Procedures Definition to Implement TPM and Standard Work in Productive Maintenance at COLEP Portugal, SA

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Master Dissertation

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To my family and friends

Procedures Definition to Implement TPM and Standard Work in Productive Maintenance

Abstract

Colep's Printing Plant is responsible for the initial transformation to the raw materials used for metal packaging production for food, industrial and aerosols industries. It is composed by the primary Cut, the Lithography, and the Secondary Cut. The lithography's production lines, either conventional or ultraviolet technology, already present some tear and wear, resultant of aging and prolonged usage. This deterioration is reflecting particularly under the form of frequent breakdowns and costly repairs. This situation led to the decision to implement a TPM methodology.

The project developed consists in the optimization of the way this methodology is implemented. The preventive maintenance routines needed to be revised and adjusted to the current state, making it necessary to fully understand this state. Data regarding breakdowns and repairs was gathered and organized in order to allow for a statistical analysis. Identifying the A-class problems, Root Cause Analysis methodologies were used to pinpoint the source of the problems. These were then subject to correction and improvement actions, consisting of revision of maintenance routines, One-Point-Lessons, and implementation of new tools to access, register and consult information. To assist in the Autonomous Maintenance implementation, an application was developed to ensure that task scheduling was followed, and also provide a way to register conclusion dates, participants and comments, and subsequently consult that information.

A TPM implementation project fundamentally consists in a paradigm shift and mentality change on all the involved, steering away from an adversary position between departments towards a synergic and cooperative posture. Consequently, it is not to be expected that drastic results occur instantaneously, but instead that progressively good results catalyse even better results, establishing a virtuous cycle between production and maintenance.

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Resumo

A Printing Plant da Colep é responsável pela transformação inicial da matéria prima para o fabrico de embalagens metálicas para a indústria alimentar, industrial e de aerossóis. Contém a secção de corte primário, litografia, e corte secundário. As linhas de produção da litografia, de tecnologia convencional ou ultravioleta, apresentam já algum desgaste resultante da idade e utilização prolongada. Este desgaste está a ser particularmente reflectido sob a forma de avarias frequentes e reparações avultadas. Este situação conduziu à decisão de implementar uma metodologia TPM.

O projecto desenvolvido assenta na optimização da forma como esta metodologia é implementada. As rotinas de manutenção preventiva necessitavam de ser revistas e adequadas à situação actual, pelo que foi necessário caracterizar essa situação. Os dados relativos às avarias e reparações foram recolhidos e tratados de forma a possibilitar uma análise estatística. Identificando os problemas de categoria A, foram utilizadas metodologias de *Root Cause Analysis* de forma a encontrar a raiz dos problemas. Esses problemas foram então alvo de acções de melhoria e correcção, que consistiram em revisões de rotinas de manutenção, lições ponto-a-ponto, e implementação de novas ferramentas de acesso, registo e consulta de informação. Para suportar a implementação de Manutenção Autónoma, foi desenvolvida uma aplicação com a finalidade de assegurar o cumprimento da calendarização das tarefas, com funcionalidade de registo e posterior consulta de datas de realização, intervenientes e comentários a assinalar.

Um projecto de implementação de TPM consiste fundamentalmente numa alteração de paradigmas e mentalidade de todos os envolvidos, abandonando uma situação de oposição entre departamentos e implementando uma postura de cooperação e sinergia. Como consequência, não é expectável que resultados drásticos aconteçam de uma forma instantânea, mas sim que progressivamente os bons resultados vão catalisando ainda melhores resultados, criando um ciclo virtuoso de cooperação e compromisso entre produção e manutenção.

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Abbreviations

BM – Breakdown Maintenance
CM – Corrective Maintenance
CV – Conventional (printing technology)
JIPM – Japan Institute of Plant Maintenance
JIT – Just In Time
KPI – Key Performance Indicator
MP – Maintenance Prevention
MTBF – Mean Time Between Failures
OEE – Overall Equipment Efficiency
OPL – One Point Lesson
PdM – Predictive Maintenance
PM – Preventive Maintenance
PrM – Productive Maintenance
SMED – Single Minute Exchange of Die
SOP – Standard Operating Procedure
TPM – Total Productive Maintenance
TPS – Toyota Production System
UV – Ultraviolet (printing technology)
VBA – Visual Basic for Applications
WIP – Work In Progress

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1 Introduction

1.1 Introduction to COLEP Portugal, SA

COLEP Portugal, SA has its production facilities located in Vale de Cambra, is a RAR Group company. Established in 1965 by Mr Ilídio Pinho, its initial target was to produce metal packages for cookies and biscuits. Due to the initial success, it soon extended its product line to reach several other markets, such as industrial packaging for paint, varnishes, lubricants and oils, among others. During the seventies, it widened even further its capabilities and started producing aerosols and supplying metal packaging to food industry.

It was during this time that Colep Portugal started its Contract Manufacturing business, formulating, producing, and filling mass consumption products, both in plastic and metal packages.

Figure 1 - Colep Vale de Cambra

In the nineties, seeking international expansion, the company started a journey of inorganic growth, composed of several M&A deals. In 1993, Colep bought a S. C. Johnson's plant in Spain, creating what would be named Colep Espanha. A few years later, in 1999, London based Shirley Jones & Associates Limited was acquired, in a move intended to gain market share in the United Kingdom aerosols business. This was also the year that yet another Spanish company, Comercial de Envases de Navarra (CENSA), was bought and renamed Colep Navarra, establishing Colep as the leading Iberic supplier of industrial products' package.

In 2001, Iberholding, a RAR Group holding company, acquired the totality of COLEP's shares, and for the first time, set out to build a new plant from scratch in Poland, Colep Polónia, specifically targeted to Contract Manufacturing.

In mid 2004, Colep merged with Canadian custom manufacturing group CCL, originating ColepCCL, with production sites in Germany, Spain, Portugal, Poland and United Kingdom.

In late 2010, ColepCCL announced a joint venture with Provider, a leading supplier of self-care products in Brazil, resulting in the creation of CPA, short for Colep Provider Aerossols, where ColepCCL holds 51% of the shares, and Provider the remaining 49%.

During 2011, RAR acquired the outstanding CCL's equity on ColepCCL, and thus becoming the sole owner of the company. Nowadays named Colep, the company has production facilities in Brazil, Germany, Poland, Portugal and Spain.

This academic dissertation project took place in Colep Portugal's plant in Vale de Cambra, specifically in the Printing Plant of the compound.

1.2 Printing Plant TPM at COLEP Portugal, SA

COLEP Portugal, SA is internally organized in terms of production plants. One of these plants is the Printing Plant. This plant contains the processes in the very beginning of the value chain in the packaging business, transforming the raw materials in a sub product ready to be transformed in Stamping and Assembly plants.

The aging and deterioration of the equipment makes it prone to frequent breakdowns, which apart from unreliability in production, also demands a costly and *ad-hoc* maintenance plan.

In order to improve the overall plant performance, it became clear that a bigger emphasis on maintenance strategy was needed. As a result, it was decided to implement a Total Productive Maintenance policy.

This was the starting point for this academic project. Its scope was to assist in Total Productive Maintenance implementation, firstly by analysing breakdown data and overlapping it with current preventive maintenance procedures, secondly by identifying patterns and imbalances and revising the procedures, and thirdly assisting in the Autonomous Maintenance Implementation.

1.3 Methodology used

Although there were preventive maintenance procedures in place, breakdowns were happening very frequently, so there was the need do understand what was going on with the equipment. The breakdown logs and the corresponding repair orders were analysed and grouped, in order to arrange the data for statically significant analysis.

Pareto analysis, also known as ABC analysis, was done on this data, identifying which problems where happening *many* times. These represent the great majority of the breakdowns, and are recurrent issues, often occurring several times per week. Even if the repairs are not very long nor very expensive, their cumulative effect and the production uncertainty created, have a huge impact on reliability.

For these A-class items, several root cause analysis techniques were performed. 5Whys, 5W2H and Ishikawa diagrams are some of them. After identifying the root causes, a list of corrective actions was constructed.

From this list, procedures were revised, One-Point-Lessons were elaborated and new forms of accessing, transmitting and storing information were engineered.

1.4 Dissertation report contents and organization

This report is the product of an academic work that took place in an industrial environment. It was written, as much as possible, following a chronological development criteria, aiming for a logical and intuitive understanding of the accomplishments throughout the project.

In this first chapter, the hosting company was introduced, and the general goals for the project were presented. The methodologies used were also briefly mentioned, and the project was contextualized in the current state of the company.

In the second chapter, the Total Productive Maintenance state of the art is presented, laying the theoretical basis for the project.

In the third chapter, the product and production process are described and the initial state is described. Problems identified are listed and presented in detail.

In the fourth chapter, the methodologies to be used are introduced, focusing on how must they be applied to ensure the desired results. Their contributions towards reaching solutions to correct specific problems are also discussed.

In the fifth chapter, the methodologies identified on the previous chapter are applied to the identified problems, in a search for solutions.

In the sixth chapter, the proposed improvements and prototypes developed throughout the project are detailed.

Finally in the seventh and last chapter, some conclusions regarding the project and Total Productive Maintenance Implementation are presented, along with some further works suggestion.

2 Total Productive Maintenance State of the Art

2.1 Maintenance

By definition, maintenance is a task that is intended to keep a system working at its original productive, reliable and safety specifications.

For a very long time, the function of maintenance was considered a necessary evil, a cost of doing business and keep equipment producing. However, with the growing complexity of processes, machinery and business in general, new practices have been developed and redefined the maintenance function as a much more strategic one.

Before exploring maintenance evolution over the time, it is important to introduce the four distinct types of maintenance that can be identified:

- <u>Breakdown Maintenance</u>

  Maintenance intended to fix a breakdown in order to get the equipment to produce again. This type of maintenance happens only after a breakdown occurs and only seeks for an immediate solution for the problem.

- <u>Preventive Maintenance</u>

  With the mission of preventing breakdowns from occurring, this maintenance consists in daily maintenance, regular inspections, and restoration to respectively prevent, assess and recover from deterioration. Such activities involve cleaning, inspecting, lubricating, and measuring equipment characteristics.

- <u>Corrective Maintenance</u>

  When a problem in equipment is identified, corrective maintenance consists in focused improvements to prevent that problem from repeating itself and escalating for an even bigger problem. It also intends to make maintenance, inspection, usage and cleaning easier by removing access restrictions and increase safety.

- <u>Autonomous Maintenance</u>

  Autonomous Maintenance starts by the daily maintenance from Preventive Maintenance being performed by operators. As they grow in skill and confidence, AM expands to include some more complex tasks, such as parts replacement and simple repairs.

In the book “TPM, total productive maintenance”, Takahashi and Osada (1990) identify several maintenance periods that can be linked to different eras of business evolution. During the first period, maintenance consisted only of breakdown fixes. Technicians would not perform any task unless absolutely told to do so. This situation was dreadful for production, which started to have their own small repairs’ personnel.

In a second period, equipment grew in number and complexity, making it necessary for a more complete maintenance force. The tasks were completely separated, creating the feeling of “I produce, someone else fixes”. For the maintenance crew, since there was a need for specialization in different backgrounds and equipment, this was a period of growth and increased morale. As a result, some preventive maintenance effort was promoted.

A third period was characterized by an evolution in the scope of the maintenance department, embracing engineering tasks and more complex fault finding and corrective maintenance. In contrast, the production crew started to be less and less maintenance oriented, only performing the operational tasks. It was around this time that the importance of having operators with preventive maintenance skills gained some recognition. Consequently, operators started doing some basic lubrication, self-inspection and cleaning.

The fourth period focused on preventive maintenance and its benefits: operators realize that better performance can be attained if the equipment is used in the best possible way. On the other hand, maintenance realizes that in order to tackle the more complex jobs, it must rely on the collaboration of the operators to perform easier tasks. Being competitive on a global scale is only possible by working in synergy.

Additionally, Nakajima, Sim et al. (1987) clarifies the evolution in Japanese maintenance from the end of that third period till the creation of Total Productive Maintenance. In the fifties there was the definition of the maintenance function, with Preventive Maintenance (PM) being traced back to 1951, while Corrective Maintenance (CM) starting around 1957. Only some years later, around 1960, Maintenance Prevention (MP) was introduced. This practice aims to *prevent* maintenance from design and conception of equipment.

The concept of Productive Maintenance (PrM), which included Preventive Maintenance, Maintenance Prevention, and Corrective Maintenance (PM + MP + CM), evolved in 1971 into Total Productive Maintenance by the inclusion of the *total* employee participation clause.

In a time when every investment must be well thought about, having control in the way equipment behaves over time is a very important asset to any company. Production, Quality, Product Development and Safety departments must work closely and in partnership with Maintenance, in order to maximize the results of their combined efforts.

2.2 Manufacturing Evolution

In the end of the nineteenth century and beginning of the twentieth century, about one hundred years ago, production was much different than what it is nowadays. In fact, different than what it was fifty years ago. In light of several reports, it is safe to say that manufacturing, along with business in general, have been undergoing continuous transformation and evolution for the last century.

This continuous evolution can be deconstructed in smaller time frames, which allow for a more accurate analysis, taking into account the global context.

The manufacturing business as we know it nowadays, in which we have companies established to produce a certain good and offer it to a wide market, started around 1890. This era was labelled the Second Industrial Revolution, and it was during this time that industry took a major leap towards its current form (Smith and Hawkins 2004). It was around this time that the production concept started shifting from the small local shop, producing just enough to satisfy the village’s demand, to a wider scale model, where a production plant, with the help of distribution network, was able to fulfil a considerably larger market. This paradigm shift created the possibility of scale economies, and meant that a production plant could grow to be much bigger than the size of the local market allowed. Goods could now be produced anywhere and then shipped to the other side of the country. In some cases they could even be shipped abroad. The growth of the reachable market was enormous, creating opportunities like never before.

This global market feeling, and its actual size for that matter, allied with a needy population, created a supply-demand imbalanced situation, in which there was virtually guaranteed demand for a said good, regardless of the time it was supplied. If there was some halt in production, the situation would be addressed, and the affected orders would be satisfied and delivered once the issue was solved (Borris 2006). Except in some rare situations, it was simply not necessary to mitigate the risks of a production stop. This market context allowed for an *ad-hoc* maintenance policy: any equipment breakdown, affecting production tools or not, would be solved when possible, and certainly *after* it happened.

On the other hand, this globalization also meant that many previously local shops were now competing with other former local shops for business and market share in a broader area. As a consequence, if by any reason some producer could not fulfil the market demand, other competitor would do it. As time went by, producers realized that differentiation was needed in order to prosper, otherwise any production loss could mean a lost customer.

While seeking for this edge, and although many chose to compete solely in price, others chose quality, reliability, innovation or even delivery time as a differentiation factor. Professor William Edwards Deming was one of the first persons to advocate in favour of Statistical Process Control as a way to control quality (Deming 2000). After the Second World War, he was deeply involved in the reconstruction of Japan, where he taught engineers, professors and even top managers. His teachings resulted in an increased product quality, leading to a global demand for the high quality Japanese products.

2.3 Lean Manufacturing

Following professor Deming's teachings, some individuals went on and developed other production philosophies. Shigeo Shingo, Taiichi Ohno and Eiji Toyoda were among these. While working to establish Toyota Motor Company as a world-class car manufacturer, they pioneered in the pursuit of manufacturing efficiency.

