spikes in this KPI, except for a few exceptions. However, with this weekly analysis focused solely on equipment, it is not possible to draw any conclusions regarding the influence of MTTA on this indicator.

By utilizing the "KPIs" module of proGrow, it is possible to conduct a more detailed analysis of the collected data using filters. Continuing with week 9 and the "machine/peripheral breakdown" downtime type, was conducted some research in this module, as shown in figure 3.10.

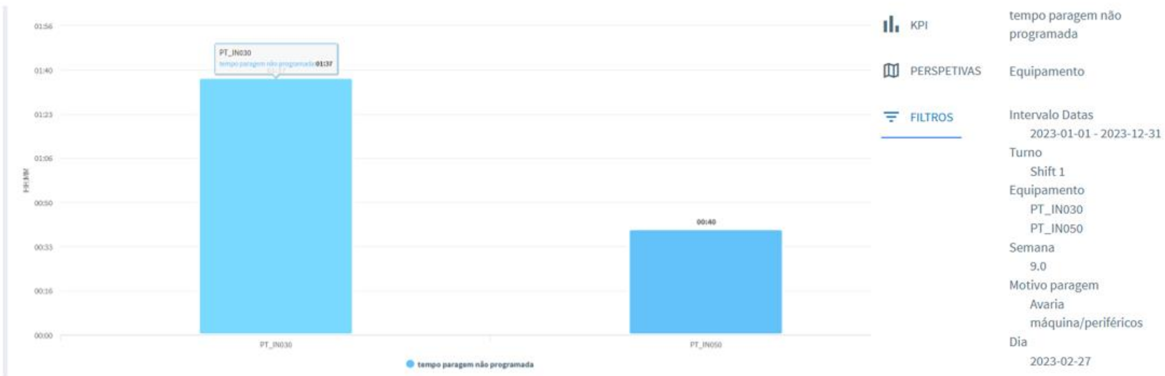

Figure 3.10 – [“KPIs” module] Analysis of unscheduled downtime.

With the research conducted during week 9, specifically for that type of downtime and applying filters to the analysed equipment (IN030 and IN050), we examined the days and shifts of that week. It was observed that the IN030 equipment experienced two instances of this type of downtime, with one of them coinciding with the same day and shift as the downtime of the IN050 machine. Furthermore, the downtime duration for the IN030 machine on that day was substantially higher compared to the following day. However, it is still unclear whether the MTTA factor has an impact here, and if so, the reason for its significant duration.

To reach a conclusion, the collected/analysed data was validated with maintenance technicians and line supervisors responsible for the respective equipment. According to their feedback, this and many other similar incidents are attributed to a lack of available specialized technicians to address simultaneous downtimes.

Considering the overall panorama of the factory floor, there are always 9 technicians available for continuous production support. However, the number of specialized technicians varies by area. Typically, there are 4 technicians available per shift who specialize in adjusting process parameters on the equipment (such as temperature, pressure, and injection flow), 1 technician specializing in robotics, and 4 technicians skilled in mould changeovers. In this specific case study, the line supervisor mentioned that while a downtime occurred on the IN050 equipment due to an intervention required on a robot, a downtime also occurred on the IN030 equipment for a mould changeover that required adjustment in the robot, and only the robotics technician was proficient in that process. Therefore, while the technician was attending to one machine, the other remained idle not due to a lack of available technicians but rather due to a shortage of technicians specialized in that area. The line supervisor highlighted that this situation applies to other types of downtime as well.

In this specific case, the problem arises when no records are made regarding indicators that exceed the defined threshold, meaning there is no historical data about what happened on the factory floor. While the operators are aware of the issues, the lack of communication and supporting data to validate the problems results in these details going unnoticed by the management, and no action is taken to address them. Data transparency is limited, and as a result, the MTTR and consequently the MTBF values are higher than expected.

One of the objectives of proGrow, through the implementation of the "Reports", "KPIs", and "Improvement" modules (presented subsequently), is to promote communication between departments and between the factory floor and the continuous improvement teams, enabling them to analyse data together using more personalized and objective reports and proceed with improvement projects and actions.

3.2.3 “Improvement” Module

After analysing the aforementioned situation, it was necessary to take measures and implement an improvement action with the assistance of proGrow.

This preventive improvement action involved planning an intensive and long-term training program for the 27 technicians responsible for continuous production support. Based on the on-the-job training method, this action will enable a technician to acquire competence in another specialized area and perform interventions under the supervision of a specialized technician. The progress of each technician in each intervention area will be monitored monthly until all technicians achieve versatility and, consequently, increase factory productivity. If all 9 technicians per shift master all intervention areas, the probability of equipment waiting for intervention will substantially decrease.

Using mobile devices or computers, the platform user (in this case, the responsible person for continuous improvement in the factory) enters the initial information related to the action (topic, problem description, objectives, and team) in the corresponding team area of the “Improvement” module, as shown in figure 3.11. As part of this project, an action was added in the maintenance area. The team responsible for this action will consist of line supervisors and the continuous improvement manager.

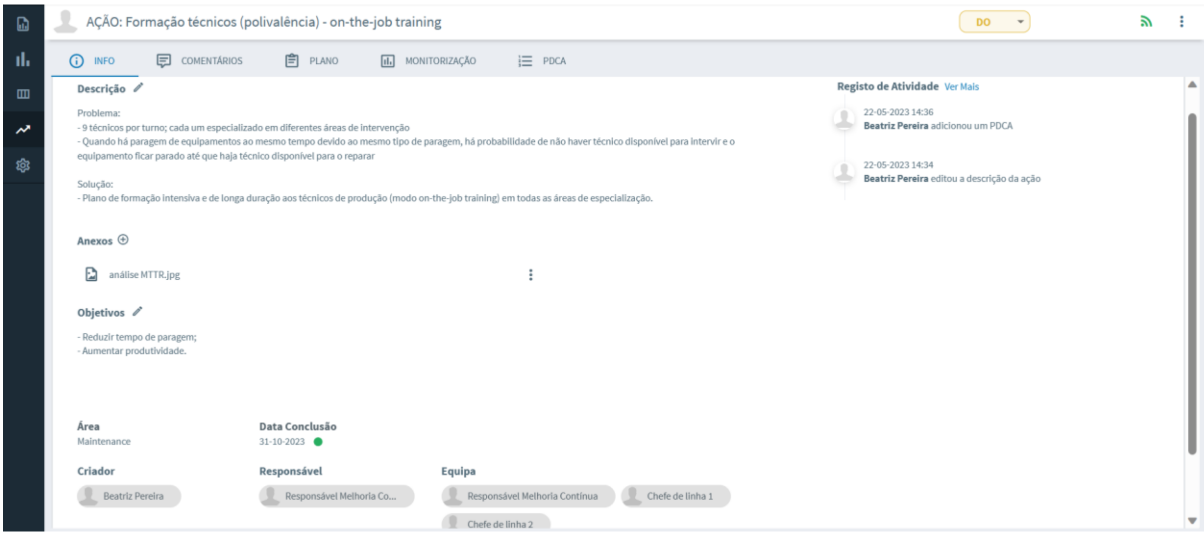

Figure 3.11 - [“Improvement” Module] Initial information about the action.

In the section related to the PDCA plan, it is possible to define dates for each phase. As each phase is completed, its completion date can be visualized in this section. The objectives for each stage of the cycle are as follows:

- **Plan**: Planning the solution with line supervisors and the continuous improvement manager;
- **Do**: The target is to complete the regular implementation testing process in the factory by the end of September;
- **Check**: While this stage is included in the Do phase as well since we monitor the progress of each technician in each specialization area throughout the training months, mid-October is estimated as the time to assess the overall/final impact of this action and evaluate its effectiveness based on the achieved results;
- **Act**: Evaluate the solution, standardize to make it recurrent on the factory floor, and take measures according to the obtained results.

Regarding the estimated savings from implementing this project, they can also be included in this section of the proGrow’s “Improvement” module, as shown in figure 3.12.

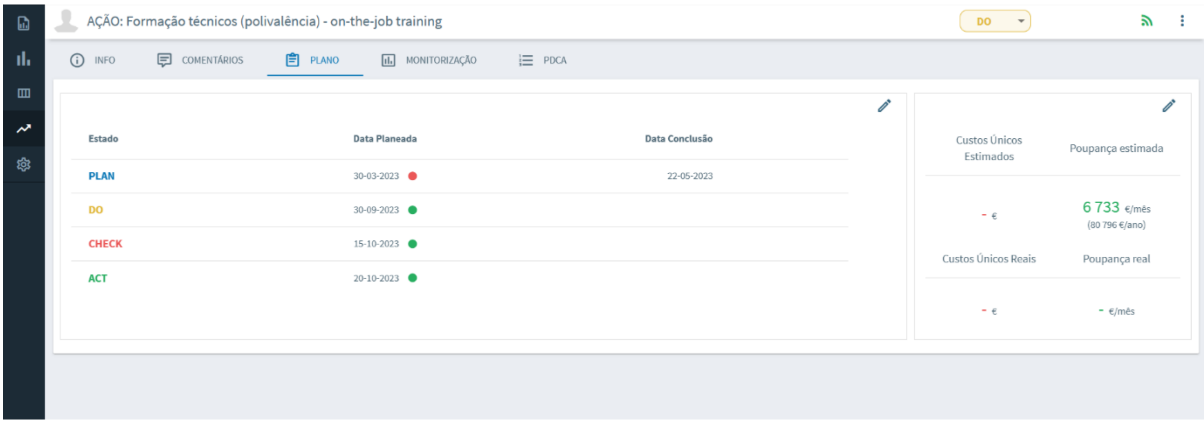

Figure 3.12 - [“Improvement” Module] Section related to the PDCA cycle and cost and savings analysis.

Depending on the type of machine, the cost per stoppage can range from €15 to €150 per hour. If we estimate 100€/h and anticipate a reduction of 4 hours per week in downtime, it is expected to save around €20,800 per year. Additionally, in terms of productivity, it will not be necessary to have as many technicians working per shift, allowing for a reduction of 1 technician per each of the 3 shifts, resulting in a yield of €20,000 per technician per year, which amounts to a savings of €60,000. These technicians will perform other functions within the company. At the end of the training and project validation period, a monthly saving of around €6,733 is expected, equivalent to €80,800 per year.

In the monitoring section, a manual KPI, MTTA, was introduced, which is not included in the indicators monitored by the client company. This indicator, measured from the time the machine stops (which was already recorded) until the moment the technician begins their intervention (currently recorded without inclusion in the company's management systems), will be monitored on a weekly basis to evaluate its evolution over time. As previously estimated, a reduction of 4 hours per week in assistance time is expected, which in turn leads to a decrease in MTTA. This reduction is based not only on achieving the technicians' versatility but also on its visibility through monitoring, which motivates all stakeholders to expedite the processes.

This is just one example of the utilization of the proGrow's "Improvement" module. Its main objective is to enable line supervisors, maintenance technicians, and continuous improvement managers to use it collaboratively as a communication and collaboration tool. This way, they can suggest and guide actions/projects effectively. Through this module, users can communicate among themselves to solve a problem and receive notifications of all activities carried out in the project or action to which they are allocated.