Mr Eiji Toyoda visited Ford Motor Company production plant, and despite being impressed with the number of vehicles produced, he was astonished with all the inefficiencies in the production line. When he got back to Japan he sought to rethink the way Toyota produced its cars. The result consisted in a series of methodologies and production techniques such as Just-in-time (JIT), Single Minute Exchange of Die (SMED) and Total Productive Maintenance (TPM). It was called Toyota Production System (TPS), resulting in what is nowadays widely known by "Lean Manufacturing" (Pinto 2009).

TPS has identified, as more critical, three types of problems that reduce efficiency and reliability in production processes: *muda*, *mura*, and *muri*.

Muda is any activity that does not add value to the product, being a waste of any resource. *Mura* is the lack of balance, something irregular and uneven. *Muri* is difficulty, such as the overload on any equipment or person.

The main target of Toyota Production System was to eliminate the wastes in production (Ohno 1988), identifying seven types of *muda*:

- Transportation

  Moving an item represents a risk to the product and is something that the customer is not willing to pay for.

- Inventory

  Whether it is finish goods or WIP, inventory represents a capital expenditure that despite often labelled as an asset, is in fact a liability (Goldratt and Cox 1984), since it is exposed to potential damage, theft, and deterioration. It also increases costs with storage expenses and space.

- Motion

  Physical motion by operators. Not having the necessary components or tools in reach, forces operators to move unnecessarily and waste time looking for what is needed. Materials should be nearby and preferably supplied frontally.

- Waiting

  When a process or person is waiting for something (sub-assemblies, authorizations, tools) caused by accidents, bureaucracy, defects or breakdowns in equipment.

- Over-processing

  This waste happens when the product is overworked, subject to unnecessary operations that do not add value or has a standard that is higher that what the customer is willing to pay for.

- Over-production

  Producing more than what is needed ‘just in case’ is a very common waste. Despite the client not wanting or need, this production consumes raw materials, energy, space and equipment time.

- Defects

  Items that are malfunctioning or may not have the necessary quality impose the presence of quality inspections, repairs and rework or even additional scrap costs.

An integrated implementation of the Just In Time philosophy solved many of these wastes: the right product is produced the right way (no Over- processing, no unnecessary Motion and no Defects) at the right quantity (no Over-Production) at the right time (no Waiting, no Inventory and consequently, no unnecessary Transportation).

2.4 Total Productive Maintenance

In order to accomplish this, there are a few requisites that needed to be attended: the demand must not fluctuate abruptly, the supply must be stable, and the production must be reliable. When there are no inventories to accommodate major production downtimes, the equipment and workforce has to be relied on, so as to meet delivery dates and established quality patterns. Therefore, equipment maintenance throughout the plant had to become fully integrated.

This was the beginning of Total Productive Maintenance. A *maintenance* policy focused on maintaining full *productive* capacity, counting on *total* employee participation (Nakajima 1988).

Although maintenance had already evolved to the point of preventive maintenance, according to Nakajima (1989), TPM was only officially created in 1971.

Objectives of Total Productive Maintenance

The objective of TPM is to create a paradigm shift and change in mentality throughout the organization.

In order to do so, there are five specific objectives identified by the Japan Institute of Plant Maintenance (JIPM):

- Maximise equipment effectiveness
- Improve maintenance efficiency and effectiveness
- Improve skills of all people involved
- Involve operators in routine maintenance
- Early equipment management and maintenance prevention

It is worth noting that the very first objective listed refers to the equipment effectiveness, which is the efficiency at which it is run and the value that the equipment adds to the product. This item aims to operate each and every equipment at its full potential, and maintain this capability over the largest possible timespan. By full potential, both the productivity and the reliability of the equipment, as well as the quality its product is included. In order to verify any improvement in this field, a measurement unit has to be used. The Overall Equipment Efficiency (OEE) measure is a tool to assess the current state of equipment performance and benchmark a production line or process across another or over its evolution over time. It takes into account the theoretical maximum performance of the equipment, and factors in three types of losses: availability, performance and quality. The result comes in form of a percentage, representing what part of the supposed capability is actually being utilized.

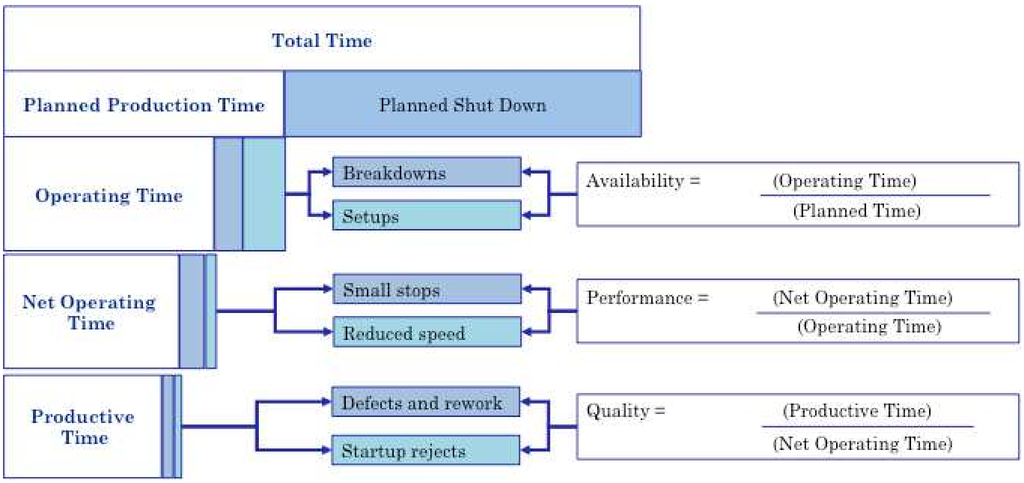

Figure 2 - OEE: Availability x Performance x Quality

As seen in Figure 2, under its ratios it contains the six big losses (Willmott and McCarthy 2000) of equipment efficiency and productivity:

- Availability:
    1. Breakdowns
    2. Setups and Adjustments
- Performance:
    3. Idling and minor stoppages
    4. Reduced Speed
- Quality:
    5. Defects and Rework
    6. Start-up and yield loss

The Eight Pillars of TPM

Because it intends to create a cooperative attitude towards loss elimination in the whole plant, Total Productive Maintenance can be labelled as a Production Management Method (JIPM 2012). The ultimate goal of TPM is to achieve the three Z's: Zero Accidents, Zero Breakdowns and Zero Defects. This is achievable due to a combination of well-trained and motivated people, well-maintained equipment and the constant search and employment of the best procedures.

The concept of the TPM house Figure 3 implies that there are eight fundamental pillars for TPM implementation, placed on top of a common base

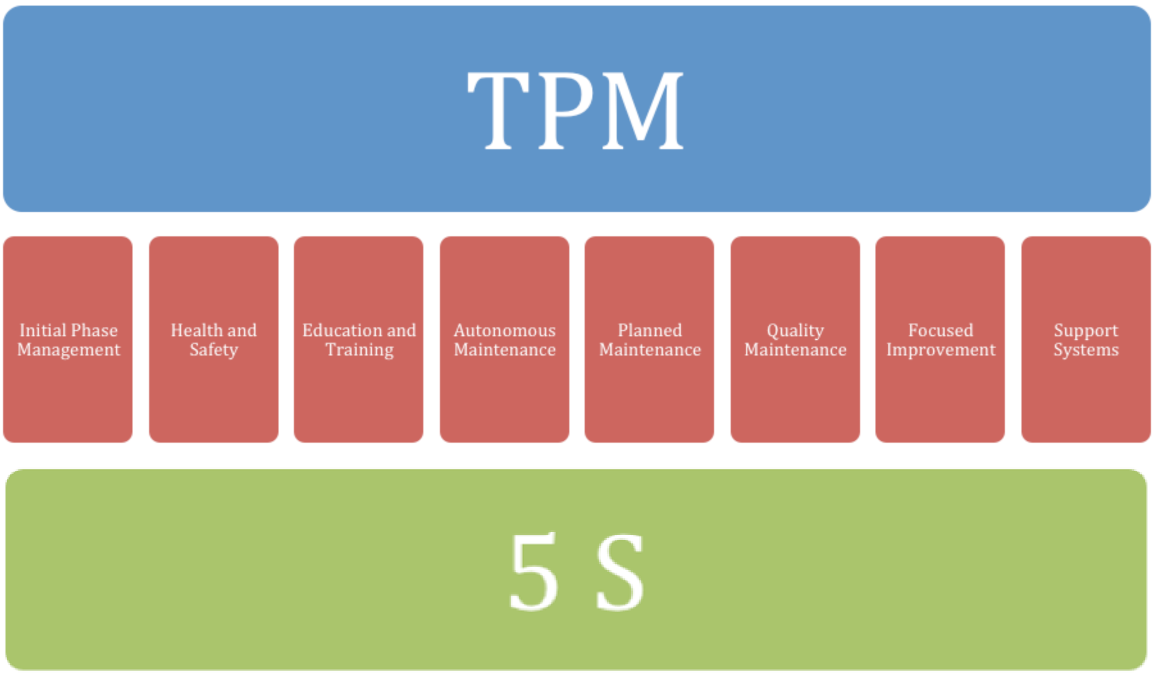

Figure 3 - TPM House

5S is a multistep process that acts as a starting point to continuous improvement. It increases productivity and efficiency, reduces waste, and simplifies the workplace eliminating non-value added tasks. It consists in several simple routines promoting the continuous growth of people and organizations, as well as teamwork and openness to other's opinions.

Despite the common misconception, it is not a cleaning campaign or committee. It was developed in Japan by Kauru Ishikawa as a tool to better workplace organization and housekeeping, and owes its name to the five Japanese works that define the processes: *Seiri*, *Seiton*, *Seiso*, *Seiketsu* and *Shitsuke*, meaning Select, Organize, Clean, Standard and Discipline respectively.

- *Seiri* – Select

  Sort out what is necessary and what is not. Get rid of everything that is not useful for the specific job.

- *Seiton* – Organize

  Clearly define what is best way to organize the necessary objects. Ensure that they are placed accessible to every person that needs them.

- *Seiso* – Clean

  Clean all the equipment, shop floor and tools. Identify and mitigate all the sources of dirt.

- *Seiketsu* – Standard

  Establish work procedures and routines. Define the organization and cleaning tasks and scheduling.

- *Shitsuke* – Discipline

  Establish the habit of apply the 5S throughout the organization, respecting standards and seek for continuous improvement.

When 5S practices get truly established within the company culture, employees start to appreciate the benefits of a well organizes workplace, increased safety and well being, boosting moral and inspiring confidence and trustworthiness on visiting customers, creating a virtuous cycle.

The eight pillars (Borris 2006; JIPM 2012) that support a successful TPM implementation are:

- <u>Initial Phase Management</u>

  This pillar focuses on organization and planning of the TPM implementation. The internal processes for customer acquisition, new products development, maintenance procedures, employees improvement suggestions and machine operation difficulty and cost are some of the issues that this pillar intends to raise and have the team discussing about. The team must look for ways to improve the complete organization.

- Health and Safety

  This is a very important pillar towards the goal of Zero Accidents. Since operators will now perform some basic maintenance tasks, which they were not aware of when they were employed, there has to be a consistent effort to support cautious risk assessments by them. They should be aware of machine dangerous zones and how to mitigate those risky activities, in order to gain confidence for further tasks with increased complexity.

- Education and Training

  This pillar should be tackled with a very complete program. In many companies training is given in a highly informal manner, often with *on the job* demonstration and teaching sessions. This implies several assumptions that are seldom true, such as the ability for the trainer to recall each and every step of the task, and do it in the correct order, the ability for the trainee to understand the tasks in the often noisy production environment, while simultaneous taking notes including schematics and parts drawing, among many others questionable assumptions.

  Training should be given firstly on a controlled environment, such as a training room, with machine drawings and the sub assembly in the room, whenever possible. Trainees should be encouraged to raise any questions and clear all the doubts before going out to the production floor and attempt to perform the task in the real situation. This way they will be aware of the potential dangers, what to look for and what to expect to happen.

- Autonomous Maintenance

  This pillar intends to increase the operators' sense of ownership of the equipment. By performing basic maintenance tasks, such as clean and inspect procedures, they are able to identify developing problems much earlier. In addition, they will also be freeing up the maintenance force to tackle much harder jobs and root cause finding.

- Planned Maintenance

  Planned Maintenance scratches beneath the surface of the problems and seeks out to the root cause. This is done by a cross functional team, composed by technicians and operators. They will not be doing emergency repairs, which would likely be happening again in the future, but instead solving the root cause of those problems, and making sure that they will not happen again.

- Quality Maintenance

  Even if equipment is performing at its best, there will always be some variation in the resulting product. This pillar focus on what can be done to reduce this variation and to keep the total process variation from increasing. If a cause of variance is found, then the team investigates a possible modification to maintain quality in the process, or eventually comes up with an alternative production process.

- Focused Improvement

  This pillar represents the focus on the improvement. Many problems may have been identified in the past, but for many reasons have not been solved yet and still haunt the technicians, engineers and operators. With this pillar, there is a clear focus on what to improve what are the issues that need to be addressed.

- Support Systems

  This is the pillar that extends the TPM implementation to the whole organization. Sometimes the information flow between departments is not smooth, with maintenance not knowing if the ordered spare parts have already arrived or not, or purchasing buying a sub standard spare part in order to save some money, not knowing that the quality consequences will be several times as much expensive as a quality replacement part. This pillar intends to unite all the support systems in an effort to achieve a global optimum, instead of several local optimums.

This array of pillars supports the notion that TPM is a company wide effort, and not just a maintenance program with limited boundaries.

Due to the project scope, a special emphasis on the Autonomous Maintenance pillar was given. According to JIPM, Autonomous Maintenance "refers to activities designed to involve operators in maintaining their own equipment" (JIPM 1996). The activities performed by operators consist in daily inspections, lubrication, simple repairs and parts replacement, precision checks and detection of abnormalities. Bill Maggard uses an acronym for these tasks, defending that operators must be given proper training and tools to perform "CLAIR tasks" (Maggard 1992), which stands for Clean, Lubricate, Adjust, Inspect and Repair.

Because operators cannot be expected to immediately be capable to perform all these tasks from one moment to the other, the Autonomous Maintenance must be implemented in gradual steps in order to build skill growth and consequently, confidence.

JIPM (1996) identifies seven steps of Autonomous Maintenance:

1. Clean and Inspect

   The first step of autonomous maintenance consists in eliminating all the accumulated dirt and dust, lubricate all grease points and identify and correct problems. It is worth pointing that cleaning *is* inspecting as well, by looking beneath all dirt and grime on the equipment.

2. Eliminate problem sources and inaccessible areas

   Once the dirt is cleared, its source should be eliminated. By doing so, every time there will be less and less dirt to clean, making the first step easier to perform. Additionally, physical modifications can and should be done to make cleaning areas more accessible, once again simplifying the previous step.

3. Draw cleaning and lubricating standards

   This step consists in standardizing the cleaning and inspection procedures. With written instructions, by following a logical list of spots and tasks, the cleaning and inspecting jobs can be done much more efficiently than just randomly cleaning what appears to be dirt.

4. Conduct General Inspections

   In this step, operators start to develop deeper knowledge of the machine and troubleshooting skills. After the previous steps, operators are much more aware of machine parts and issues, and with proper training should now start to inspect the equipment and correct problems they eventually find. In this step operators also start to develop visual controls to help gauge equipment conditions.

5. Conduct Autonomous Inspections

   With the improved sense of responsibility and ownership of the equipment, operators can now be accountable for the cleaning and inspection procedures, revising the standard schedules and points of special attention. At this stage, operators and maintenance technicians should articulate in order to decide what is the best task distribution among them.

6. Visual Maintenance Management

   This step consists in standardizing all procedures, especially the ones consisting in visual inspection and management. Workplace organization, from raw materials to measuring tools should be stored in standardized locations, in order to be visually manageable.

7. Consistent Autonomous Management

   The final step of AM implementation consists in establishing it as a routine practice to be autonomously followed by operators, ensuring that it is an on-going effort of improvement.

The 12 Stages for TPM Implementation

In his book, Seiichi Nakajima (1988) presents a twelve-stage program for TPM implementation, divided into four phases. The first five stages belong to the preparation phase, and are:

1. Announcement of top management decision to implement TPM
2. Introductory campaign and education on TPM
3. Create organizations to promote TPM
4. Establish basic TPM policies and goals
5. Formulate a master plan for TPM development

The sixth stage, belonging to the preliminary implementation phase, is:

6. Hold TPM Kick-off

The next five stages comprise the TPM implementation phase:

7. Improve Equipment Efficiency
8. Establish Autonomous Maintenance program
9. Set schedule for planed maintenance
10. Train and up skill operators and maintenance technicians
11. Develop initial equipment management program

The final stage, in the stabilization phase, is:

12. Full TPM implementation and aim for higher goals

This multi stage approach can be used as a roadmap to guide the efforts towards the implementation of a TPM campaign, and also as a milestones' target to measure the overall program evolution.

By the end of this chapter, the overall state of the art regarding maintenance practices, especially Total Productive Maintenance, have been presented and explained to some detail. The following chapter introduces the identified problem, as well as the production processes used on site.

3 Printing Plant Initial Status

3.1 The Product

The Printing Plant in Colep Portugal is responsible for the transformation of the first raw material in the whole process, steel, in a sub product that is ready to be supplied either to the Assembly Plant at Vale de Cambra site (Figure 4), or shipped to other remote plants for assembly and filling.

The products of the Printing Plant, are classified regarding type, shape, dimensions, model and brand.

Each and every product consists of a specific steel sheet and a combination of varnish and colour layers, ranging from a single varnish layer, to multiple varnishes and up to 9 different colour layers.

The varnishes applied can affect both the aesthetic component, providing options like glossy or matte finish, but also the usability component, such as the ability to contain food or highly oxidant products.

Figure 4 - Aerosol body ready for welding

Regarding the colours, the flexibility passed on to the customers is immense. The ability to produce almost any design demanded is due to the overall company flexibility and a client focused approach. The more than 3000 different orders that were produced during 2011 can support this statement.

3.2 The Productive Process

The Printing Plant can be divided in three main areas. The primary cut, the lithography, where this project took place, and finally the secondary cut.

<u>Primary cut</u>

Figure 5 - Steel coils at the primary cut

The whole productive process starts in the primary cut. The steel used, also known as tinplate, arrives in coils at the facility. It is stored according to its proprieties, namely thickness of the sheet, width, and tin mass. It is cut in the "Littell" cutting machine, taking into account the current production needs, and temporary placed in the primary cut buffer, a storage unit located in the temporary cut hull. It is worth mentioning that the best cutting length and coil width is used for every product, in order to minimize the so-called *technical waste*, which is the mass of steel that is cut out on the secondary cut and sent to recycling.

Figure 6 - Warehouse of cut steel sheet

Figure 7 - 'Littell' cutting machine

Lithography

The lithography receives the bales of cut steel and has the mission of converting them into printed product. Here, the productive process consists in the application of coatings of varnish, paint, or both, to the plain steel sheet, followed by the cure of the component.

There are two technologies in use at the lithography: cure by temperature, named 'conventional technology', and cure by exposure to ultraviolet light, named 'ultraviolet technology".

The conventional technology is found on production lines 2, 3, 4, 5 and 6 (Figure 8). These are the only lines capable of applying varnish, which means that virtually every single product in the lithography will be processed at least once in one of these lines. Additionally, lines 3 and 5 can also apply colours before varnish in the same pass.

Figure 8 - Conventional Lines

Figure 9 - Ultraviolet Lines

The ultraviolet technology is used on lines 11, 13, and 15. These lines apply colours to the steel sheets. The number of different colours that each line can apply in a single pass is presented in Figure 10.

Regardless of the technology used, the actual process of printing has several similarities: both require a steel sheet to pass between a rolling press, where paint or varnish, in liquid form, is deployed in the exact place and quantity. Figure 11 below shows this process, called offset printing. The product applied, being paint or varnish, must be cured afterwards.

Figure 10 - Number of colours capability

	Line	Number of Colours
UV	L11	4
	L13	2
	L15	7
CV	L03	1
	L05	2

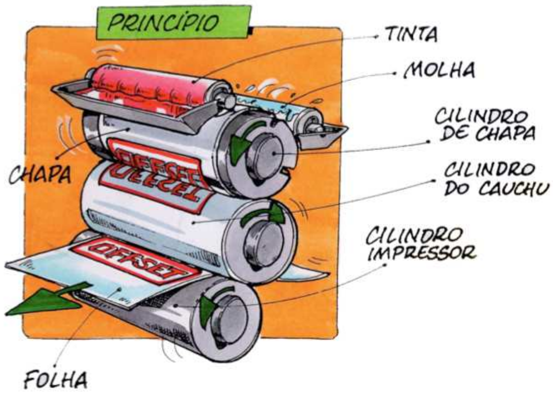

Figure 11 - Offset printing drawing

Secondary Cut

After being printed and varnished, the steel sheets contain several individual bodies as seen on Figure 12. At this time, they must be cut to individual bodies (Figure 12 and Figure 13) in order to be welded and then assembled with components.

Figure 12 - Product before secondary cut

Figure 13 - Product at secondary cut

3.3 Conventional Lines

Despite being in use for almost 30 years, the conventional lines are quite robust. They obviously have some maintenance issues, specially in supporting systems such as the feeding or unloading, but the printing units still perform fairly well.

Production Lines 2, 4 and 6 are varnishing lines, meaning that are only used to apply varnish layers to the steel sheets. This can be external, as a primer layer for posterior colour layers application or as a final protective coating on top of these; or internal, used in tins for food and whenever the product would attack the steel.

The varnish, applied in liquid form after being mixed with a solvent, is passed between a series of rolls until it reaches the roller. This main roll is very important, since it must apply the product in every inch of the sheet, except in the place where the tin will be welded. As a result, after application the sheet looks like plain varnish minus some stripes (Figure 14 and Figure 15).

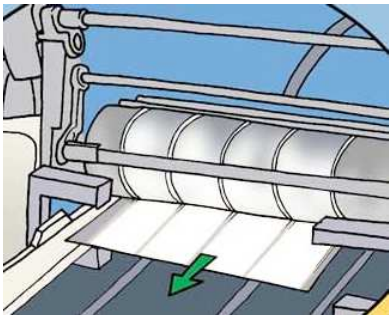

Figure 14 - Varnishing roller drawing

Figure 15 - Applying varnish

The sheet rolls in between to pressing cylinders, the upper one containing the varnish on its surface, and the lower one applying force upwards. Between two consecutive steel sheets, there is a period when there is now sheet in the middle of the two cylinders. In these brief moments, noticeable in the difference between the pictures below, the upper cylinder is deploying varnish to the lower one (Figure 17). As a result, there is a mechanism in place to remove this varnish from the lower cylinder, acting like a knife, cleaning it and preventing the next steel sheet from getting varnish residues on its lower side.

Figure 16 - Knife detail

Figure 17 - Varnish being passed to the lower roll

Production Lines 3 and 5 are also printers, applying paint as well as varnish in the same pass. Because of the varnish, they also employ the same knife system described previously

After product application, it goes into an industrial oven (Figure 18), working in continuous mode. The ovens have different lengths, as shown on Figure 19. This oven length directly sets the maximum production line speed: each varnish has its curing time in its specifications sheet, which means that the speed needs to be lower in a shorter length oven in order to guarantee a complete product cure. Consequently, different products attain different speeds in a same production line. Figure 20 below shows an overall drawing of a conventional line.

	Line	Oven Length (m)
CV	L02	27
	L03	24
	L04	36
	L05	30
	L06	24

Figure 19 - Oven length

Figure 18 - L05 Oven

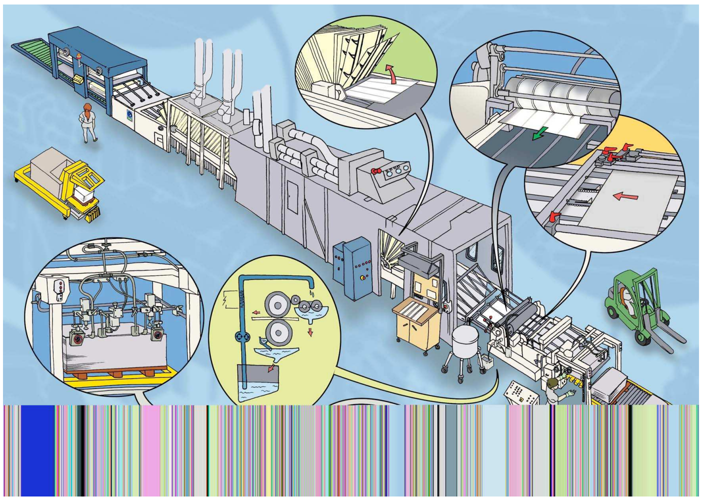

Figure 20 - Conventional line drawing

3.4 Ultraviolet Lines

Production lines 11, 13 and 15 use a set of ultraviolet lamps to cure the paint applied.

Line 15, seen on Figure 21, was the state of the art when installed brand new in 2007. It has seven printing units, capable of semi automatic change of patterns. After each two units there are some sets of ultraviolet lamps to cure the layers applied previously. In the end of the printing units there are extra lamps to ensure total cure of the paint. Figure 22 shows its double stacker, to minimize the time to change the bales of finished product.

Figure 21 - Production Line 15

Figure 22 - L 15 double stacker

Lines 11 and 13 are both from the same vendor, and where installed approximately 15 years ago. Line 11 has four printing units, with UV drying immediately after each unit. Line 13 is identical, but with only two printing units. (Figure 23) These lines are prone to frequent breakdowns, especially in the printing units and UV drying system.

Figure 23 - Ultraviolet lines 11 and 13

The steel sheets are loaded into the machine, in the loader (Figure 24) and then transported with belts and pushers through the printing units. Figure 25 shows an overall drawing of an ultraviolet line.

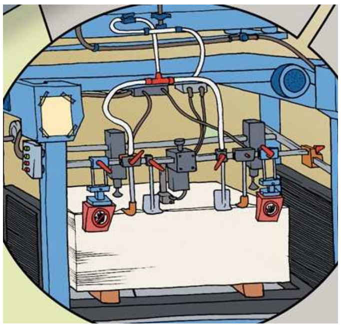

Figure 24 - UV line loader

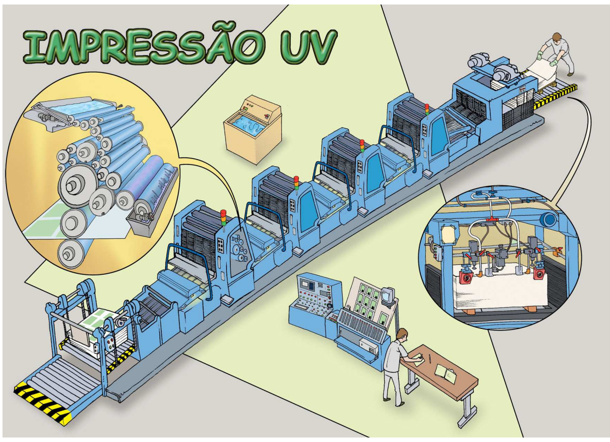

Figure 25 - Ultraviolet line drawing

3.5 Maintenance

Planned Preventive Maintenance

There were maintenance procedures to be performed with an established frequency for each line. However, the increasing frequency of breakdowns and consequent escalade of downtimes and maintenance costs, led to the belief that the maintenance procedures were either inadequate, inadequately performed or the frequency was not aligned with equipment needs.

The maintenance tasks can be weekly, bi-weekly, monthly, bi-monthly, trimestral, six-monthly, annual or bi-annual. In the beginning of each week, the list of tasks to be performed in that week is print. The maintenance chief then schedules what tasks are to be done in each day by maintenance personnel.

There is not an established routine to follow for each preventive maintenance task. Technicians are expected to know how to perform each task. When a doubt arises, either a more experienced technician or the vendor manual for the equipment is consulted.

Breakdown Maintenance

Breakdown Maintenance intends to fix a specific breakdown to get the equipment working again. The flowchart bellow (Figure 26) presents the current sequence of events leading to a corrective maintenance work order.

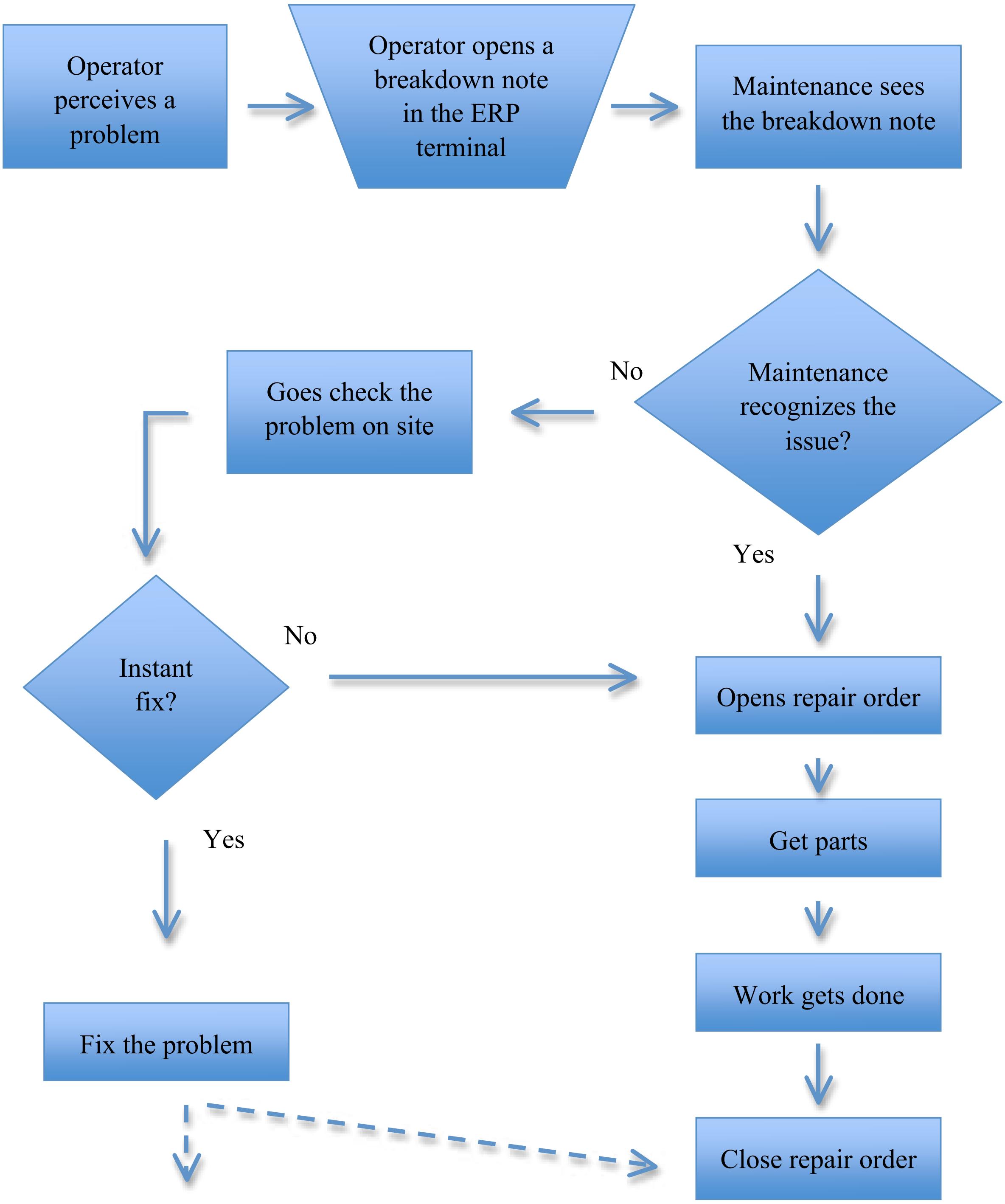

Figure 26 - Sequence of events for breakdown repairs

As it can be seen, there is plenty of slack for a breakdown note to go a number of different paths. The lack of a procedure for repair orders registration, despite the time taken to fix the issue, causes some breakdown notes no never be addressed a repair order. This can happen because it was an instant fix that the technician resolved on the spot when checking the problem, or because it was misdiagnosed by the operator opening the breakdown note. On another hand, the repair orders issued are closed in bulk, and only after some time has passed, so that the technician can close several orders at the same time. Despite the breakdown note having the initial timestamp, the time when the issue was indeed solved is not always registered, making these records useless when calculating breakdown-related downtimes.