3.2.4 Impact of the solution

The solution presented in this chapter has a beneficial impact on various dimensions of the client company's operations. The improvement achieved through the implementation of this project can be measured by assessing certain performance indicators of the company. It should be noted that the values of the indicators presented throughout this section are estimates resulting from an effort to gauge the impact from the very beginning of the implementation, but they already have a very positive perspective.

Reducing reaction time is crucial in the automotive industry, where there is close integration between suppliers and automobile manufacturers and minimal tolerance for delays and defects. By including new analyses in the reports, it becomes possible to quickly identify bottlenecks and inefficiencies, optimize processes, and increase their visibility. Visualizing these indicators leads to:

1. Increased competitiveness among employees and motivation to achieve goals;
2. More effective decision-making by management;
3. Improved responsiveness of operational teams.

On the other hand, continuous improvement is one area where the solution's impact is strongly felt, with savings from these initiatives increasing by 15% to 20%. Digitizing and centralizing continuous improvement tools result in:

1. A higher number of executed improvement initiatives;
2. Enhanced quality and rigor of improvement initiatives;
3. Encouragement of interdepartmental collaboration, between production and maintenance;
4. Utilization and replication of best practices.

Based on the analysis of the reports, a problem was identified on the shop floor, and a solution was implemented using the improvement module. The estimated downtime is expected to be reduced by 4 hours per week, thanks to the training plan aimed at achieving versatility among technicians. As a result, the MTTR is expected to decrease by approximately 4% (estimation) from its previous value, demonstrating a reduction in costs and a subsequent increase in shop floor productivity. On the other hand, there is a tendency for availability to increase by 0.2%. These results only capture a fraction of the potential offered by this solution. Over the long term, it will be feasible to identify additional issues on the shop floor and take appropriate actions, thereby further enhancing availability.

In conclusion, communication and collaboration among the client's internal departments have been improved through the standardization of data records and continuous improvement initiatives. The maintenance managers now have the necessary information to immediately address the most critical and prioritized issues, enhancing an improvement in OEE.

4 Case Study at Furniture Industry

In this chapter, the case study at client company 2 is presented. Firstly, the entire production process is addressed to understand the company's digital maturity level. Subsequently, improvement aspects that can be implemented through the use of proGrow are identified. All phases of the solution implementation process are presented, along with the consequent impact on the production process.

4.1 Current situation AS-IS

In this subchapter, a brief presentation of the organizational reality of client company 2 is provided in order to enable understanding of the processes used in the company's production cycle and to appreciate its technological maturity. Thus, the production flow of the factory is presented, as well as the production data collection process, including production records and performance indicators. Additionally, improvement actions are identified, and the needs related to the digitization of the shop floor are recognized, for which a solution is intended to be presented and implemented.

4.1.1 Production workflow

The manufacturing process comprises multiple operations, and each product may undergo various stages within the factory. Figure 4.1 presents a comprehensive depiction of the entire production flow.

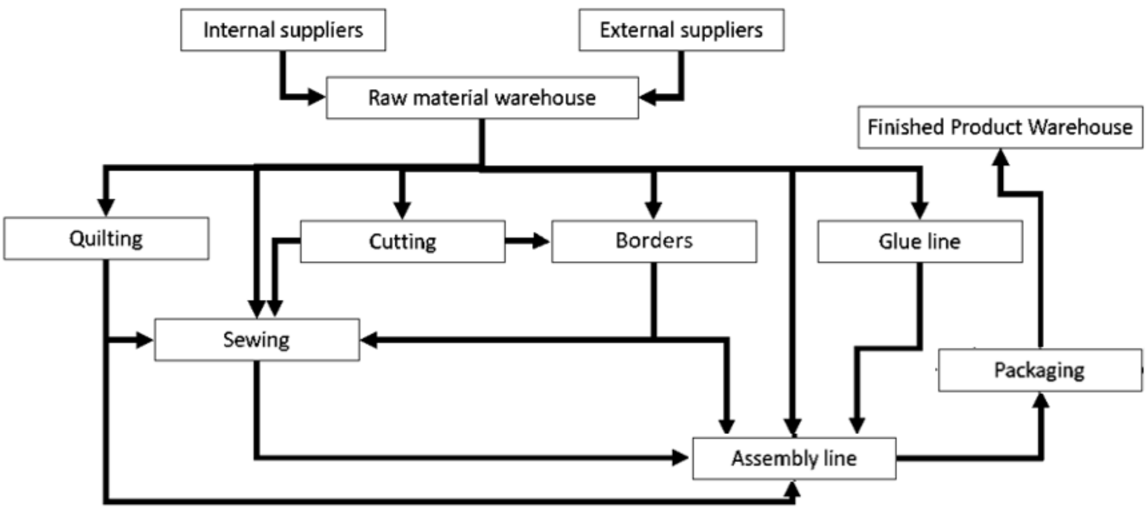

Figure 4.1 - Production process flow.

The cutting sector transforms/cuts the fabric rolls. It supplies two other sectors, borders and sewing.

The quilting sector is responsible for transforming fabric rolls, along with fiber, foam, TNT, cotton, and linen, into upper and lower mattress tops. This sector is divided into two sections: quilting 1 and quilting 2. In quilting 1, also known as multi-needle quilting, continuous quilting is performed. In quilting 2, also known as top-to-top quilting, the quilting is done top by top, resulting in a deep quilting effect. Depending on their destination, the mattress tops are either placed on pallets for shipment to the top dispatch area or loaded onto carts to be sent to the sewing sector.

The borders sector transforms the cut fabric rolls, along with fiber and TNT, into side panels. At the end of the process, the borders can either be sent to the sewing sector or directly dispatched.

In the sewing sector, the transformation of mattress tops and side panels into mattress covers (the assembly of one side panel with two mattress tops, i.e., the exterior of a mattress) takes place, as well as the production of components for making bags and headboards.

Although the spring production is also carried out in another factory within the Group and can be supplied through that means (i.e., directly from RMW to the glue line), there is also a spring production sector in this factory. Its sole supplier is RMW. In this sector, wire is transformed into springs, which are then forwarded to the glue line.

The glue line handles the transformation of foam and springs into foam boxes. A foam box consists of foam with a spring inside. Each model has specific requirements for foam and springs.

The assembly department is divided into three sections: CM1, CM2, and CM3. Assembly 1 consists of three lines (line 1, line 2, and line 3). This project will focus on this section (layout of CM1 is presented in figure 4.2). This department receives supplies from the sewing sector, another factory within the Group (for foam components), and RMW (for labels). The foam pallet is placed on the machine, and then the foam is inserted into the mattress cover. The mattress is compressed (to a specific height or the maximum allowed), and then it can be either horizontal, flat (referring to a non-rolled or folded mattress, similar to a mattress found in a household), or rolled. Five operators and one replenisher are required for this line. Two operators place the foam into the cover, the third operator closes the mattress and initiates the machine for compression and packaging. The remaining two team members prepare the packaging, whether it is rolled or flat, and arrange the mattresses on pallets for transportation to the finished goods warehouse. The replenisher is responsible for preparing the covers in the designated area and timely placing orders with RMW to ensure the necessary materials are available when required. The process of Line 1 is detailed in figure E-1 of appendix E.

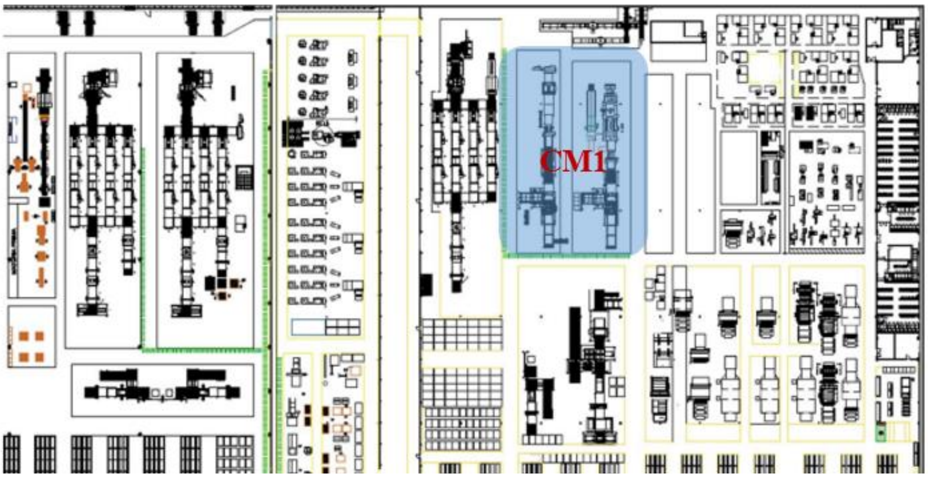

Figure 4.2 - Layout of assembly sector 1.

CM2 consists of lines 4, 5, 6, and 7. In these lines, the mattress is equipped with the traditional closure, where the piping (Debrum tapes) is applied at the junction of the mattress top and the side panel.

CM3 is responsible for the preparation of bases and headboards. The wood is pre-cut to the desired dimensions, which are supplied from another factory within the Group.

4.1.2 Collecting/recording data on the shop floor

- **Shop Floor Management Systems**

For the entire production process, the company uses ERP software to manage and enter production orders. For all production records, including downtime, types of downtime, quantities produced, and rejected quantities, an online report in Excel is used. The equipment operator enters all the information into this report during or after production. This process results in a time-consuming and manual recording flow, allowing for the inclusion of errors associated with the recorded information.

- **KPIs and continuous improvement initiatives**

Currently, at client company 2, the traditional model of manually generated visual boards is used for daily production and process control meetings. Excel reports are also generated for monitoring critical indicators. An example of a continuous improvement board currently used in the factory is presented in figure 4.3. These boards are analysed daily in meetings coordinated by the line managers.

Figure 4.3 - Example of current continuous improvement board.

These tools undermine the centralization, flow, and transparency of information, making it difficult to monitor processes. The decentralized nature of the process prevents regular overall improvements and creates barriers to communication and collaboration within the company, limiting knowledge sharing. Additionally, there is a significant amount of non-value-added work resulting from the manual generation of Excel reports.

The aforementioned traceability methods are quite rudimentary and manual, highlighting the lack of digitization of most essential documents related to the mentioned production, contributing to the organization's low level of digital maturity.

4.1.3 Problem presentation

Through a thorough analysis of the processes used in the production area and information recording, it was possible to gather improvement opportunities in order to advance towards the digitization process.

As observed, recording KPIs on each sector's board, due to its manual nature, is highly susceptible to errors. It is important to reduce the time spent on this task by automating it, thereby increasing the productivity and accuracy of the company.

On the other hand, there is a lack of visibility within the factory regarding the most pressing issues to address. An Excel report is used by the operator to record production, which is susceptible to errors during data entry. It is necessary to establish a more reliable connection between the data and its causes, enabling easier access to the information and identification of the most important factor to be studied and addressed, resulting in a quicker response from the teams to urgent matters.

Regarding improvement initiatives, each sector is responsible for implementing certain measures to enhance KPIs, leading to manual reporting. The A3 reports, widely used by the company to manage continuous improvement projects, are created in Excel, resulting in a time-consuming process. Additionally, the decentralized nature of the process prevents regular overall improvements and creates barriers to communication and collaboration within the company, limiting knowledge sharing. There are several improvement workflows throughout the organization's production cycle that demonstrate significant potential for digitization. By digitizing and streamlining their completion, reducing non-value-added activities, the analysis of the production process is facilitated.

proGrow emerges as a platform that enables the digitization of the shop floor in all its components providing five modules for this purpose: KPIs, Shopfloor, Reports, Kanban, and Improvement.

4.2 Description of the TO-BE solution

This section endeavours to present the devised and executed solution, derived from the preliminary assessment of the current state (AS-IS) of the factory floor within the client company. The solution has been formulated and implemented by utilizing the information gathered during the earlier data collection phase.

The solution presented in this subchapter is based on different stages. In the initial phase, project initiation meetings are conducted with the responsible individuals from the client company. Subsequently, the equipment connectivity stage is carried out, with shared responsibility between the technical teams of both proGrow and the client company. During this phase, a hands-off approach is adopted, focusing on supervision and establishing a communication bridge between the teams. Thirdly, the stages of visibility and transparency, involving configuration, implementation, and impact assessment, are areas of independent intervention, requiring a hands-on approach. The programming and deployment of the solution's modules, specifically the reports and factory floor page, were pivotal aspects of the undertaken work. Additionally, the development of new functionalities constituted additional, necessary, and tailored contributions, ensuring that the production registration flow in the platform aligns with the workflow utilized on the client company's factory floor.

4.2.1 Data validation

The initial focus of data validation is to understand the processes and implement strategies that involve all stakeholders. Only after grasping the initial situation can a solution be conceived and implemented. Throughout the project, several steps were taken to specify customer requirements and review the project's scope and objectives. Documenting the flow of production processes on the shop floor and assessing the digitalization needs of the shop floor became imperative. Understanding the production cycle on the shop floor and familiarizing oneself with the various departments of the company were important to ensure that the presented solution seamlessly integrates into the company's daily operations, causing minimal disruption to its procedures, guided by the principle of adapting the solution to the company.

In order to involve all stakeholders in the project and incorporate their suggestions, as well as validate the gathered information and project progress, several meetings were conducted. These took various forms throughout the project:

- Visits to the shop floor of the client company;
- Project kick-off meeting with project leaders and managers;
- Weekly project status meetings held with the project manager and the feedback team until the delivery of the fully implemented final solution.

The client company assembled a team responsible for managing the digital transformation, consisting of project leaders who oversaw the project's approval and overall direction, a maintenance team responsible for technical issues related to equipment signal mapping, and shop floor operators who contributed to evaluating the current situation and identifying potential improvements to be integrated into the implemented solution.

4.2.2 proLink

The service offered by proGrow is a web-based platform that can be accessed through various types of interfaces, including traditional computers with a web browser, tablets, or smartphones. The tool provided to the client aims to run the proGrow platform on a cloud infrastructure. The client does not manage or control the underlying cloud infrastructure behind the service, minimizing the involvement of the client's IT department. This solution is comparatively more cost-effective as it can be used in multiple locations through a single license. Updates are deployed on the server-side and reflected instantly in the client company's system. The same applies to maintenance and issue resolution, simplifying the process and reducing time and costs for both proGrow and the client.

The traditional solution employed by proGrow to integrate equipment data from client companies involved the utilization of IoT hardware provided by a proGrow partner. Electrical signals were collected from the equipment's electrical panel through sensors. Each sensor was connected to a Programmable Logic Controller (PLC), which received signals from the machines and converted them into readable and storable signals for the cloud server. In collaboration with the proGrow's IT team, the signals from the machines were translated into data compatible with the platform's database. This conversion was achieved through ladder programming in the PLC, enabling the definition of variables that the platform needed to read. The PLC was then connected to the IoT gateway, an industrial router known as Flexy eWon, responsible for acquiring and transmitting the data to be stored in an Open Platform Communications (OPC) server in the cloud.

By configuring a virtual machine, the proGrow platform could read and write data on this server. The read or write data was accessible to the cloud platform using the Message Queuing Telemetry Transport (MQTT) protocol, enabling the exchange of information with the virtual machine. This solution allowed real-time monitoring of the shop floor and was used to calculate various KPIs.

However, one disadvantage of this approach was that only 25% of the responsibilities in the process were assumed by the proGrow team, while the remaining 75% was the responsibility of the client company and the proGrow partner. The collection and logic of signals, including the hardware, were the partner's responsibility, while the acquisition of hardware (tablet or PC) for monitoring shop floor data was entirely the client's responsibility. proGrow only configured the platform and had no control over the remaining processes. This approach failed to convince many clients due to the significant portion of the process falling under their responsibility. The dependence on partners necessitated relying on the availability of hardware on their part. On the other hand, clients would have to purchase it without a subscription plan, which, in the short term, was relatively costly.

Based on the inconveniences that the existing solution could cause, a new solution was developed, called "proLink”. proLink is an integral part of the proGrow IoT solution, designed to facilitate a seamless and reliable connection between industrial assets and the proGrow platform. Its connection architecture is represented in figure 4.4. The core of proLink consists of a rugged, industrial-grade tablet equipped with a support/dock, making it suitable for use in harsh industrial environments. The tablet serves as a versatile IoT gateway, utilizing a software for data processing and control. The read or write data remains accessible to the cloud platform using the MQTT protocol.

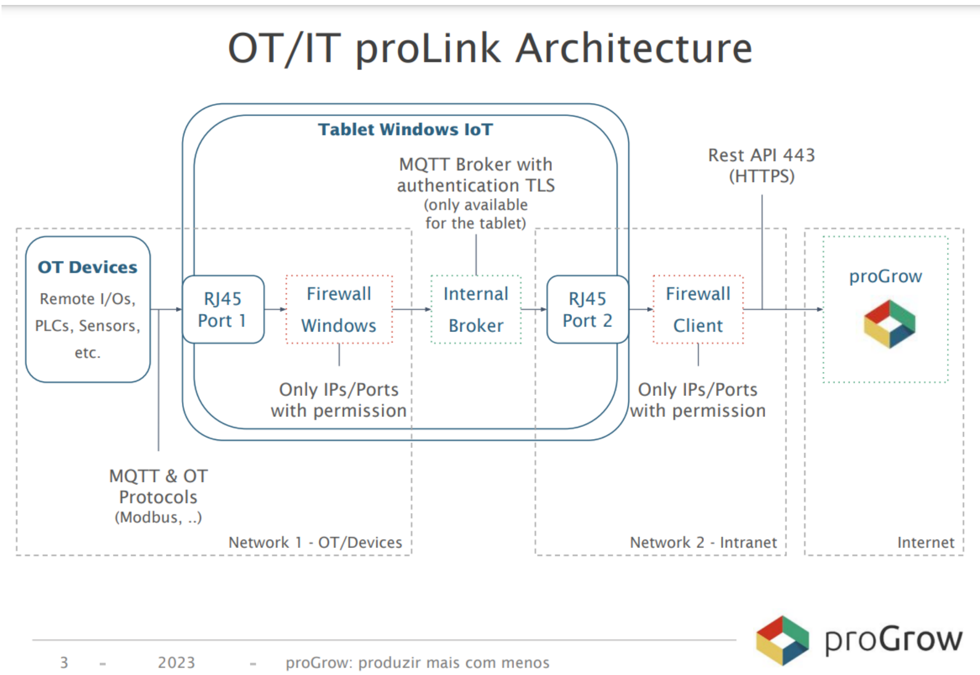

Figure 4.4 - proLink architecture.

With proLink, customers have the option to add either a module for IO data or an asset for PLC connectivity. The module allows for advanced digital input and analog input capabilities, enhancing the monitoring and control of external devices or sensors from a remote location. The asset, on the other hand, facilitates seamless communication between the IoT system and programmable logic controllers (PLCs), enabling efficient data exchange and control across various industrial processes.

The proLink tablet is prepared with a programming tool for wiring together hardware devices, APIs and online services. This provides a standard application programming interface (API) for connection to the proGrow platform, ensuring efficient data exchange and seamless communication.

The proLink offers a comprehensive solution for industrial IoT connectivity, including a rugged tablet, options for IO or PLC connections, and a standard API for integration with the proGrow platform. With its rugged design and versatile capabilities, the proLink delivers reliable performance even in the most demanding industrial environments. Furthermore, compared to the traditional solution previously implemented, this method ensures that proGrow takes 75% of the responsibility for the entire process, minimising external dependency, with the remaining 25% delegated to the customer or proGrow partner for proLink installation and signal mapping. Consequently, the time spent on implementation is reduced by about 60% compared to the implementation time of the traditional solution. On the other hand, the customer does not buy hardware, but enjoys a much more appealing subscription plan in the short term.

One of the first clients to adopt this new solution was Client 2, which also served as a test case for the new approach. In the chosen approach, the client decided to digitize the equipment known as "Line 1" in the CM1 section.

4.2.3 Solution design

The implemented solution at the client company is divided into four components related to connectivity, visibility, transparency and change management. It will encompass all modules of proGrow.

- **Connectivity**

In the connectivity stage, the focus was on the connection and integration between the platform and the machine to be digitized. Regarding the platform's data sources, there is the possibility of digitizing the machine signals, importing information regarding production orders into the platform, or even manually recording data directly on the platform interface.

The I/O module was installed in its electrical panel to establish connections with the electrical signals, as depicted in figure 4.5. For this project, the collected signals from the machine were the machine's status (Production or Stop) and the count of produced parts. The I/O module was connected to a 24V power supply, the electrical signals, and directly to the tablet through a network cable (point-to-point connection), creating a separate OT network from the client's network. The tablet, in addition to its connection to the module, was linked to a power supply and the client's internal network via a network cable (representing the IT network).

Figure 4.5 - I/O module installed in the equipment's electrical panel.

Regarding the data source that will feed the information of the production orders and the employees who will be in charge of operating the equipment to be digitized, in the initial phase of the project, it will be generated manually. Thus, manual file uploads are performed on the platform, providing contextual information about the production orders, references, employees, planned quantities, theoretical cycle time, and product description.

To initiate production, operators are responsible for opening the production order they are currently working on. This information cannot be captured through machine signals, so it must be provided by users to supply the appropriate production context to the platform, ensuring that the data generated by the machines is indexed to the correct production order. This context will be defined by the manually imported files into the platform. Therefore, machine operators, when opening production, will find seven preconfigured production registration fields - Operator, Production Order, Reference, Theoretical Cycle Time, Product Description, Planned Quantity, and Projection ID. Figure 4.6 illustrates the production start pop-up of a production order in the “Shopfloor” module.