Corrective Maintenance

Since there are so many breakdowns, the technicians are much more focused on quick fixing those breakdowns than root-cause-analysing the problems to come up with a permanent solution for that issue.

Most of the corrective maintenance performed is the result of the work of the Printing Plant Continuous Improvement Group, which seeks for points of improvement throughout the Printing Plant.

Autonomous Maintenance

Despite long plans for Autonomous Maintenance implementation in the lithography, there was not an established procedure in place. The Continuous Improvement Group was on the process of establishing the routines for each of the production lines, but at the start of this project, these were not finished nor approved by production managers yet.

The routines proposed, bearing in mind that operator's skill in maintenance was at an early stage, were essentially cleaning and inspect tasks.

3.6 Breakdowns and Maintenance Data

All decision making is based on the application of knowledge about one topic and the information available in any given moment. The ability to make better decisions, without a change in the knowledge, is therefore directly related with the quality of the information available.

In the lithography production figures are manually recorded by operators, using a spreadsheet-styled paper. In this paper, operators must register the number of steel sheets done on each production order, information about setups, production stops, and breakdown times in a series of codes (Figure 27).

Litografia - Códigos de paragem

Paragens diversas
Controlo Paragens diversas

Código	Pré Impressão	
PI 1	Defeito Fotolito	Paragem devido a problemas de fotolito (Nº fiadas incorrecto, OPF trocada, trama errada, etc.)
PI 2	Espera/ Problemas de Transportes	Tempo de paragem devido a problemas com transportes não relacionados com a produção (ex: *banding*)
PI 3	Falta de Transportes (*)	Tempo de paragem por não se encontrarem prontos os transportes necessários
PI 4	Problemas de acerto	Paragem devido a dificuldades de acerto por o fotolito não ter sobreposições (incluir o tempo de set-up se avançar o trabalho)
PI 5	Envernizar prelos/ tiras IGT	Paragens para envernizar prelos e tiras IGT
PI 6	Trabalhos Novos Que Não Dão Padrão	Tempo que se perdeu na máquina com um trabalho novo que não deu padrão (Setup + Acerto Padrão)
PI 7	Trabalhos Combinados Que Não Dão Padrão	Tempo que se perdeu na máquina com um trabalho combinado que não deu padrão (Tempo de acerto padrão + troca transportes)
	Laboratório Tintas	
LT 1	Falta de tinta (*)	Paragem da produção por a tinta não ter sido preparada
LT 2	Reformulação de tintas	Paragem para reformular tintas, na linha ou no laboratório.
LT 3	Tinta Insuficiente (*)	Tempo de paragem devido à necessidade de fazer tinta adicional
LT 4	Falta de carta de côr (*)	Tempo de paragem por falta de cartas
LT 5	Falta de Elementos na Carta de côr (*)	Tempo de paragem por falta de elementos necessários para a realização do trabalho (referir quais)
LT 6	Erro de form. e/ou pes. de tinta no Lab.	Tempo de paragem devido a erros na formulação e/ou pesagem de tinta no laboratório
LT 7	Tinta de retorno fora de padrão	
	Planeamento	
PL 1	Falta/ Espera de Escala	Tempo de paragem por não haver escala ou esperar por folha de outras linhas
PL 2	Falta de Materias Primas	Tempo de paragem por falta de verniz, tintas, cartas relacionado com planeamento (trabalhos não planeados etc.)
PL 3	Base de dados	Paragens devido a erro de base de dados (esquema trocado, verniz errado, alguma informação incorrecta na ordem, etc.)
PL 4	Espera de Rolos de Verniz	Tempo que a máquina esteve parada porque o rolo programado ainda está a ser utilizado em outra linha
	Produção	
P1	Arranque Linha	Tempo necessário para a linha atingir as condições normais de operação
P2	Arranjos	Tempo que a máquina esteve parada durante a execussão de um arranjo (contabilize a folha dada)
P3	Recuperações	Tempo que a máquina esteve parada durante a recuperação de um trabalho (contabilize a folha dada)
P4	Problemas Transportes Produção	Paragens da linha devido a problemas com transportes, originados na produção
P5	Falta de Pessoal	Tempo que a máquina esteve efectivamente parada por falta do impressor/Envernizador (não incluir tempo de refeições)
P6	Confirmação/ estabilização de padrão	Tempo que a máquina esteve parada para mandar folha ao verniz para confirmar padrão (côr e verniz)
P7	Segunda passagem de tinta/verniz	Espera de folha para aplicar 2ª demão de verniz ou outra cor
P8	Folhas Caídas no Forno	Tempo que a máquina esteve parada para retirar folhas caidas no forno das envernizadoras
P9	Espera/ Problemas Fundo de Linha	Tempo de paragem devido a problemas de fundo de linha relacionados com produção (deve procurar conhecer as causas)
P10	Espera/ problemas de Produção	Tempo de paragem devido a problemas de produção não contemplados nos restantes códigos
P11	Espera de decisão de Chefias	Tempo em que a máquina se encontra parada aguardando, apenas, decisão de chefias
P12	Aumento/ Diminuição da temperatura	Paragem da produção para atingir a temperatura necessária (excepto quando originada por outra paragem)
P13	Reuniões	
P14	Paragens Segurança	Tempo que a máquina permaneceu parada por razões relacionadas com segurança
P15	Problemas Troca (aut.) de Transportes	
P16	Problemas/Afinações alimentador	
P17	Folha Dupla	
P18	Folha Torta	
P19	Folha Mal Acamada	
P20	Folha Estragada	
P21	Blocking	
P22	Folhas de Provas	
P23	Riscos	
P24	Formação Programada	
P25	Tarjas de BE	
P26	Folha Perdida/Encravamento Grave	Encravementos graves no interior das linhas
	Qualidade	
Q 1	Queimar Folha	Paragens durante a operação de queimar folha (contabilize nº folhas)
Q 2	Escolha em Linha	Tempo de paragem durante escolha em linha. Contabilize nº folhas e adicione estimativa por velocidade reduzida
Q 3	Ensaios	Tempo de paragem durante ensaios (contabilize nº folhas)
Q 4	Auditorias	Paragens para realização de auditorias
Q 5	Acamar/ Desamassar Folha	Paragens durante a passagem de folha para acamar/desamassar (contabilize nº folhas)
Q 6	Espera/ Problemas Qualidade	Tempo de paragem devido a espera e/ou problemas de Qualidade
	Movimentação	
M 1	Espera Matérias primas	Paragem por falta de matérias-primas relacionada com movimentação
M 2	[illegible]	[illegible]

	Controlo A.E
Código	**Avaria eléctrica**
AE 1	Avaria no quadro Eléctrico
AE 2	Avaria eléctrica de motores
AE 3	Substituição de Fusíveis/ Micros
AE 4	Avaria no Alimentador
AE 5	Avaria de electroválvulas
AE 6	Detector dupla espessura
AE 7	Secagem U.V.
AE 8	Fornos C.V.
AE 9	Microcolor
AE 10	CNC
AE 11	Sincronismo
AE 12	Falta de Energia eléctrica
AE 13	Falta/ Espera Electricista
AE 14	Avaria no Descarregador

	Controlo A.M
Código	**Avaria mecânica**
AM 1	Sistema de molha
AM 2	Sistema de Registo
AM 3	Correias
AM 4	Mudança de Rolos bateria
AM 5	Afinação Baterias
AM 6	Espera de Rolos/ Rolos Mal Rectificados
AM 7	Troca de Facas/ Facas Mal Rectificadas
AM 8	CNC
AM 9	Avaria no Alimentador
AM 10	Rodas dentadas
AM 11	Veios
AM 12	Secagem U.V.
AM 13	Montagem/ Avarias Motores
AM 14	Microcolor
AM 15	Envernizadora
AM 16	Sincronismo
AM 17	Compressores/ Embraiagem/ Transmissões
AM 18	Lubrificação
AM 19	Avaria nos tapetes
AM 20	Substituição de Correntes
AM 21	Mudança de Válvulas
AM 22	Fornos C.V.
AM 23	Turbo
AM 24	Rede de Ar comprimido
AM 25	Queimadores
AM 26	Trocar Garfos
AM 27	Chiller
AM 28	Falta/ Espera Mecânico
AM 29	Garfos Empenados
AM 30	Avaria no Descarregador

Motivo de troca de cautchú	
1	Mudança de Formato
2	Cortado/Amassado
3	Descascar nas Reservas
4	Desgaste/Batido

Figure 27 - Lithography stoppage codes

This information is then manually inserted in a computer, where it is stored in a file. It is then copied into another file, which aggregates the production, stoppage and breakdowns figures for each week and computes a series of KPI's and charts to gauge performance for any given week.

In parallel, when a breakdown occurs, operators need to open the breakdown note on the ERP terminal in order for a maintenance order to be issued. It is worth pointing out that these two systems do not interact in any way, and since routinely maintenance repair times are not registered in repair orders, it is not feasible to assess how much time-consuming each breakdown is.

For the operators, who spend time registering breakdown codes and times, and also have to open the breakdown note, this duplicate data gathering proves quite inefficient. Not only they spend more time to register in separate places, but also this data is not combined to a central and more complete intelligence.

Additionally, since information is typed in when creating a breakdown note, and the production registries uses a list of breakdown codes, information could be much better handled if the data was combined together.

4 Methodology Used

During the course of the project, several methodologies were used according to the desired goal of each step. In the initial part of the project, there was the need to understand what was the situation, what was happening with the equipment and all the breakdowns. As so, considerable time and effort was put into gathering and sorting all the data regarding breakdowns and curative maintenance. Once this was done, Pareto analysis was done in order to identify the most impactful occurrences.

One way or another, the seven statistical tools (Imai 1986) were used throughout the analysis: fault-finding techniques were employed in order to identify the possible root causes of each of the most common issues. When these were identified, problem-solving methods were used to explore the options for root cause corrections. Finally, One-Point-Lessons where used to deploy some of the improvements and knowledge.

In parallel, it was decided that in order to track the progress and long-term success of the measures, information should be made available. Mean Time Between Fails, Average Repair Cost and Last Fail Date were the indicators chosen to be made available in the interface to be developed.

As in all improvement efforts, there must be a routine to, in a first instance, validate the contribution of the measures, and afterwards, sustain those improvements as a base for further ones. The DMAIC cycle, along with PDCA, were the selected ones.

4.1 Gathering and sorting data

The Enterprise Resource Planning (ERP) system used by Colep is provided by SAP and includes a “Maintenance Management” module. As seen previously in the flowchart (Figure 26), there are two different types of records regarding the breakdowns.

Firstly, when aware of a problem, the operator opens a “Breakdown Note”. In this note, the operator should identify what major equipment is faulty, such as “Feeder” or “Printing Unit”, pick the symptom of the problem from a drop-down menu, and type in a brief description of the issue.

The chief mechanic then analyses this note and eventually opens an associated “Repair Order”. This repair order is the instance that registers what parts were replaced, what was the cost, and whether or not it was an external repair service from the equipment vendor.

When it comes to analysing the breakdown history to treat it statistically, there are some immediate difficulties: since the specific failure is identified by an open text-field description by the operator, it is subject to the wording use to describe the perceived problem. The same problem can be registered in a series of different descriptions, regardless of the operator filling it in. On the other hand, if an operator choses a more generic wording for a description, for example “problem in the feeder”, it can also mean a variety of different problems.

Not even taking into account the probable and understandable operator misdiagnose of the problem, there is little confidence and usability in this data alone. The solution to this shortcoming consisted in the standardization of the data, cross-checking individually hundreds of notes it with the associated repair orders, in order to identify what was the real breakdown.

4.2 Pareto Analysis

In the end of the nineteenth century, Italian economist Vilfredo Pareto first observed a power law that would became widely used in business, production and society in general. He noticed that 80 per cent of the wealth was controlled by only 20 per cent of the population. This proportion, named Pareto Principle, can be observed in many unequal distributions of a parameter in given sample.

Since only a minority of the causes are responsible for a majority of the consequences, it was also dubbed as the law of the vital few and the trivial many by Joseph Juran (1974). It was interpreted as if the majority of the causes responsible for a minority of the consequences was trivial, as in not important, so Juran rephrased it to “the vital few and the useful many”.

Several of these proportions are often verified in business:

- 20% of the customers are responsible for 80% of the sales
- 20% of the sales provide 80% of the profits
- 20% of the sales people sell 80% of the products
- 20% of the time spent accounts for 80% of the value

In maintenance this is also verified:

- 20% of the equipment has 80% of the breakdowns
- 20% of the repairs 80% of the maintenance costs

In this project, there was the need to identify and label the different types of breakdowns: from the few issues happening many times, to the many issues that happened very few times. An ABC analysis classifies the sample items in three classes:

- A items: 20% of the issues represent 80% of the breakdowns
- B items: 30% of the issues represent 15% of the breakdowns
- C items: 50% of the issues represent 5% of the breakdowns

This type of analysis was conducted during several stages of the project. In an initial phase, it was used to identify which of the major components were the A-class items in each line. In a second moment, it was used in each of those components, to identify the most common issues.

4.3 Ishikawa Diagrams

Kauru Ishikawa was a Japanese engineer that who specialized in process analysis and developed several control tools, intended to the understanding of quality problems, their effects and causes.

As a tool to establish relations between verified effects and possible causes, he created a graphical tool that separates the root causes into six categories, also known as the six M's:

- Machine

  Causes affecting the machine can come from the operation, such as being use beyond its designed capability or the use the proper tooling, to maintenance, like being properly maintained, with specified lubricants and spare parts, and even updated to the latest software update.