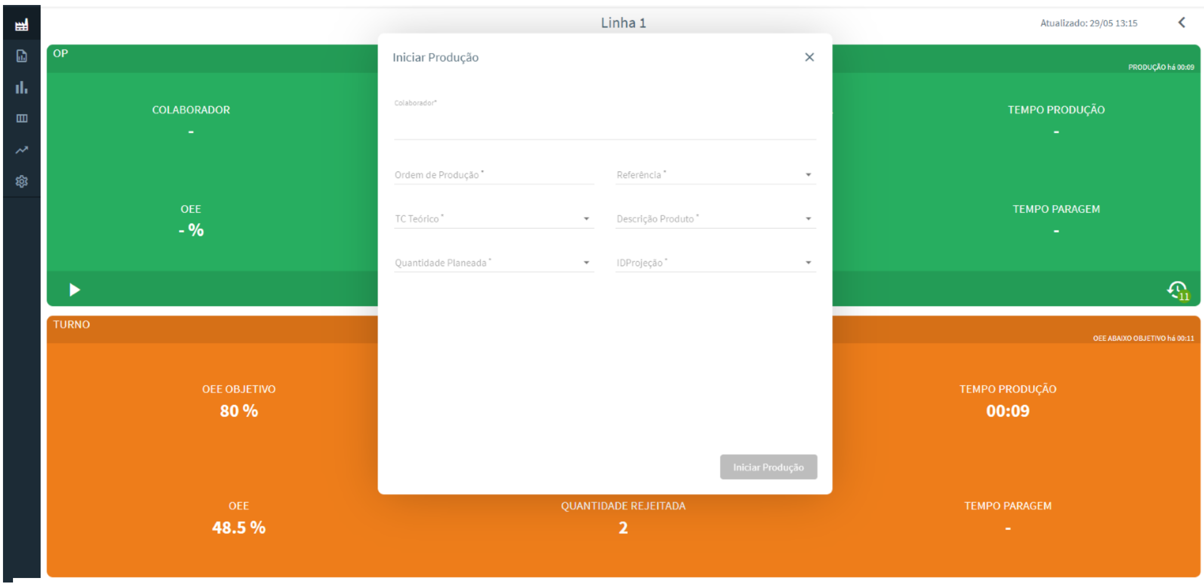

Figure 4.6 - Interface for manual registration of production contexts on the proGrow platform.

In order to ensure the adaptation of the platform to the reality of the shop floor information of the client company, some adjustments were made to how the information in this pop-up was generated, creating dependencies between the reference and the planned quantity, product description, and theoretical cycle time, so as to avoid significant disruptions in the information recording that workers are accustomed to.

On the other hand, information related to production stoppages and rejected parts is also directly entered into the platform, in this module, by the employees. They are responsible for associating a type and reason for the stoppage or rejected part. The figures F-1 and F-2 in appendix F represent the interfaces for justifying production stoppages and recording rejected parts, respectively.

- **Visibility**

Once the connection between the platform and the data sources is established, the information is made available intuitively, so as not to be an obstacle to the employees' adaptation to the platform. The visualization of the collected and processed data is done through the platform modules - "Shopfloor," "KPIs," and "Reports." These modules are configured according to the specifications and requirements agreed upon with the client to better meet their needs and facilitate the transition and adoption of the platform.

The “Shopfloor” module provides real-time information about each equipment, sector, or factory in general. This module involves the highest platform-to-employee interaction on the shop floor, as it is where machine operators initiate production at a workstation and record data related to production contexts, stoppages, and rejections, complementing the data acquired from other sources, including machine-generated signals and contextual tables. It offers a high degree of customization, allowing the configuration of layout and displayed information according to the specific needs of the client.

In this module, and as this implementation is for testing purposes, only one section was implemented, CM1, within which only one page is configured, illustrated in figure 4.7, with one PO card and one Shift card for the respective machine under test, Line 1.

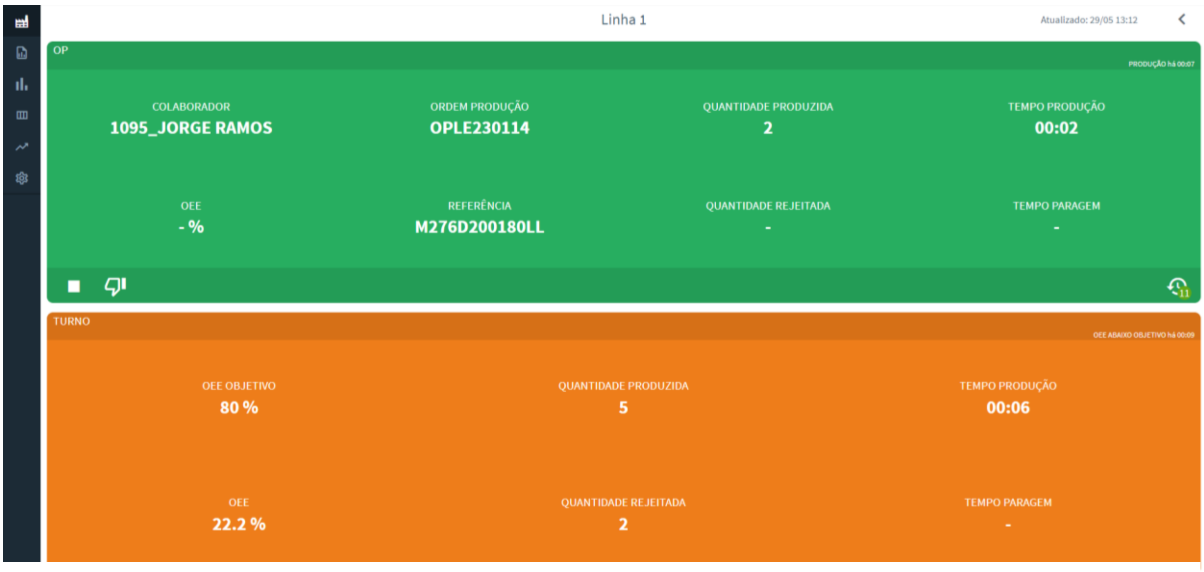

Figure 4.7 - "Shopfloor" module interface.

The PO card provides real-time information related to the current production on a specific machine, including details about the ongoing production order (code and reference), produced and rejected quantities, downtime and production time, and a KPI (OEE). The colours assigned to the PO card are associated with the type of stoppage encountered. Each time a stoppage is recorded, the colour of the PO card changes according to the implemented colour code for each stoppage type. This colour code is detailed in table F-1 of appendix F.

The topic of associating the collected information was also a matter considered in the configuration of the solution. Each rejected piece is associated with a rejection reason. The reasons used by the company to justify a rejection are: incorrect sealing; incorrect winding; incorrect folding; incorrect PO; coverage damaged; incorrect moulding; incorrect RM. On the other hand, a stoppage and its subsequent duration are related to a type and reason for the stoppage (presented in table F-2 of appendix F). By making this interconnection between data and their causes, managers can query and link downtime and part rejections to a particular type of downtime/rejection, but also to a particular production order or worker. By identifying the most important factor for downtime or part rejections and using the "Improvement" module, this information can be studied to implement continuous improvement initiatives.

Similarly, the shift card presents information related to the current production shift, particularly the OEE of the shift and its target, produced and rejected quantities for the shift, and production and downtime duration. The colours of the shift card are determined by comparing the OEE value for the current shift with its respective target. This colour code is summarized in table 4.1. In addition to real-time monitoring of equipment production provided by the “Shopfloor” module, the solution allows users to configure specific alerts to be notified when a particular state on the factory floor undergoes a change. The alerts enable certain users to be notified via the platform or email when the OEE of the current shift changes state below/above the defined target. The same can be configured for the status of the OP card, specifically for stoppage warnings.

Table 4.1 - Colour coding of the shift card.

OEE Value of the Current Shift	Shift Card Colour
Above Target	Green
Below Target	Orange
Colour after reset shift and no Pos in production	Grey

The “Reports” module can generate reports based on the real-time monitored KPIs by the platform, presenting the performance of a specific equipment, sector, or even the entire factory. These reports provide valuable information to managers, enabling them to monitor production on the shop floor using various analyses (shift, day, week, month). This allows for their utilization during relevant moments such as meetings, eliminating non-value-added activities like manual report creation. Additionally, this module enables user collaboration, as users can comment on the reports, indexing these comments for future reference. Two reports have been configured for the client company – “Production Control”, a daily report analysing 5 KPIs including OEE, its components, and average setup time, and “Factory Efficiency Summary”, a weekly report monitoring the same KPIs. Figure 4.8 illustrates an example of the “Production Control” report.

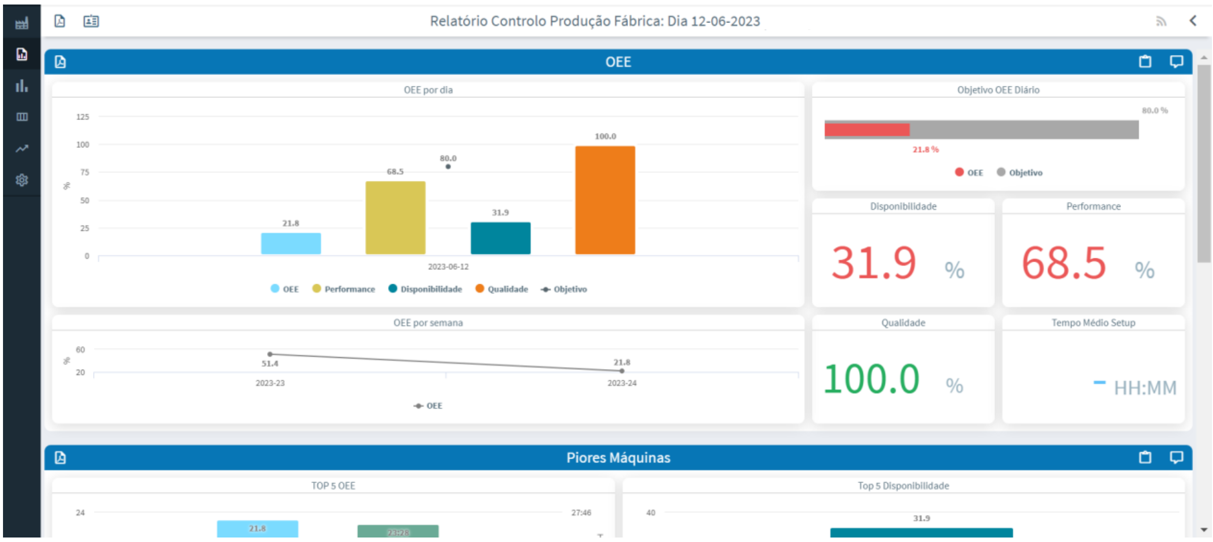

Figure 4.8 - "Production Control" report, automatically generated by the platform.

The implemented solution aims to address the identified gaps in the way data is recorded. As observed in the initial situation of the company, data is manually recorded on boards in each sector on the factory floor. In the “KPIs” module, it is possible to have an overview or detailed view of the KPIs monitored by the company, generated automatically based on the data collected from the equipment (such as production time or downtime) or entered manually (such as rejected quantity). The KPIs monitored by the client company are presented in table 4.2, along with their granularity.

Table 4.2 - KPIs implemented on the platform.

KPI	KPI granularity
OEE	Analysis by plant, machine, shift, PO and reference
Availability	
Performance	
Quality	
Available Time	
Production Time	
Setup Time	
Average Setup Duration	
Number of Setups	
Quantity Produced	
Quantity OK	
Rejected Quantity	Analysis by plant, machine, shift, PO, reference and type/rejection reason
Stop Time	Analysis by plant, machine, shift, PO, reference and type/cause of stoppage

Table G-1 in appendix G displays a document created throughout the project's development that lists the client company's requirements for KPIs and the formulas used to determine them. When collected into various time frames (year, month, week, day, or shift) or levels (factory, machine, production order, or reference), these indicators can be examined and contrasted against specific targets established by the company. An example page from this module is shown in figure 4.9.