- Measurement

  This is affected by the reliability of measuring technic and equipment, proper calibration performed, sampling intervals and gauge resolution. Eventual measurement biases caused by the environment are also listed here.

- Materials

  Root causes under this branch can relate with the quality of the materials used, reliability of the suppliers, suitability to the intended task, how the material was handled or has it been exposed to contamination. Information regarding the material is also part of this M: the accuracy of the information, is it updated or where can it be retrieved when needed are topics to be looked into.

- Method

  The details in the procedure, how where they tested, what where the test results, is it prone to mistakes and errors or has it been reviewed are some useful questions to be asked when exploring this category.

- Man Power

  Causes originated by the operator or technician may be traced back to the lack of proper training and consequent lack of skill, undefined judging guidelines, difficult or no access to information, distractions in the workplace, fatigue or even irresponsibility.

- Environment (Mother Nature)

  Environment can affect the way processes and equipment behaves, so the influence of temperature, light, noise, humidity, wind and rain must be taken into account when analysing the possible causes of an effect.

After identifying the root causes, a creative process of idea generation must be employed to come up with solutions.

4.4 5W 2H

The 5W 2H is a root cause analysis technic that essentially aims to understand the circumstances that lead to failure.

Its name is an acronym for the questions it asks:

- Who?
- What?
- Where?
- When?
- Why?
- How?
- How many?

4.5 5 Whys

This technic consists in repeatedly question "why?" to reach the root cause of the problem being analysed.

4.6 One-Point-Lessons

A One Point Lesson is a simple technic that is "used for specific features that need to be understood and remembered." (Borris 2006). It uses clear language and drawings intended to be understood by workers. It can be a:

- <u>basic lesson</u>, that operators and technicians must remember daily throughout their work;
- <u>problem case study</u>, based on specific problems and what should be done to avoid them;
- <u>improvements case study</u>, based on actual improvements made by the TPM implementation team.

(JIPM 1996)

4.7 Mean Time Between Failures

This indicator, MTBF, "is a measure of the reliability of the equipment and the standard of any maintenance and repair work done" (Borris 2006). It is calculated as the average time between failures of a part of component. There are at least two different modes of using this indicator: assuming immediate repair, meaning that once an issue is reported it is tackled immediately; or assuming infinite repair time, meaning that the part is replaced, hence not being repaired. This second approach is often named Mean Time To Failure (MTTF).

In this project, due to what was observed in the shop floor (and despite admitting that *immediate* may not be used literally), failures data was analysed under the conventional immediate repair assumption.

4.8 Data Base and Interface Application Creation

During the development of the project, some lack of awareness of the excessive breakdown issues was encountered. The breakdown data is available to be accessed on the ERP interface, but only in bulk form and with difficult analysis.

On the other hand, for the persons who have to deal on a daily basis with the problems on multiple production lines and equipment, it is difficult to keep track of how often a specific breakdown has happened in the last quarter. It may be relatively easy to remember that it broke down a *couple of times* in the last *couple of months*, but this is not a valid measurement, even as a ballpark figure. Since breakdown data was retrieved and sorted out, it was useful if this data could be presented in a much simpler and more accessible form, both to maintenance and production people.

As part of the Microsoft Office software package, the spreadsheet editor Microsoft Excel includes a software called Visual Basic for Applications (VBA). This is a Visual Basic programming language editor that runs embedded in Microsoft Excel.

This solution was chosen not only because Colep holds a Microsoft Office license and virtually every terminal has Microsoft Excel installed, but also because of data practicality since all the analysis was performed using this software. Additionally, the graphical interface is aligned with what most users are familiarized with, resulting in improved user experience and usability.

4.9 DMAIC Cycle

DMAIC is an acronym to the sequence Define, Measure, Analyse, Improve and Control. Used as an improvement and optimization tool, it consists in a systematic approach to a problem or challenge, relying in available data:

- <u>Define</u>

  Clear identification of the problem, under a problem statement, the process affected, the client, the target, the critical success factors and the project scope.

- <u>Measure</u>

  Under this stage, data is selected and collected. It is essential that good data is selected and that the sources are reliable, because as this is a data-driven method, questionable data will lead to questionable results.

- <u>Analyse</u>

  The collected data is analysed critically in order to identify the difference between the desired state and the current state of the problem. The sources of this gap are identified and the course of action is determined. The evolution of causes and consequences is analysed over the time frame.

- <u>Improve</u>

  Using idea generation techniques, a large number of possible solutions is created. These seek to prevent and correct the root causes of the observed problems. Ideas can be as innovative as wanted, but the easiest and simplest ones are to be preferred, since there is a lower risk of these evolving into possible problems in the future.

A detailed implementation plan should be created for the introduction of the improvements.

- Control

  Once the improvements are implemented, this stage has an important role in assuring continuous gains and sustainability for further improvements. Procedure manuals must be updated to the new standard and key performance indicators should be kept.

This improvement cycle is not a one-time measure. It should be used in continuous form to keep process improvement (Figure 28).

Figure 28 - DMAIC continuous cycle

4.10 PDCA and SDCA Cycles

Professor William Edwards Deming is credited as the evangelist of the Plan-Do-Check-Act cycle. An iterative management method, the PDCA is widely employed in business, process and product improvement.

- Plan

  The initial step consists in identifying what are the desired goals to achieve in the said project. After identifying what is the future vision, a set of actions must be planed in order to accomplish that vision.

- Do

  Having a clear set of actions and a clear path, it is under this second step that implementation occurs. In parallel with this implementation, measurements should be made to critical indicators to the project.

- Check

  After collecting the data and measurements made in the previous step, a cautious analysis must be done to address whether or not the actions are leading in the desired way.

- Act

  In case of discrepancies between forecasts and actual results, corrective measures must be taken. Eventually, more detail should be taken on the planning step, validating each assumption in an early stage.

Iterating through this cycle the necessary number of times, improvements will become visible. At this time, the alternative cycle, SDCA, should take over. The first letter stands for Sustain (or Standard), meaning that the newly introduced practices must be standardized so that the improvement does not fade away after some time.

5 Search for Solutions

The application of the previously mentioned methodologies on the identified problems resulted in the procedures, standards, documents, application interfaces and achievements that follow.

5.1 Sorting of the data

The original breakdown data was prevenient by the notes introduced in the system by the operators (as seen in Figure 26). The system, by design, lacks uniformity in data insertion format, since operators have to type in the breakdown description. In Figure 29 and Figure 30 show below, this problem can be seen clearly: many different ways of registering the same problem. To assess the real dimension of a breakdown this data was treated to standard definitions, as shown on the right column in the figures below.

avaria nomicroclor	Avaria Microcolor
abestoradores furados lampada n-5	Avaria Obturadores
avaria nos obestoradores lanpada n3	Avaria Obturadores
falha nos obesturadores n3	Avaria Obturadores
problemas nos obturadores lampada uv nº3	Avaria Obturadores
Falha Obsturadores Lampada Nº3	Avaria Obturadores
obturador da lampada N7 partiu	Avaria Obturadores
avaria nos obesturadoresn lampada n-1	Avaria Obturadores
lampada n 6 obesturador partido	Avaria Obturadores
Obsurador Roto	Avaria Obturadores

Figure 29 - Example of typing differences and errors regarding the same breakdown

bateria desafinada	Afinação Bateria
afinação da bateria un-4 não lavava	Afinação Bateria
AFINAÇÂO DA BATERIA UNIDADE N-1	Afinação Bateria
Afinação bateria unidade 1	Afinação Bateria
afinaçao da bateria da und2	Afinação Bateria
afinaçao bateria und2	Afinação Bateria
Afinar rolo de conexão	Afinação Bateria
Afinação Bateria Unid 2 Linha 11	Afinação Bateria
afinacao de bateria	Afinação Bateria
afinacao das baterias	Afinação Bateria
Afinar rolos da bateria un:2	Afinação Bateria
Unidade 2. Bat. desafinada	Afinação Bateria
afinar bateria unidade 2	Afinação Bateria
afinação bateria unidade 2	Afinação Bateria
afinar bateria unidade 3	Afinação Bateria
Afinação bateria unidade 4	Afinação Bateria
a imprimir mal,afinar rolos da bateria	Afinação Bateria
Afinação dos rolos da bateria un :1	Afinação Bateria
afinação bateria unidade 3	Afinação Bateria
afinaçao de bateria fazia arrasto emanch	Afinação Bateria
afinar bateria unidade 2	Afinação Bateria
Afinação de Baterias	Afinação Bateria
Bateria Desafinada!...	Afinação Bateria
afinar bateria e molha da un 3	Afinação Bateria
afinar bateria e molha da un 1	Afinação Bateria
Afinação Bat. unid. 2...	Afinação Bateria
afinar baterian3	Afinação Bateria

Figure 30 - Another example of typing variations

5.2 Identifying the A-class problems

On this organized data, a Pareto analysis was performed, in order to identify which were the most impactful problems. Production lines 11 and 06 were selected as an example for UV and CV respectively, and the data used throughout the analysis will be presented next to step by step details and reasoning[1]. Data for the remaining production lines can be found on "ATTACHMENT A: Summary of Breakdown Data Analysis", at the end of this report.

[1] For corporate strategic and confidentiality reasons, the absolute cost values, number of occurrences and consequent average costs are not disclosed in this report. This, however, does not compromise the explanation of criteria followed and analysis results. The charts show the accurate relative proportion between different equipment affected and frequency of issues.

Production Line 11 (UV)

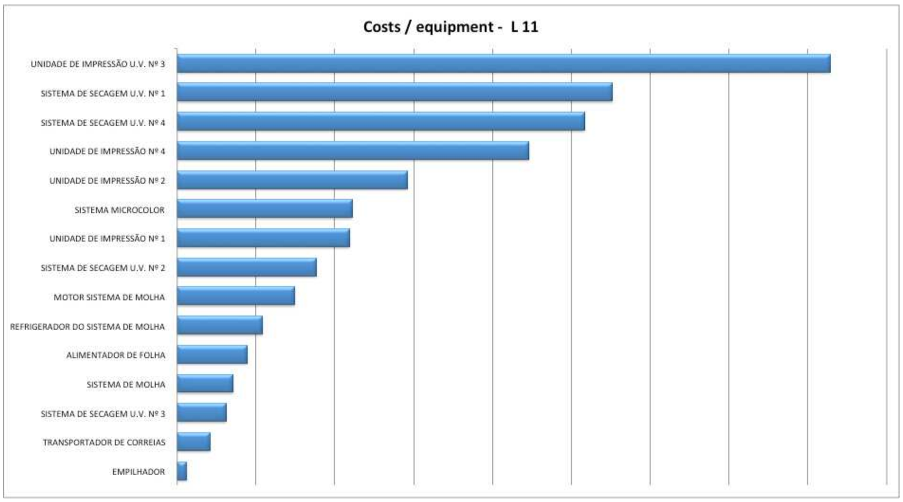

Figure 31 - Relative equipment repair costs on L11

A pattern can be identified in the cost distribution. The printing units and the UV drying units are the most costly equipment in terms of breakdown maintenance. Aggregating the printing units and the drying units results in the following distribution for the top five major equipment breakdown maintenance costs, shown on Figure 32 below.

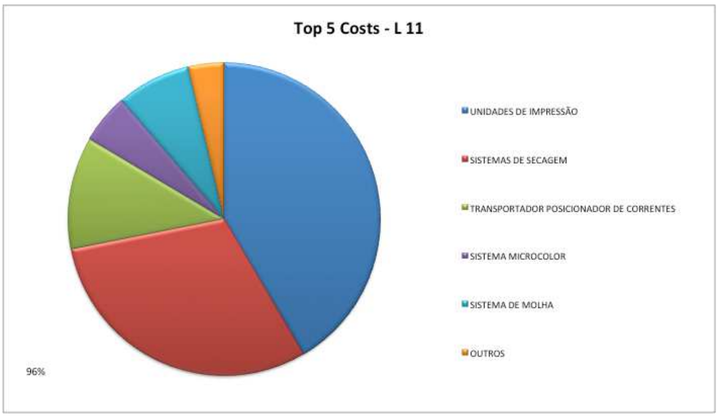

Figure 32 - Top 5 costs on L11

These five machines are responsible for 96% of the repair costs in production line 11. In order to filter potential one-time major breakdowns that would cause an inclusion in this shortlist due to a single (or few), yet very expensive repair, an average repair cost was also computed, as shown on Figure 33.

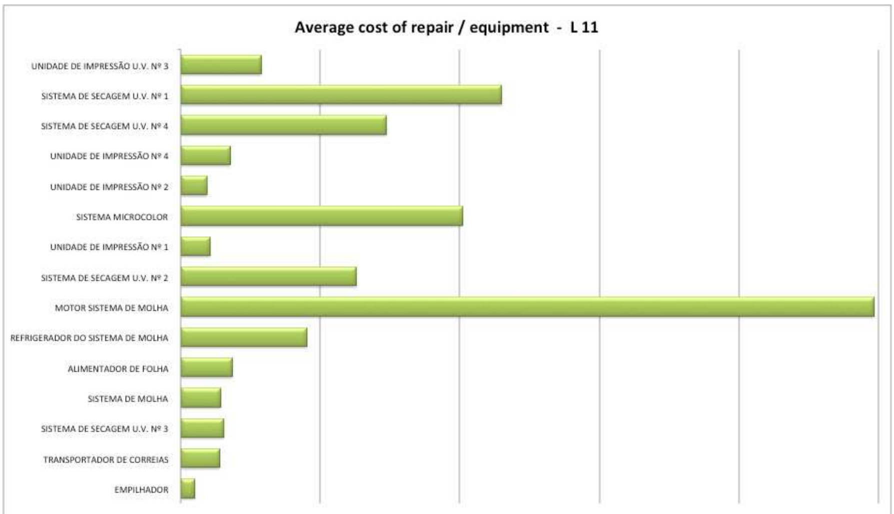

Figure 33 - Relative average repair cost for L11

Taking into account that the data is vertically organized in the same order of the relative total cost of repairs (Figure 31), it can be understood that the lower an equipment is on the list, the less its critical mass this average cost has. The "Motor Sistema de Molha" (dampening system engine) value in this chart is an example of an outlier: a single yet very expensive repair, which is not representative of typical maintenance needs on the equipment.

Once the equipment most affected by breakdowns was identified, the data sorting shown above was the need. Thanks to the standardized problem descriptions it would now be possible to statistically identify *which* where the problems happening on *what* equipment and *how often* were they happening.