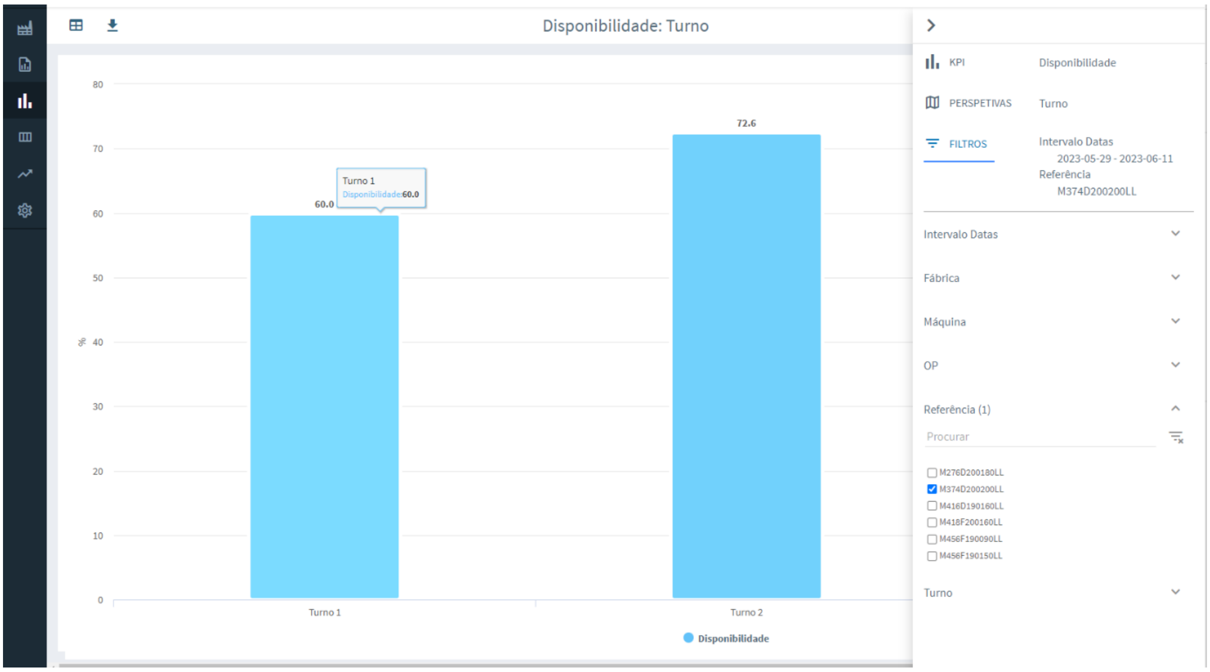

Figure 4.9 - "KPIs" module interface.

- **Transparency**

The transparency phase of this project is achieved by linking the previously calculated KPIs with continuous improvement initiatives in the form of projects, actions, and tasks included in the presented solution. These initiatives are configured around a responsible team, promoting collaboration and visibility across various sectors of the company, facilitating the identification of problems and bottlenecks in the production lines. To achieve this, the “Kanban” module and "Improvement" module has been implemented.

The “Kanban” module, consisting of continuous improvement initiatives, is presented in figure 4.10. In this module, employees can have an overview of all ongoing projects and actions, as well as the phase of the PDCA cycle they are in. It is also possible to visualize the delay of each one relative to the estimated completion time or apply search filters at different levels.

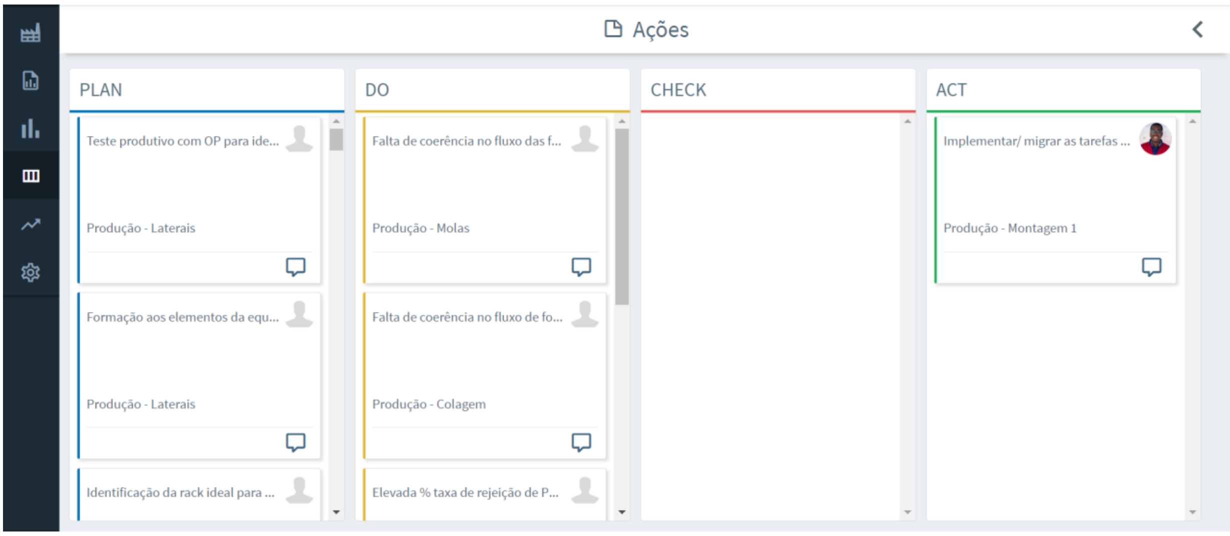

Figure 4.10 - "Kanban" module interface.

Continuous improvement projects are created and managed in the "Improvement" module, allowing collaboration among all workers. The client company's projects have six tabs: general information, comments, causes and effects, action plan, monitoring, and closure. These tabs depend on the nature of the project and can present the content of an A3 report or an 8D report. An example of an automatically generated A3 report by the platform is depicted in figure H-1 of appendix H.

- **Change management**

Throughout the project, it was essential to establish measures that facilitated a clear channel of communication between proGrow and client company 2, promoting proactivity and establishing the responsibilities of each party involved in the project. The communication between the client company and proGrow was continuous, providing opportunities for additional clarifications and addressing situations that arose during the project, including changes and improvements to the proposed solutions. This practice, established from the beginning of the project and materialized through weekly meetings, supplemented by ad-hoc meetings at the request of the client or proGrow, was crucial for aligning expectations and overcoming potential obstacles.

The project also included training on the use of the platform for the users. The objective was to establish the habit of utilizing the solution described in this dissertation during the company's daily production processes, enabling the emergence of continuous improvement initiatives in the form of projects, actions, and tasks. Through training and direct interaction with operators, it is possible to ensure that all workers are included in the digitization process of the factory floor. In figure 4.11 it is possible to visualise the new flowchart of the entire process in Line 1.

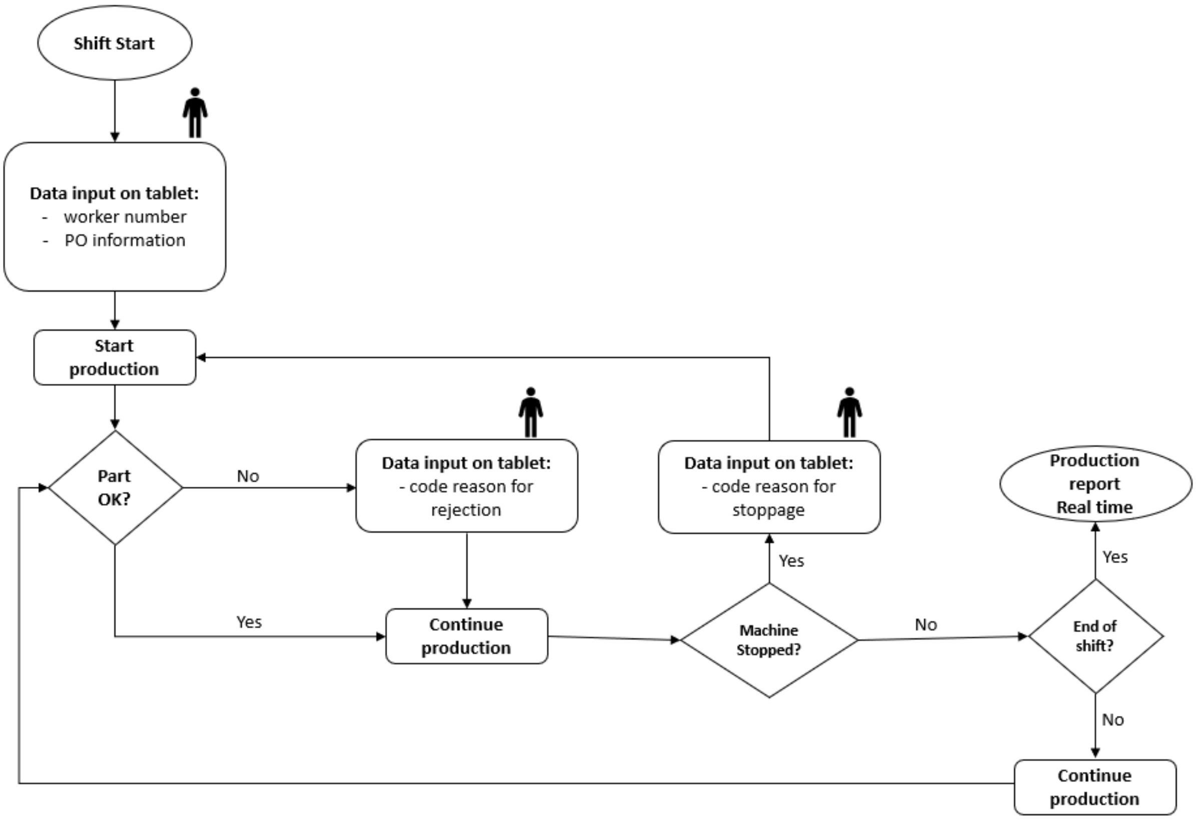

Figure 4.11 - Flowchart of the entire process from the start of the shift to the generation of the production reports.

4.2.4 Impact of the solution

With the analysis of the results, it was possible to understand how the project objectives aligned with the company's strategies. It is worth noting that this implemented solution only covers the digitization of indicators for a single equipment (in addition to digitizing improvement initiatives), so the impact will not be as significant as if it were implemented for the entire factory. With these positive results, it is expected that the company can reach that final level.

The improvement in operational performance resulted from real-time monitoring of key indicators, which accelerated and improved the decision-making process regarding critical situations. The flexibility of the analysis on the platform provided users with more tools to identify the root causes of problems and act more quickly on them. They now have the necessary information to immediately address the most critical and prioritized issues, enhancing OEE improvement. On the other hand, there is greater data reliability, enabling more robust and effective decision-making. These are now obtained in real-time through sensors, without requiring manual records by the operator. Improvements in operational performance are achieved not only due to real time visibility of indicators like OEE but also due to the dynamic analysis capabilities provided by the platform. As a result, previously undetected problems can now be analysed and corrected more rapidly. The increase in operational productivity had an impact on OEE, particularly in the following components:

- Fast access to information and reduction in reaction times to downtime (Availability);
- Fast access to information and decision-making in rejection management (Quality).

In terms of administrative work, there has been a significant reduction due not only to the elimination of the need for operators to manually record production information and manually calculate indicators but also to the elimination of the need to spend time preparing daily and weekly reports summarizing production information. Quantitatively, it is estimated that 1 hour per day has been reduced in administrative work.

Through the digitization of continuous improvement processes, it was possible to standardize the process of creating and managing improvement projects, as well as facilitate access for all team members involved, promoting collaboration among the team. The comment system and visual management of deadlines also increased visibility into the status of each ongoing project and assisted employees in managing priorities.

In conclusion, this solution has promoted:

1. Digitization and increased initiatives of Continuous Improvement;
2. Real time collection of production data;
3. Real time data visualization from anywhere;
4. Greater visibility and transparency in results;
5. Faster and more effective decision-making.

As for the quantitative results, they are difficult to estimate in the short term. However, it is estimated that in the future, the digitization process could encompass the entire factory and increase the company's operational efficiency by 1.0 to 1.5 percentage points. The OEE would see a 15% increase resulting from improved availability, performance, and quality productivity. At short term, there is an expected increase of around 15% in savings associated with continuous improvement initiatives. These estimates, made by proGrow, take into account their experience in implementing this platform in other organizations within the same industry, in long-term projects.

5 Conclusions and perspectives for future work

Industrial organizations are actively seeking solutions to increase productivity by reducing cycle times, minimizing defective parts, and minimizing unproductive periods and downtime. The adoption of digital transformation and leveraging advanced technologies are crucial for organizations to optimize their production processes, increase efficiency, and remain competitive in the market.

The objective of this dissertation was to apply the concepts of shop floor digitalization in two companies from different sectors. The theoretical foundation was explored in Chapter 1, with a particular focus on calculating KPIs, especially Availability, which was extensively addressed by client company 1. Special emphasis was given to the digitalization architecture, mainly focusing on the general aspects of interconnecting traditional systems, such as their advantages and types of data and information that can be shared. Research in this field is considered relevant for future work, to demonstrate how information architecture models, such as the ISA-95 standard, can be used to contribute and prepare real and practical use cases of interoperability between enterprise information systems. Among other aspects, the information flow of the proGrow platform, used in the project to digitalize processes for client companies, was also studied in detail.

To achieve the project's objectives, it was essential to gain a detailed understanding of the initial situation in which the companies were located, both in terms of digital maturity and workflow. The solutions identified for each company were obtained through an iterative process, in constant contact with all project stakeholders (through meetings or visits to the shop floor), taking into account the collected feedback. Clearly defining responsibilities, deadlines, and deliverables, and considering short-term gains, ensured that unnecessary obstacles were avoided during the course of the projects. This builds customer confidence in the presented and implemented solution and minimizes resistance to the change process.

The solution for company 1 included the digitization of reports, KPIs, and continuous improvement initiatives for the proGrow platform. Recognizing that unproductive periods and downtime are significant inhibitors of productivity and actively seeking solutions to minimize these periods through efficient maintenance strategies, the company turned to the proGrow platform to put them into practice. Focusing on the availability parameter, the reports used by the company were updated with new analyses and digitized. This solution made it faster to identify equipment failures or performance issues, thereby reducing unplanned downtime and maximizing production time. After identifying the problem, it was essential to use a collaborative tool to monitor the implementation of the solution. The proGrow “Improvement” module was included in the project for this purpose. This solution promoted more effective decision-making by management and improved responsiveness of operational teams, as well as contributing to increased quality and rigor in continuous improvement initiatives.

As a result of the new information flow generated by the implementation of the platform in client company 1, an opportunity for improvement was identified through the digitized reports, even during the project implementation phase. It is expected that the estimated downtime will be reduced, thanks to the training plan aimed at achieving the versatility of technicians. Consequently, a decrease in MTTR is anticipated, demonstrating cost reduction and subsequent increase in shop floor productivity.

The objectives set in the project introduction have been achieved. These results capture only a fraction of the potential offered by this solution. In the long term, it will be possible to identify additional issues on the shop floor and take appropriate measures, allowing for further exploration and integration of improvements in the presented solution, as well as broader suggestions for advancement in adopting its paradigm. It would be advantageous, as shown in the specific improvement action taken, to include the MTTA indicator in the company's records and reports. This would increase visibility around the time spent attending to a stopped equipment. Furthermore, in the perspective of future projects, it would be interesting to propose the real-time digitization of shop floor equipment indicators, eliminating the error associated with manual entry of downtime by the operator. Additionally, according to the analysis of the ISA-95 architecture included in the literature review, the integration of MES and ERP systems configure levels 3 and 4, respectively, of this model. However, the client company has not implemented the predecessor levels. Level 1, which concerns the use of PLCs and actuators for production detection, manipulation, and management, is not present. On the other hand, there is no real-time production monitoring and supervision, nor any degree of automation provided by systems such as SCADA, belonging to level 2. By including proGrow in the machine data collection process, it would be possible to visualize them in real time and generate customized reports. The platform would thus emerge as a complement to the already implemented management systems, connecting through the importation of data tables with production orders and employees from the ERP and through the sending of production data to the MES. The implemented solution would include the development of an API, ensuring that the information would be ready to be collected by the client at the desired frequency.

Regarding the solution implemented in client company 2, it is important to note that only a trial of the platform's functionality and real time data collection was performed. This solution also included the "Shopfloor" module of the platform, in addition to the previous solution. The indicators of one equipment (Line 1) were digitized in real time, using the recently integrated proLink solution developed by proGrow. This new solution not only reduces dependence on external parties (client company or proGrow partner) but also reduces the implementation time of the platform in the company.

The project plan in client company 2 initially involved collecting signals from the equipment and importing the data source files into the platform. Subsequently, efforts were made to visualize and provide transparency to the collected information on the shop floor, providing tools for decision-making in the form of continuous improvement initiatives.

It should be noted that this implemented solution only covers the digitization of indicators for a single equipment (in addition to the digitization of improvement initiatives). In the short term, the project contributed to a reduction in the work and time spent on production performance monitoring, reducing the allocation of time to non-value-added tasks. The ability to view real time shop floor data, configure alerts based on collected data and calculated KPIs, facilitated faster response times for production teams, enabling the identification of bottlenecks. Communication and collaboration among the client's internal departments were improved through standardized data records and continuous improvement initiatives.

As the trial result was positive and satisfactory for the company, it is expected that in future work projects, the solution can encompass more equipment in the factory. This would lead the factory towards a more accurate view of its overall indicators. Additionally, it would be advantageous to integrate proGrow with the client company's ERP system, enabling production orders launched in the system to be accessible in the proGrow platform, eliminating the need for manual import of the production order list into the platform.

The proGrow platform emerges as an aid tool for companies to optimise their production processes. Among other advantages of its use, the fact that it is a cloud-based solution stands out, reinforcing the visibility and accessibility of data. In addition, it is also advantageous for being a customisable application with a modern and user-friendly interface design.

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APPENDIX A: Layout of the injection/metallisation area

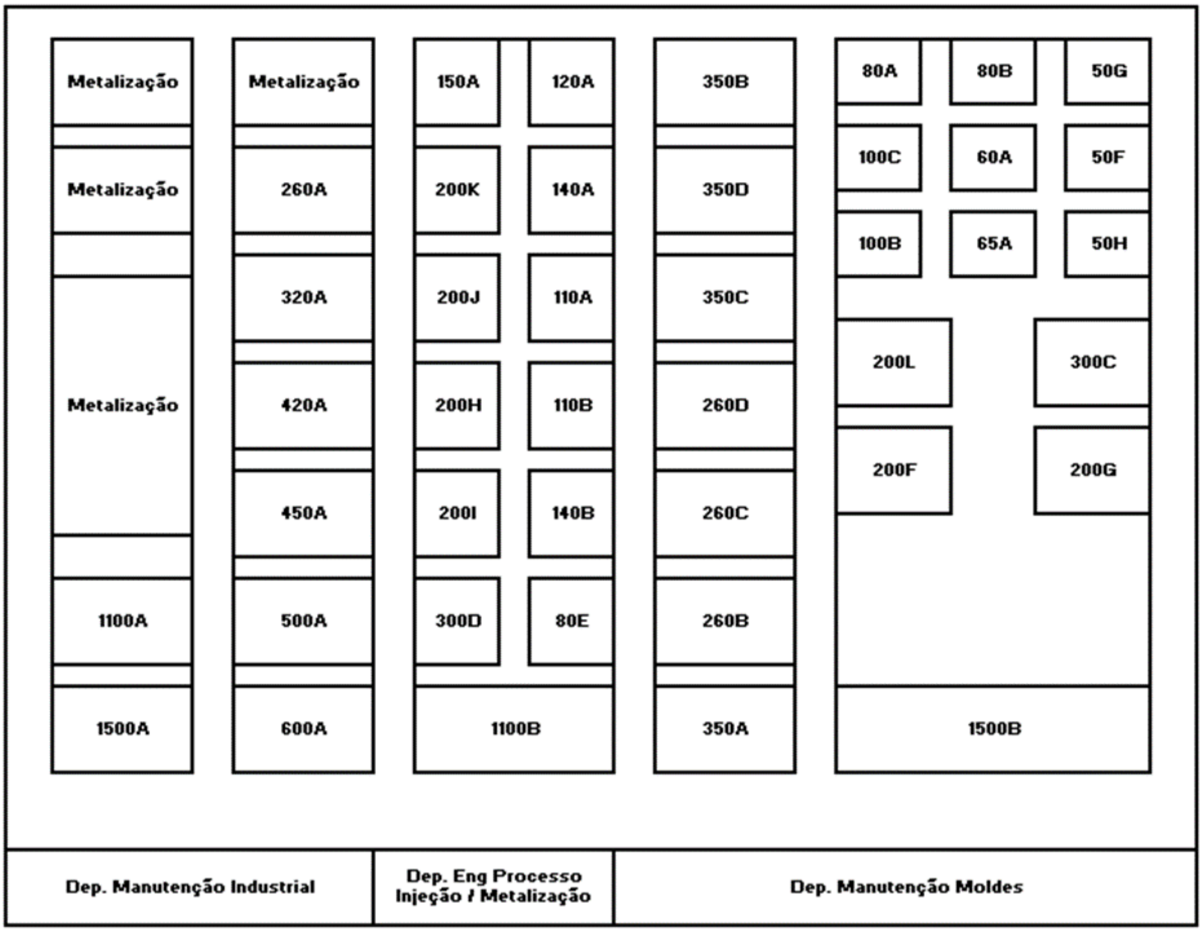

Figure A-1 - Layout of the injection/metallisation area.