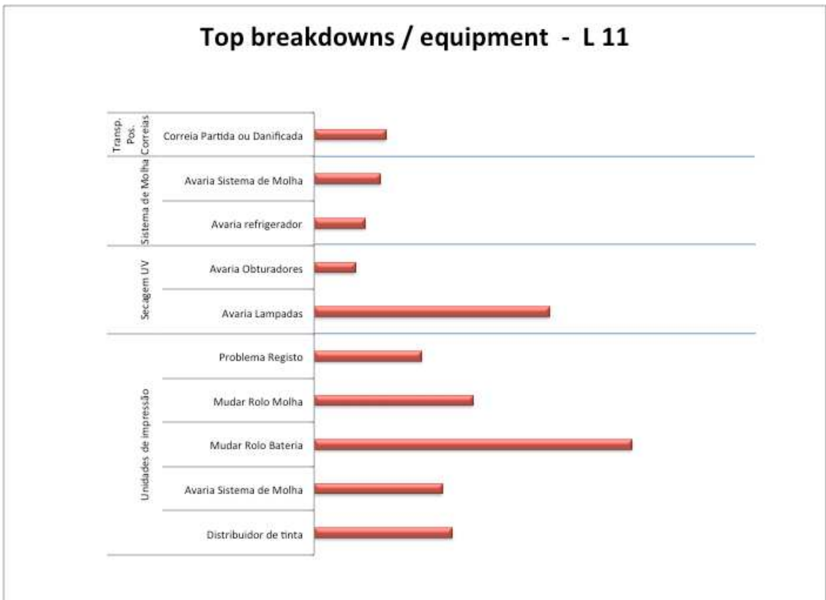

Figure 34 - Relative frequency for the Top breakdowns / equipment on L11

Production Line 04 (CV)

The following charts refer to L04 data, used as an example of a conventional line. Again, data regarding the remaining lines can be found on charts in attachment A.

In this case, Figure 35 shows that the cost distribution is even more concentrated on few equipment.

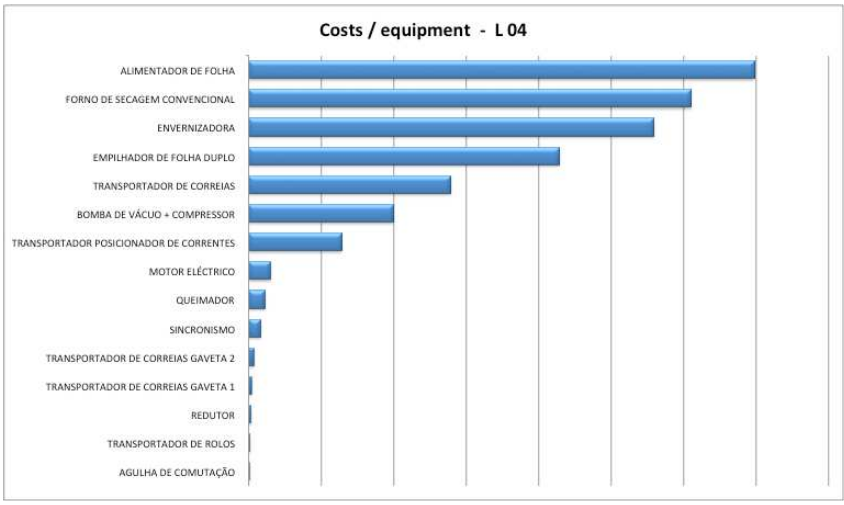

Figure 35 - Relative equipment repair costs on L04

The Top 5 most costly equipment on Figure 36 compounds to 86 % of total L04 repair costs.

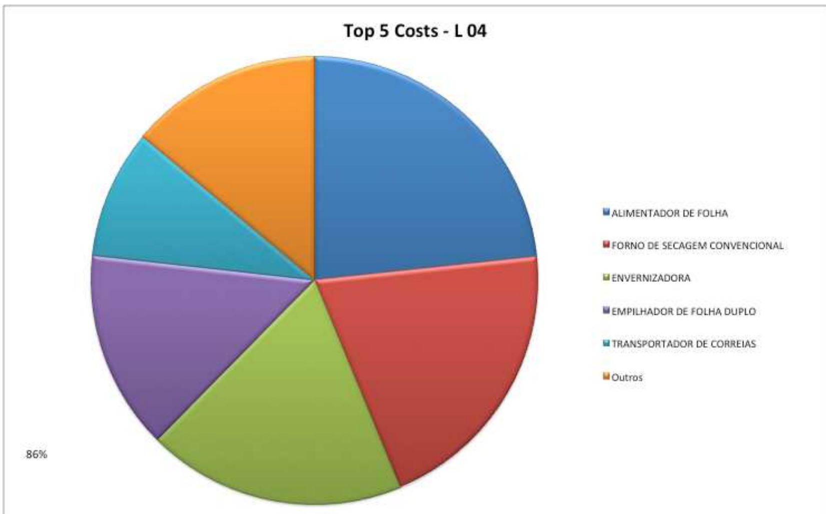

Figure 36 - Top 5 repair costs for L04

Once again the average cost for repair was calculated, so that potential outliers could be identified (Figure 37).

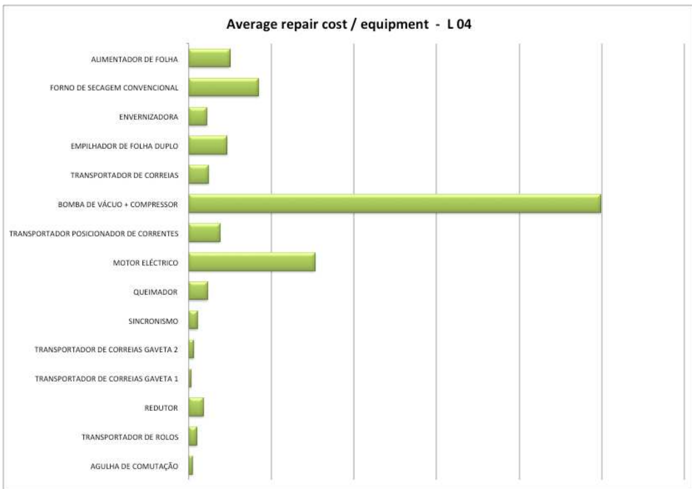

Figure 37 - Relative average repair cost for L04

And finally the most common breakdowns were identified:

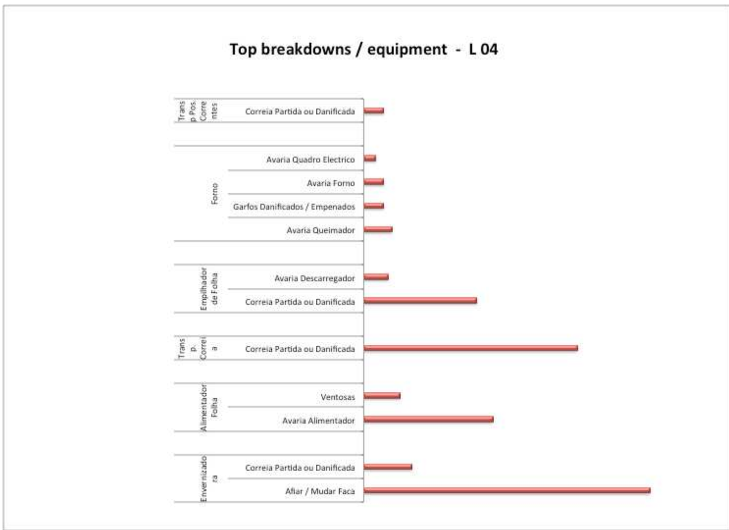

Figure 38 - Relative frequency for the Top breakdowns / equipment on L04

The absolute most common breakdown notes submitted involves changing the knife of the varnishing cleaning system. Other frequent breakdowns are broken transportation belts and problems in the feeder.

5.3 Critical analysis on breakdowns

Once the most impactful breakdowns for each line were identified, there was the need to perform some critical analysis on that information obtained. This step involved an on-the-field approach, talking to both maintenance technicians and machine operators[2]. For each common breakdown, for each production line, three initial questions were asked:

- What breaks down?

  This was the most essential question to be answered by production and maintenance personnel. What exactly was the problem that happened when the description read “issue in the stacker” or “feeder problem”. It was clear that the ultimate these descriptions could be caused by an array of diverse problems, but typically it would be a well-known and fairly common issue.

- Why?

  This second question intended to count on the experience of operators to track down a root cause for the problem, whether it was the run’s specifications, the steel sheet used, or atmospheric conditions that affected equipment. This question did not get as many answers as the first one.

- Can it be prevented?

  This was the last question asked regarding each breakdown, and aimed to appeal to the sense of improvement and get suggestions to prevent breakdowns. Not only did this question get even fewer answers than the previous one, but it also got some remarks that breakdowns are inevitable and there is no point in trying to prevent them.

Figure 39 shows an example of the retrieved data. More examples can be found in “ATTACHMENT B: Breakdowns and Root Cause Analysis”.

LINHA 13
Avarias frequentes

	Descrição	O que avaria?	Porquê?	Pode ser prevenido?
Unidades de impressão	Avaria Ar Comprimido	Não avaria	Nem sempre é falta de ar, operários fazem diagnostico errado	
		Pneumatico		
		Sistema de referenciamento 'manual'		
	Avaria CNC	Guia 'não vai à medida'	Tem que ser referenciado manualmente pelo operador, o que nem sempre acontece	Sim, se o operador referenciar manualmente quando muda de formato (estabelecer procedimento) (treinar)
	Mudar Rolo Bateria			
	Mudar Rolo Molha			
	Avaria Sistema Molha	Roda de teflon	Desgaste	
Sistema Secagem UV	Avaria Lampadas	Sobreaquecimento / falha ar		
		falha agua / entupimentos		
	Avaria Obturadores	partir encaixes		
Empilhador Folha Duplo	Avaria Descarregador	'Já não avaria'	Agulha comutador foi trocada, deixou de avariar. So parte correias	
	Trocar Correia	Desgaste Normal		
Transp Posicionador Correntes	Trocar Correia			
	Problema Esquadria	Ajuste fino	ajuste muito fino, a maioria dos operadores não faz, chama o mecanico. Até se faz rapido, mas a linha tem que parar ate chegar la o mecanico	
	Distribuidor de Tinta	Parafuso		

Figure 39 - Example of critical analysis of breakdowns for L13

[2] When first contacting with each person, the context was properly clarified, in order for the person to know what were the project’s goals, why were those questions being asked, and how could they be most helpful. The majority of them notably tried to be helpful and brainstormed eventual prevention solutions.

5.4 Root Cause Analysis

With all the data gathered and the information compiled from technicians and operators feedback, root cause analysis was performed.

A logic way of looking at breakdown problems is to ask "Why". Often there is not even need to reach the fifth why, as the 5 Whys methodology suggests. This was the case of the CNC unit root cause analysis.

CNC Breakdown
Why?
Because the equipment is old and gets stuck
Why?
Because operators do not reference the positioning system, switching directly from one size to the next
Why?
Because it is not established in the procedures

Figure 40 - CNC unit root cause analysis

Moreover, when looking at several problems, sometimes after the third "Why", the root causes from different 'final' problems start to converge into a common initial issue. This was especially noted while analysing the issues occurring in the ovens (**Error! Reference source not found.**).

In this case, the maintenance procedure was revised to include more frequent inspections and cleanings in the ovens, in order to reduce breakdowns and decrease those quality flaws.

The steel sheets are getting dirty and damaged while in the oven.
Why?
Because the forks are dirty, bent and the speed is irregular.
Why are they dirty?
Because they are not cleaned often enough
Why is the speed irregular?
Because the turbine was not working smoothly
Why?
Because the oil level was below the recomended
Why?
Because it was not verified during maintenance
Why?
Because it was not specified in the procedures

Figure 41 - Oven issues root cause analysis

The problems with broken transportation belts was analysed as well. An Ishikawa diagram can be found in "ATTACHMENT B: Breakdowns and Root Cause Analysis", displaying the various causes for belts to break.

In order to design corrective actions, this analysis was done for all the common issues identified. The corrective actions include revised maintenance procedures, information flow tools, and One Point Lessons, presented in the next chapter.

5.5 List of Corrective Actions

Throughout the project, several improvement points were identified. These range from very concrete work procedures to more abstract ones, such as the way information is passed along.

Figure 42 below shows a list of these improvement points, and Figure 43 some possible actions to accomplish the desired improvement.

	Problems
P1	Difficult to find and filter information regarding breakdowns
P2	Breakdown records not very efficient
P3	Damaged / Broken Belts
P4	Suction cups
P5	Suction cups' arms
P6	Unable to pull sheets
P7	Steel sheets gets dirty / damaged in the oven
P8	Burners shut down
P9	Irregular functioning
P10	CNC stuck
P11	Paint transporting roller breakdown
P12	Dampening system
P13	Shutter breakdown
P14	UV lamps breakdown
P15	Store Autonomous Maintenance records
P16	Keep Autonomous Maintenance schedule and task list

Actions

Figure 42 - List of identified problems

Figure 43 - List of possible actions

Some of the proposed actions are somewhat specific to address individual problems, but others have a wider scope and end up affecting more than just a single issue. Figure 44 below gauges the effects of proposed actions on each problem, where the numbers 5, 3 and 1 represent high, moderate, and low impact, respectively.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
A1	5		1	1	1	1	1	1	1	1	1	1	1	1		
A2		5														
A3			5													
A4			5													
A5			3													
A6			1													
A7			1													
A8				3		1										
A9					3											
A10						3										
A11							5									
A12							3									
A13								3								
A14									3							
A15									5							
A16										5						
A17											1					
A18												3				
A19													3			
A20														3		
A21		1	1	1	1	1	1	1	1						5	5

Figure 44 - Impact of actions on the identified problems

As it can be seen, some actions only have a moderate or low impact on a single problem. On the other hand, actions addressing a more global problem, such as the information flow, or the way breakdowns are registered, on top of having an obvious high impact on those issues, also affect indirectly most of the specific problems. This is a by-product of the increased awareness of what is happening on the shop floor.

In the next chapter, these actions will be further explained.

6 Improvement Proposals and Prototypes

6.1 One Point Lessons

CNC Manual Referencing

There were considerable issues with the controller of the guides in UV production lines 11 and 13 (Figure 45).

During the breakdowns' investigation, it was verified that the information operators had about this equipment was not complemented with the knowledge of the technicians.

Figure 45 - CNC Interface

Since the equipment is old, there is the need for an intermediate step while changing the format for the next job. This step intends to reference the positional system to the axis origin before setting the new target coordinates for the axis motors to move to.

Although some operators might know that this practice should be done, it was not a standard procedure. The One Point Lesson created clarifies what is the correct procedure and what is the reason to perform this task. The document can be found in "ATTACHMENT C:
One Point Lessons and Standard Operating Procedures", at the end of this report.

This document points out the procedure that must be performed and highlights its importance. In addition, the Standard Operating Procedure for the change in format task was rewritten to explicitly include this step. This rewritten procedure can also be found the same attachment in the end of this report.

Belts cleaning procedure after changing knife

As detailed before on the production process description in chapter 3, the varnishing process consists of a rubber roll that receives varnish all around, opposed to the offset printers with the dampening units that only transport product in the intended place to be print. This causes an excess being passed on to the pressing roll in the time between two sheets. This excess needs to be cleaned off, by mechanical action of a blade commonly known as "cleaning knife". Since both the cylinder and the knife are in permanent contact, tearing occurs, at which point the knife starts to lose its edge and allows for varnish to pass. Steel sheets then start to get contaminated with this varnish residue on the underside. When the operator notices this, the machine has to stop and the knife must be sharpened again.

The process of changing the knife is not utterly complex, and can often be performed in around ten minutes by the technicians. The installed knife must then adjust to the cylinder, a process that, depending on the sharpening done, may take up to 30 minutes.

When steel sheets contact with varnish on the underside, besides getting varnish on the undesired side, they contaminate the transporting belts throughout the line (), creating several issues, starting with twisting steel sheet due to belts stickiness, stuck and trapped sheet, and eventually broken belts.