APPENDIX B: POD interface

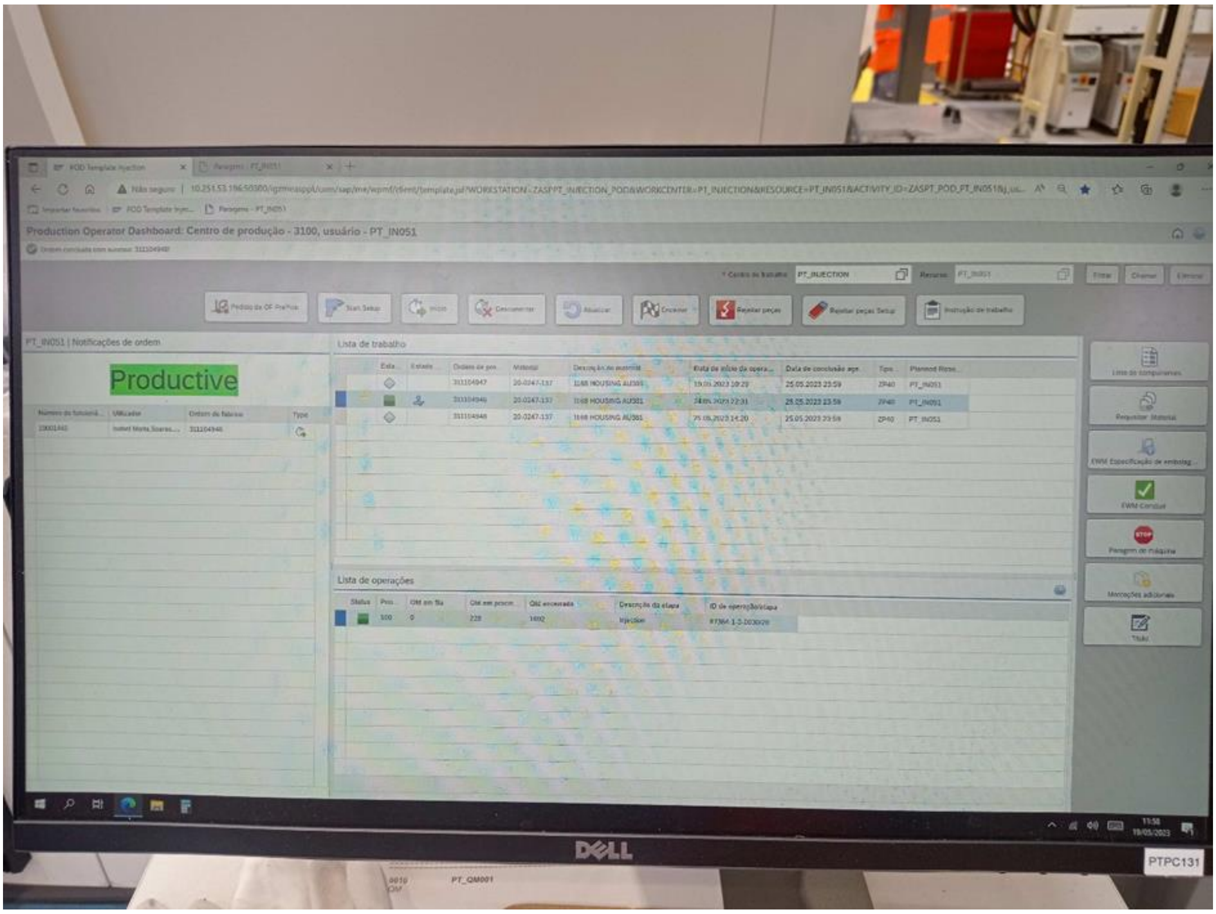

Figure B-1 - POD interface.

APPENDIX C: Label method used on the shop floor

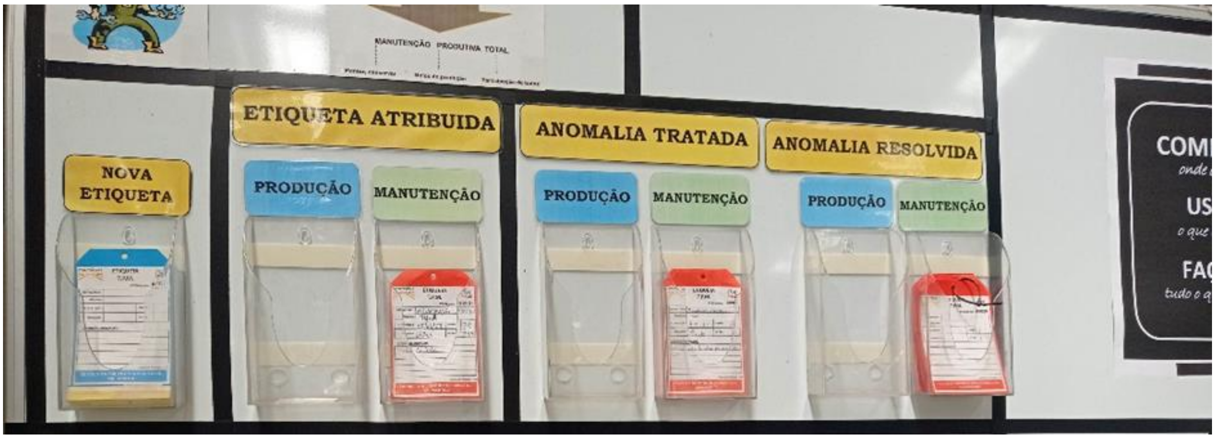

Figure C-1 - Label method used on the shop floor.

Figure C-2 - Example of a label assigned to maintenance.

APPENDIX D: Details of KPIs calculated

Table D-1 - Details of KPIs calculated.

KPI	View	Data source proGrow	Aggregating formulas
Unscheduled Downtime	View Downtimes	Downtimes	KPI: *sum* (unscheduled downtime)
% Unscheduled Downtime	View Downtimes	Downtimes	KPI: *sum* (unscheduled downtime)/((*count* (DISTINCT ressource)*86400*(*count* (DISTINCT Data)) -(*sum* (scheduled downtime)))
MTTR	View Downtimes	Downtimes	KPI: *sum* (unscheduled downtime)/*count* (reason)
MTBF	View Downtimes	Downtimes	KPI: *count* (DISTINCT ressource)*86400**count* (DISTINCT Data)/(*count* (reason))
% Scheduled Downtime	View Downtimes	Downtimes	KPI: *sum* (scheduled downtime)/(*count* (DISTINCT ressource)*86400**count* (DISTINCT Data))
Scheduled Downtime	View Downtimes	Downtimes	KPI: *sum* (scheduled downtime)
Average Setup Time	View Downtimes	Downtimes	KPI: *sum* (unscheduled downtime)/ *count* (reason) [filter: reason = ‘setup’]
Unscheduled Downtime Costs	View Downtimes	Downtimes	KPI: *sum* (custos paragem nao programada)

APPENDIX E: Production process of Line 1

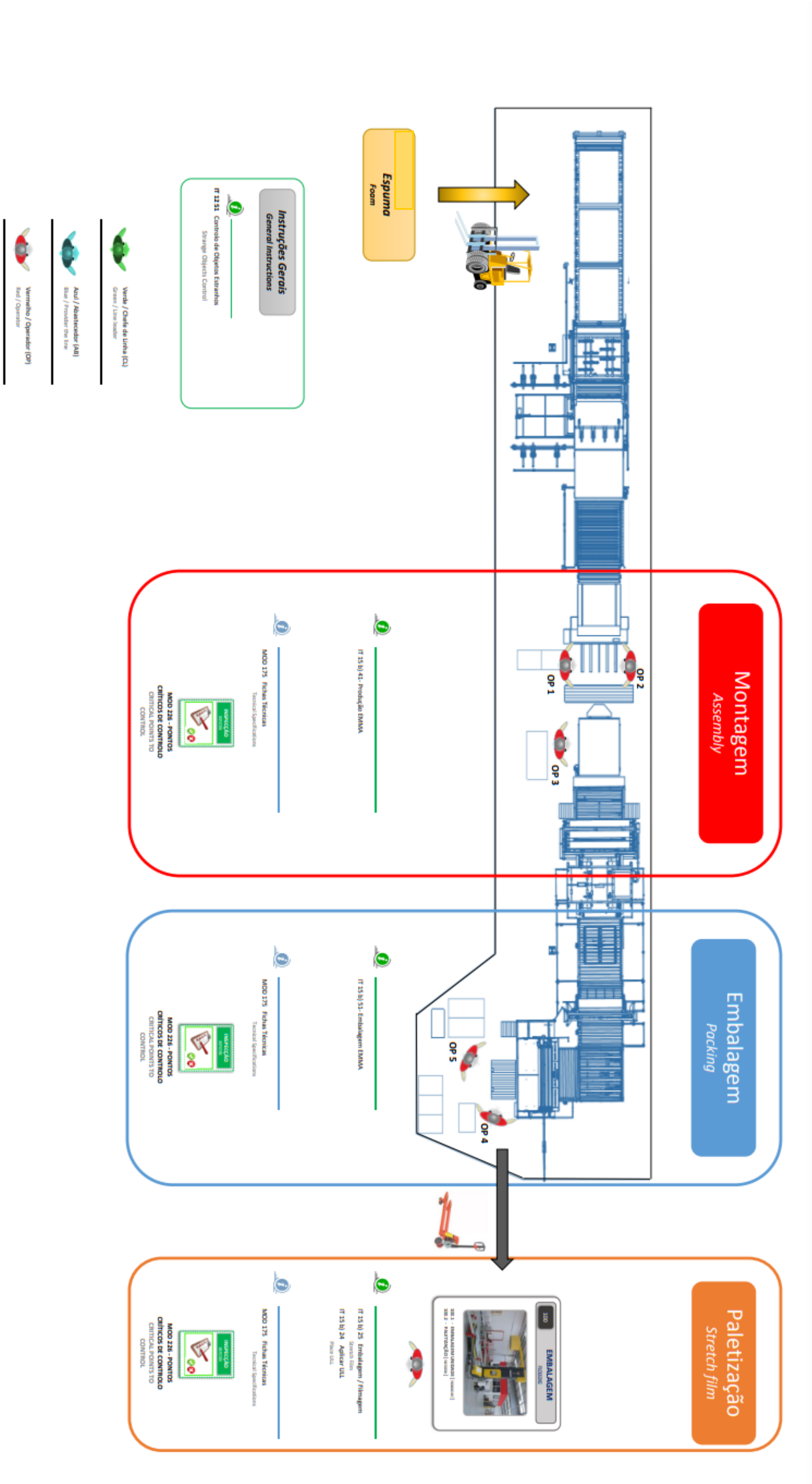

Figure E-1 - Production process of Line 1.

APPENDIX F: Colour coding of the PO card, types/motives for stoppages and rejections of produced parts and their registration interfaces

Table F-1 - Colour coding of the PO card.

Equipment Status	**Colour of the PO Card**
Stop “Engineering”	
Stop “Quality”	
Stop “Maintenance”	
Stop “Breakdown”	
Stop “Lack of Raw Material”	
Stop “Setup”	
Stop “IT Failure”	
Stop “Planned Downtime”	
Stop “Lack WIP”	

Table F-2 - Types and reasons for downtime.