Figure 46 - Dirt accumulated in the belts

The knife changing SOP was revised to include the belts' cleaning task as well. This does not add up to non-productive time, since it can be done while the installed knife is adjusting to the cylinder. The One Point Lesson created highlights the differences introduced with the procedure revision: whenever the knife gets changed, the belts must be cleaned with a simple pass with a cloth imbibed on alcohol. Both the revised SOP and the OPL can be found on "ATTACHMENT C: One Point Lessons and Standard Operating Procedures".

6.2 Revision of Preventive Maintenance Procedures

As identified in the previous chapter, some preventive maintenance procedures were not adjusted to the reality of the equipment.

For these situations, the computed MTBF was compared against the frequency of preventive maintenance routines, and according to the results, new frequency was scheduled. As with all the improvement actions, these changes are to be monitored and adapted accordingly to the results obtained.

For the conventional lines, the most accentuated discrepancies were upon the ovens, their gas burners and the transportation forks' system that moves the steel sheets inside the oven. Since each production line was analysed individually, and some were considerable worse than others, the new revised frequencies reflect this information. Moreover, some verification tasks were included in the autonomous maintenance routines, hence not being included in the revision of the preventive maintenance procedures.

For the ultraviolet lines, the biggest imbalances between breakdowns and preventive maintenance frequencies were found to be on the ultraviolet drying system.

These changes can be consulted in "ATTACHMENT E: Preventive Maintenance Procedures Revision", where a comparison between before and after procedures' frequency is included.

6.3 Make information available

After the extensive breakdown data sorting and organization performed initially in the project, it became clear that simply showing the breakdown frequencies for each line, and presenting some comparison charts between the lines was both ineffective and time wasting. It was ineffective because it was still difficult to navigate the data and apply the wanted filters, ranging from production line, to equipment within that line. In order to do so, people had to familiarize themselves with the way data was stored and listed.

From the maintenance point of view, it is certainly difficult to mentally keep track of how frequently does equipment X on line Y breaks down. If, by a simple interface, technicians could easily look up how often did a problem occur and when occurred for the last time, they could become much more aware of patterns and cyclic breakdowns. Eventually, this information could lead to better maintenance practices, especially regarding preventive maintenance.

From the production point of view, having access to this information in plain language, such as "average time between fails = x days" and "last fail = y", would also be a step in the direction of more responsible operators, focusing their attention on specific potential issues under a "breakdown alert".

Combining these advantages, prototype was developed. Working with Visual Basic for Applications (VBA), a visual basic programing editor built in Microsoft Excel, an interface was built. Its requisites were:

- Intuitive Interface
- Easy-to-understand Information
- Useful Information Listing
- Easy to keep updated

With these requisites in mind, Figure 47 shows the initial interface of the prototype built.

Users can select any specific production line by either clicking it on the lithography plant, or selecting it from a list (Figure 48).

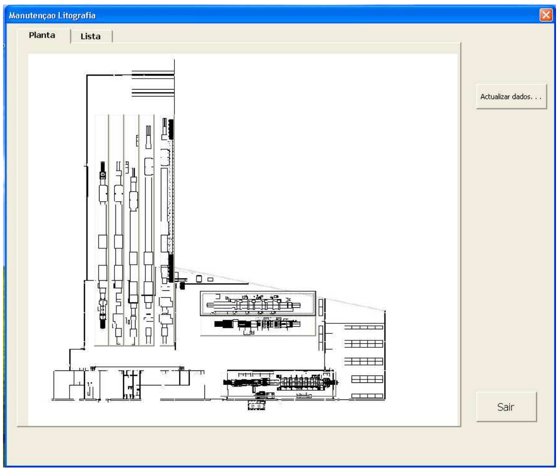

Figure 47 - Application initial interface selecting line from plant

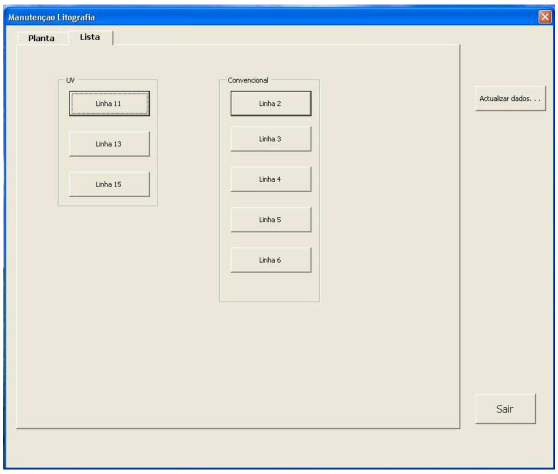

Figure 48 - Select line from list

Once a Line is selected, there is a global information page (Figure 49), where the overall average time between failures, the last failure date, and the average time between the last three failures are presented. This last indicator is intended to be used as a trend monitor, signalling relevant variations in the present and recent past when compared to long time measurements on the same equipment. To contribute to simplified visual management, its back colour changes between red with exclamation marks, when the recent trend identifies that equipment performance is deteriorating; and green with positive characters when it is improving.

For each line, the application then lists the most problematic equipment, based on stored data. It is then possible to gauge equipment reliability by selecting the wanted one. This triggers a similar form, shown below on Figure 50, with data for that specific equipment.

Figure 49 - Line global information page

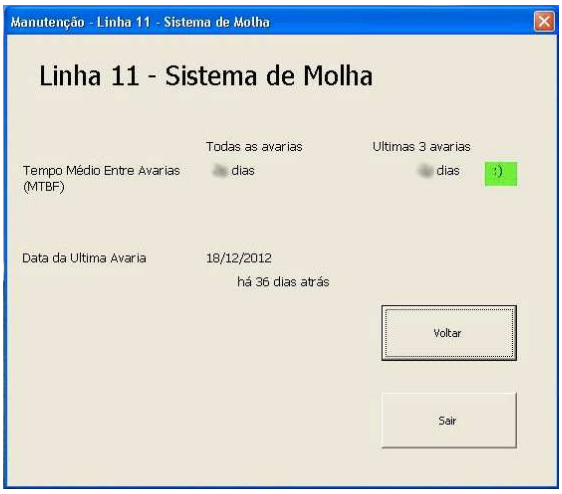

Figure 50 - Equipment specific information

Two final remarks about this application should be made:

- The program computes the data shown in real time, as opposed to simply displaying static values for a given moment in time. This means that it remains coherent over time, provided that records are kept up to date.
- Updating the application backend database is a user-friendly operation. Although the application does not automatically retrieve the data from the ERP records, it reads the report and updates only the newer information that was missing. The user simply has to point to where the report file is located. A step-by-step guide was created with update instructions.

6.4 Autonomous Maintenance Interface

Now that Autonomous Maintenance is about to be initialized on the lithography, it is important to keep records of its deployment from the start, so that coherent conclusions and changes can be made in the future.

In the initial deployment of Autonomous Maintenance tasks, there are weekly jobs, once-every-two-weeks ones, once every three weeks, and monthly ones. As a result, in any given week, many combinations of job frequencies can be done. Added that lithography lines often labour in three-shift mode, it would be difficult to track what should be done, what was already done that week, what was still missing, and who did what task in what week. Furthermore it would be hard to register operators' feedback on both the tasks and their descriptions and the equipment state after regular AM.

With the "Effective Autonomous Maintenance Implementation" goal, a prototype for managing the AM information was designed. Similar to the previous interface presented, it needed to:

- Be easy to use
- Have the information needed
- In an understandable way
- Provide the ability to check other weeks' AM tasks
- Register done maintenances and comments
- Show these records
- Be updatable

The initial interface is identical to the breakdowns' application. This intended to make users more familiar with both applications, by interacting with the same design and mode of operation, and also because this way, if the usage justifies so, both applications can easily be merged into a single one with both features, even attaining synergic gains, by having Autonomous Maintenance performers specifically aware of risky equipment.

After selecting one production line, the screen updates to a general interface, where the week number is emphasized. As seen in Figure 51, the current week is shown by default.

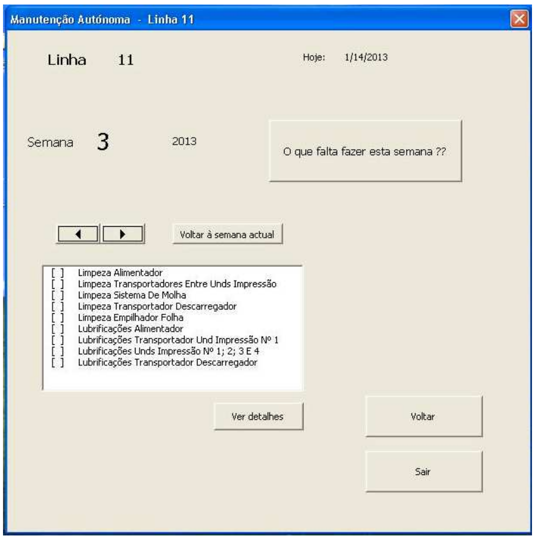

Figure 51 - Effective Autonomous Maintenance Implementation weekly schedule

Next to the week number there are two arrows. These control the week being shown. By clicking either one of these controls, the user will update the interface to show the previous or next weeks' list of AM tasks. Since there is no stop in place, a user can navigate throughout the entire month's, or even year's, list of tasks. Fortunately, there was also designed a button to get back to the current week, for increased usability.

The list of tasks shows everything that has to be performed in that specific week, regardless of being a weekly or monthly task. The tasks that have already been performed are marked with an X inside the brackets, while those waiting to be done present an empty space. The entries are indicative of the type of maintenance, such as cleaning or lubricating, and the equipment.

Once a task is selected, users can see its details. Figure 53 shows the form that pops out. It details what is the task, on which line, what week is it referring to, what equipment, what components, what materials are needed and whether it was already executed or not. If it was, then a button linking to the registered information is shown. If it was not performed yet, there is the option to register it as done, opening a register form. This form, shown on Figure 52, is pre-filled with the information filtered so far (production line, equipment, week), and takes in the date when the maintenance was done, the employee's code and eventual comments regarding equipment condition or performance.

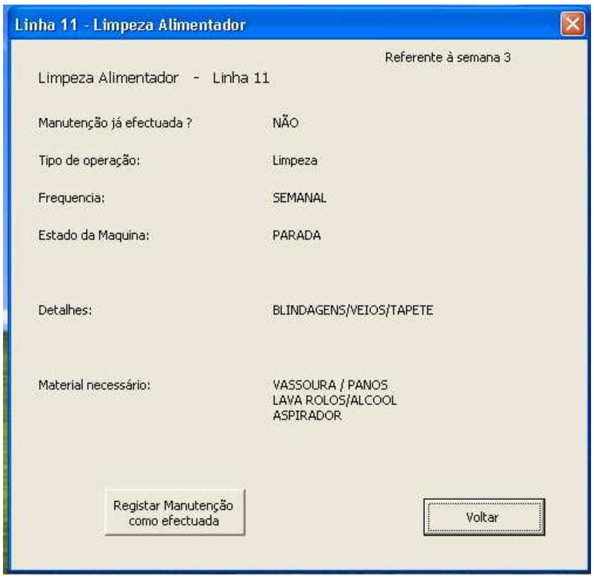

Figure 53 - AM task details

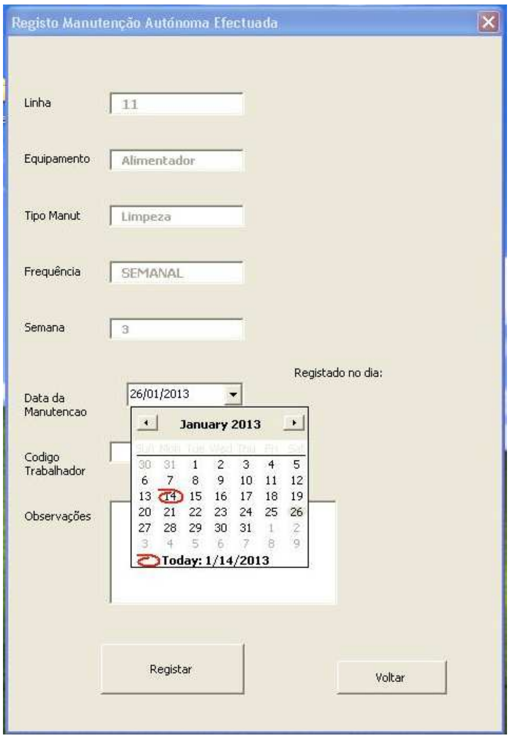

Figure 52 - Registering done maintenance

As validation mechanisms, it is not possible to register a maintenance execution with a date still to come, and employees' codes must comply with the stipulated format.

For any give week, back in the general interface, a big button makes it possible to see what tasks are yet to be done to complete the designed Autonomous Maintenance routines.

6.5 Correcting the data problem

Early in the project, a data registration inefficiency was identified when opening breakdown notes in the SAP ERP terminal. Operators would have to manually type, in an open text field, a breakdown description. As mentioned before, this prompted to many descriptions of a same problem, which is increasingly frustrating when that problem happens frequently. To improve this situation, a "Breakdowns Catalogue" was developed.

This catalogue would focus on the most common issues, and to simplify its usage, it would be multi-staged. Instead of the open text field, there would be up to three progressive drop-down selection menus.

The first one contains the equipment common designation, and is intended to do a gross filtering. The possibilities for the conventional lines are listed in Figure 54 below. The following drop-down list would subsequently be filled upon selection of the "parent" category. This list contains the equipment-specific part that was affected in the issue being reported (Figure 55). A third and final selection is intended to identify if the part has broken of is just damaged and needs replacement, and eventually the failure mode (Figure 56). On every level there is the option to select "Other" and unlock a text field to still type in the issue, if not present in the list. A table containing all the combinations of the three lists can be found on "ATTACHMENT D: List of Common Breakdowns for Drop Down Menus". As shown on the tables, a mere three clicks can translate in the accurate description of 33 different breakdowns, with this number being easily expandable.

Figure 54 - Example of drop-down menu 1

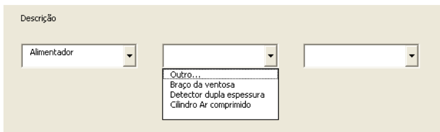

Figure 55 - Example of drop-down menu 2

Figure 56 - Example of drop-down menu 3

It is worth mentioning that the data structure, specifically the ERP database entries, will remain unchanged, since the result of these menu selections will concatenate into one string, replacing the open text field input. This new system is still pending implementation in the ERP user interface.

7 Conclusions and further works

Throughout this project development, there was the need to put in practice many of the teachings from the most diverse courses of the academic curriculum. In addition, several other skills and techniques were studied, which allowed for an increase in industrial, manufacturing, and business knowledge, that will certainly be very beneficial in a time when changes and challenges are constant.

The project aimed for an optimization in the implementation of the Total Productive Maintenance methodology, with an analysis of the existent routines and eventual redesign of those practices, and also to support the Autonomous Maintenance implementation.

For a more structured analysis of the results and work developed in this project, the identified problems and the solutions implemented are detailed in the following list:

- <u>Preventive Maintenance Routines</u>

  During the project, the preventive maintenance practices were compared with the breakdown data and repair orders. Some disparities were identified and new routines and schedules created in order to mitigate these imbalances.

- <u>Breakdown Maintenance Awareness</u>

  During the data-gathering phase, it became clear that access to quality information about the breakdowns' trends would help technicians see the big picture in maintenance. The Breakdown Data Application developed corrects this information issue, providing not only indicators of maintenance effectiveness, but also their evolution along the TPM implementation.