Stop Type	Stop Reason	Stop Category
Lack of Raw Material	RM Gofoam	Unplanned
	RM Coverings	Unplanned
	Supply Logistics	Unplanned
	Other RM	Unplanned
Lack WIP	Covers	Unplanned
	Borders	Unplanned
	Coverings	Unplanned
	Collates	Unplanned
	Springs	Unplanned
Failure	Loader	Unplanned
	Sealer	Unplanned
	Bar Seal Stockinet	Unplanned
	Press	Unplanned
	Turner	Unplanned
	Bender	Unplanned
	Winder	Unplanned
	Bed in a Box	Unplanned
	Handler	Unplanned
Setup	Sup. Press Film	Unplanned
	Inf. Press Film	Unplanned
	Wind Film	Unplanned
	Stockinet	Unplanned
	Covers	Unplanned
	PO Change	Unplanned
IT Failure	PQN	Unplanned
	NLRJ	Unplanned
	ULL	Unplanned
	Network/Internet	Unplanned
	RFID	Unplanned
	Incorrect Sealing	Unplanned
	Incorrect Folding	Unplanned
	Incorrect Winding	Unplanned

Quality	Incorrect Stockinet Welding	Unplanned
	RM not in Accordance	Unplanned
	WIP not in Accordance	Unplanned
Maintenance	Preventive Main.	Planned
	Primary Main.	Planned
Engineering	Process Adjustment	Planned
	Production Test	Planned
	Prototypes	Planned
	Series 0	Planned
Planned Shutdowns	Daily Meeting	Planned
	Training	Planned
	Awareness/Meeting	Planned
	Lunch/Dinner	Planned
	Break	Planned
	5S	Planned
	Lack of Programming	Planned

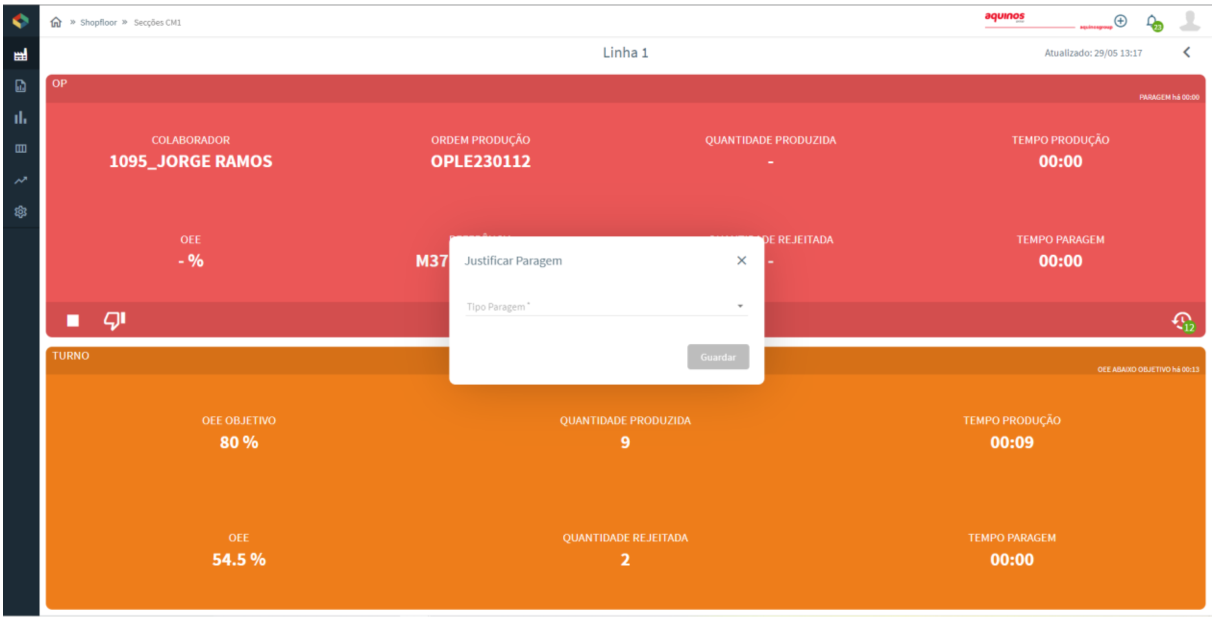

Figure F-1 - Interface for registration of production downtime justification.

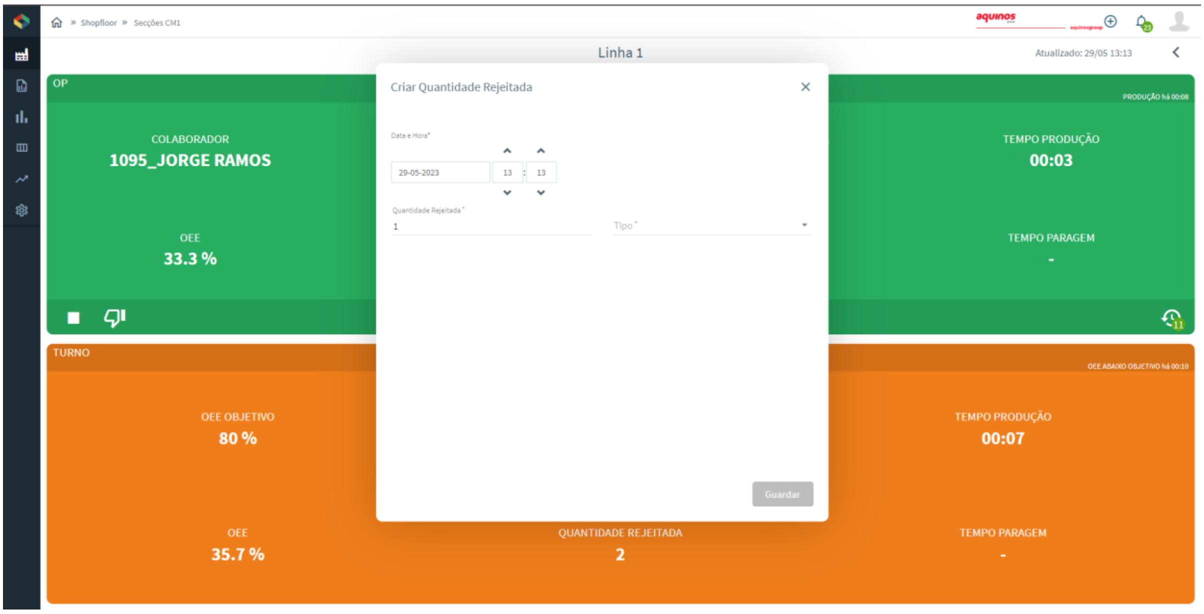

Figure F-2 - Interface for registration of rejected quantity.

APPENDIX G: KPI Aggregating Formulas

Table G-1 - KPI Aggregating Formulas.

KPI	View	Data source proGrow	Aggregating formulas
OEE	Shift	View Shift	KPI: (*sum* (Quantity Produced)/ *sum* (Planned Quantity)) * (*sum* (Production Time)/ *sum* (Available Time))* *sum* (Quantity Ok)/*sum* (Quantity Produced)*100
Performance	Shift	View Shift	KPI: *sum* (Quantity Produced)/ *sum* (Planned Quantity)*100
Availability	Shift	View Shift	KPI *sum* (Production Time)/ *sum* (Available Time)*100
Quality	Shift	View Shift	KPI: *sum* (Quantity Ok)/*sum* (Quantity Produced)*100
Stop Time	Status	View Stop Status	KPI: *sum* (Duration)
Number of Stops	Status	View Stop Status	KPI: *count* (Distinct ID Stop)
Available Time	Shift	View Shift	KPI: *sum* (Available Time)
Production Time	Shift	View Shift	KPI: *sum* (Production Time)
Planned Quantity	Shift	View Shift	KPI: *sum* (Quantity Produced)
Quantity Ok	Shift	View Shift	KPI: *sum* (Quantity Ok)
Rejected Quantity	Rejectio ns	View Rejections	KPI: *sum* (Rejected Quantity)
Average Setup Duration	Setup	View Setup	KPI: *sum* (Duration)/ *count* (Distinct PO)
Setup Time	Setup	View Setup	KPI: *sum* (Duration)
Number of Setups	Setup	View Setup	KPI: *count* (Distinct ID Stop) Filter: Setup

APPENDIX H: Automatically generated A3 report by the platform

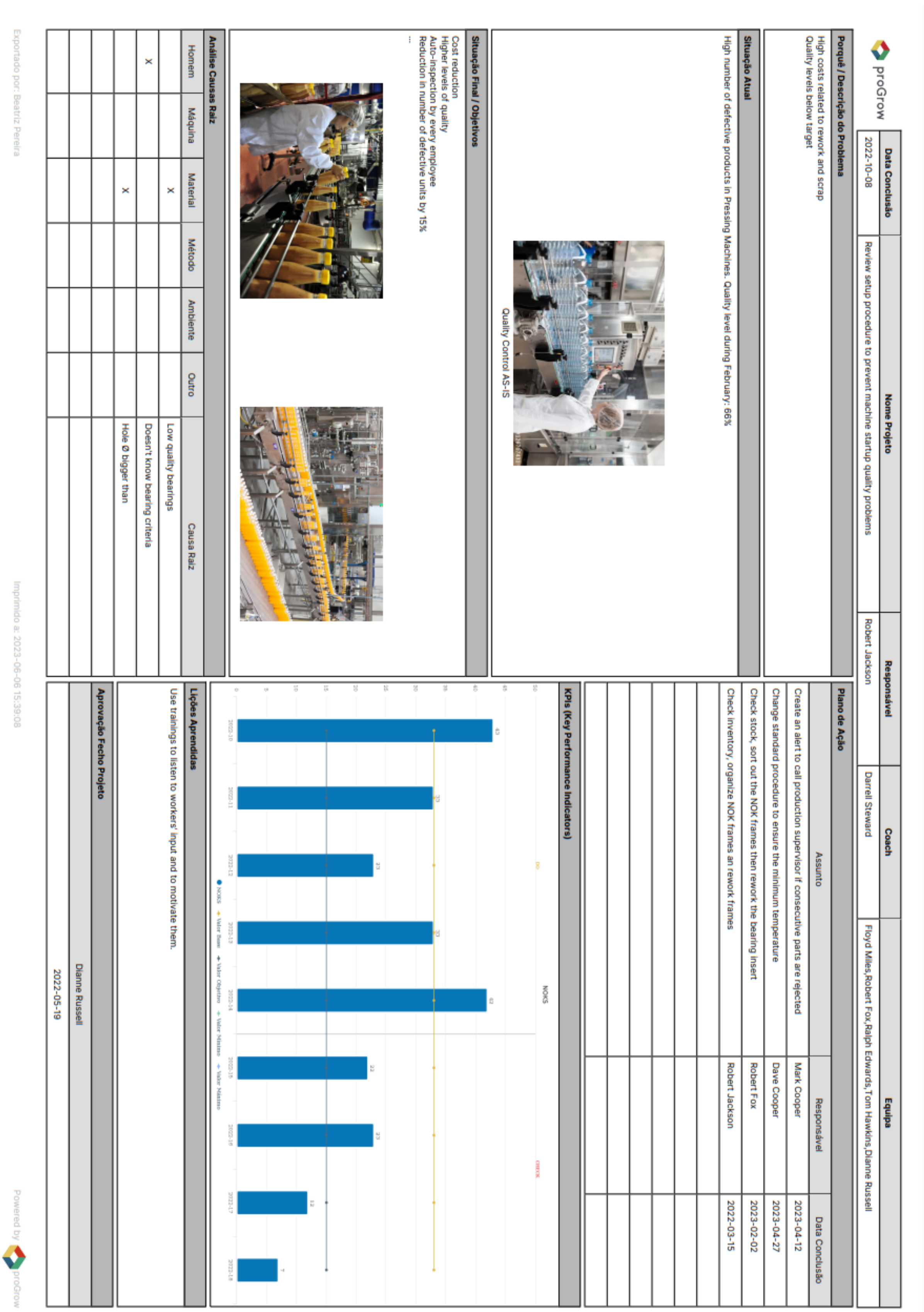

Figure H-1 - Automatically generated A3 report by the platform.