- <u>Breakdown Data Registering</u>

  A new method was designed for breakdown description while opening a breakdown note, consisting of a series of dropdown selection menus instead of an open text field, reducing the typing errors and variations in descriptions for a same problem.

- <u>Focused Improvements</u>

  Some issues were discovered where a focused improvement action could solve and prevent them from happening again. These actions were developed and procedures created to sustain the improvement benefits.

- <u>Autonomous Maintenance Implementation Assistance</u>

  The Autonomous Maintenance routines consist in tasks to be performed with different frequencies, and often by different people. Consequently, it is extremely important that accurate records are kept to ensure that tasks are performed, and do so according to the established schedule. Additionally, these records contain operator's comments regarding the task's execution, which allows for accurate AM monitoring and eventual fine-tuning.

Overall, and as mentioned before in this report, Total Productive Maintenance should not be thought about as a short term or one-time program for problem fixing. It is long term commitment towards skill transfer and total employee participation. Most of all, it is a change in mentality. Like all changes, it will always find some resistance upon the way, product of the human-nature inherent inertia to leave the comfort zone. Dr John Kotter defends that 70% of major changing efforts in organizations fail (Kotter 2012). Furthermore, 50% of the transformations attempts fail by “not establishing a great enough sense of urgency” (Kotter 1995). Analysing the case according to Nakajima’s proposed 12 stages for TPM deployment, the Printing Plant is already in the *Implementation Phase*, with multiple stages happening in parallel. However, in light of the statistics mentioned above, there could be a greater *sense of urgency* in the need for change in paradigms and consequently, behaviour.

All in all, the tools developed provide a base for this sustained change, by either easily showing the current state of equipment, improve procedures and monitor Autonomous Maintenance. Together, these enable a way to track short-term wins, for which recognition and reward must be given, to enhance long-term success in organizational transformation.

As for further works, the scheduling of production jobs for each line could be looked into. Nowadays performed manually by very experienced people, they could be aided by an algorithm to help achieving a more efficient scheduling. Following a set of dynamically adjustable restrictions, such as operators’ experience or production line current issues, the algorithm would compute all the possible sequence of jobs for all the lines, iteratively sorting them in the most efficient possible way. With this planning, the overall average throughput time in the lithography would be reduced, lowering capital and storage costs, and setup times would be improved as well. In addition, this structured planning would allow maintenance to be schedule in advance and taken into account while assigning jobs to production lines.

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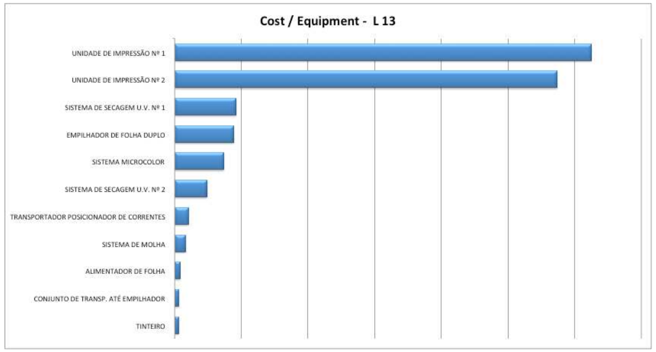
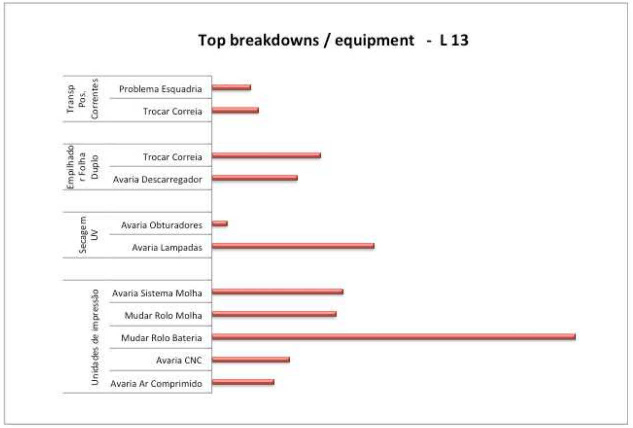
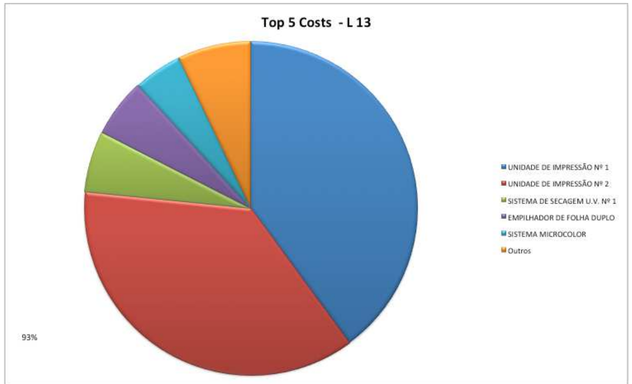
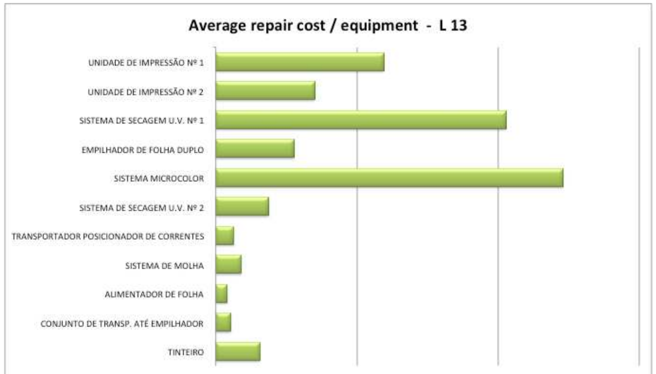
ATTACHMENT A: Summary of Breakdown Data Analysis

Production Line 13

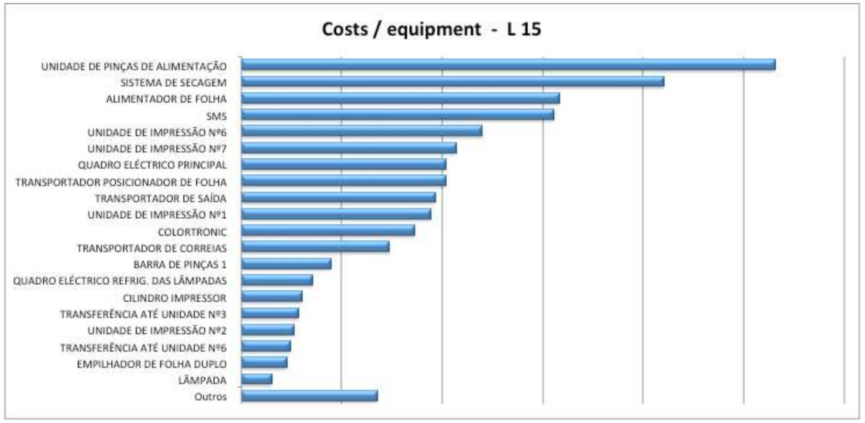


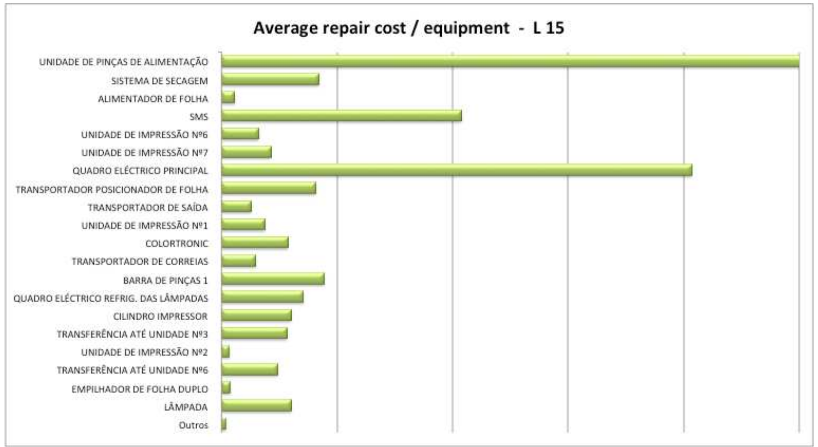


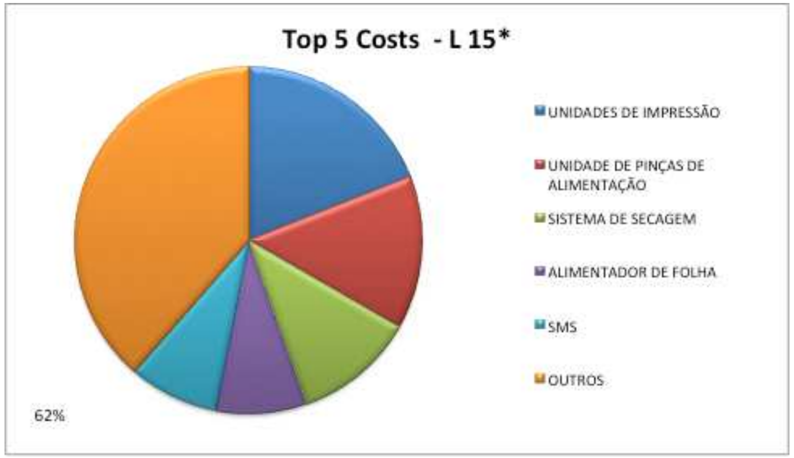


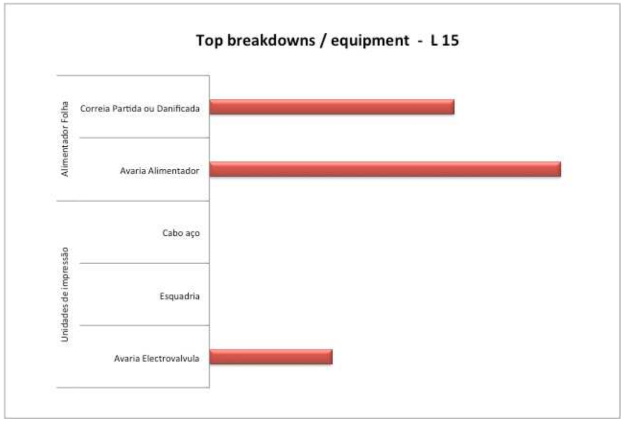


Production Line 15

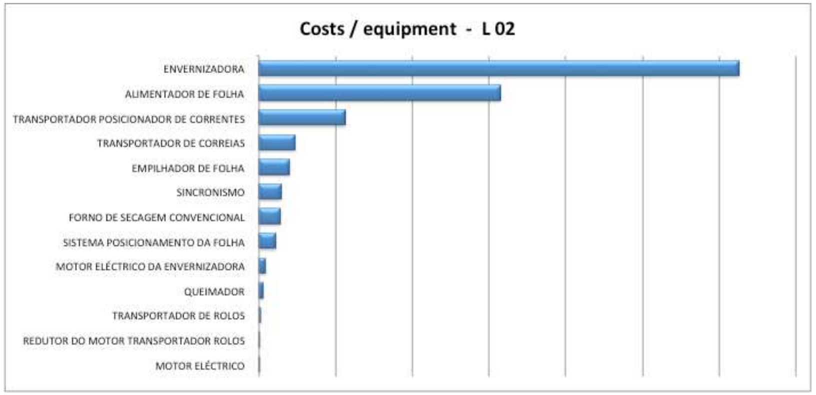


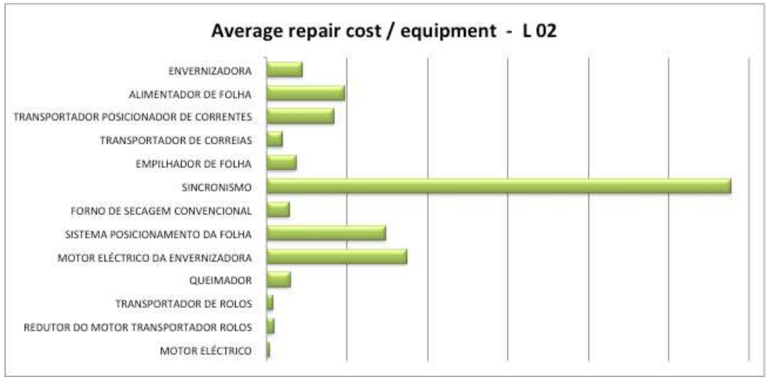


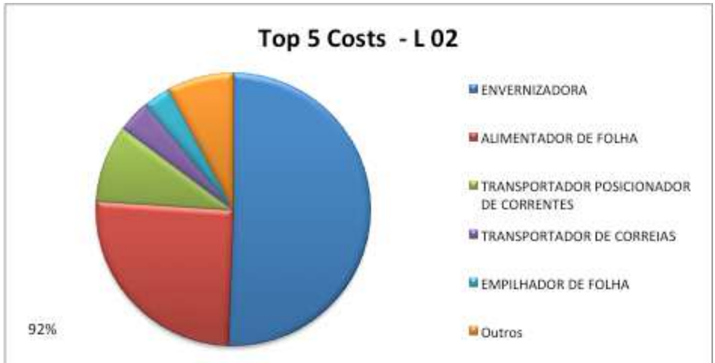


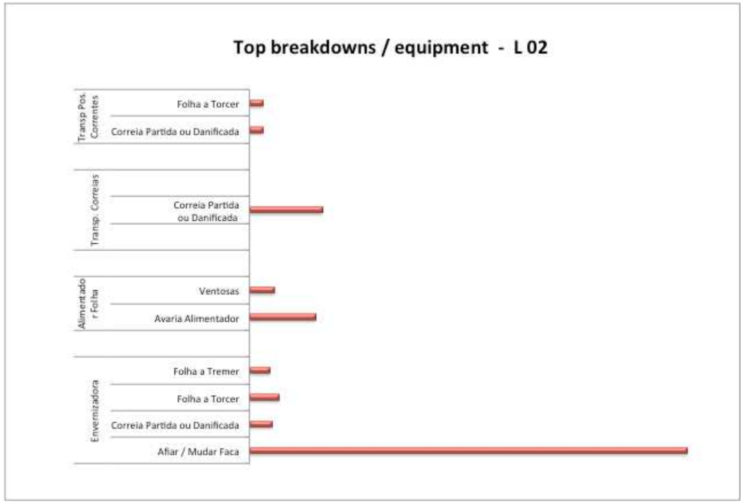


Production Line 02

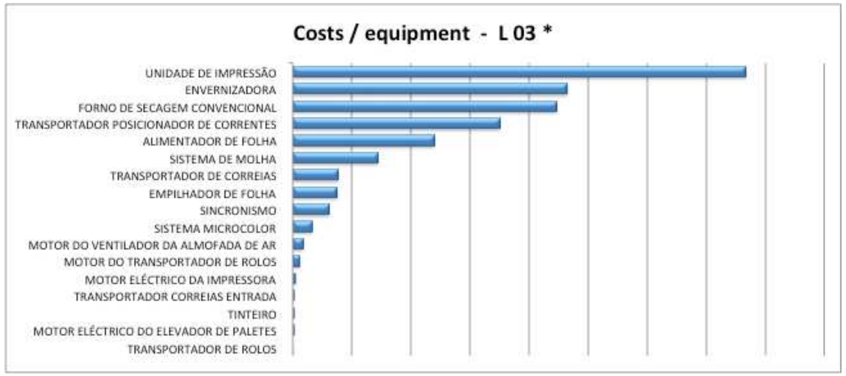


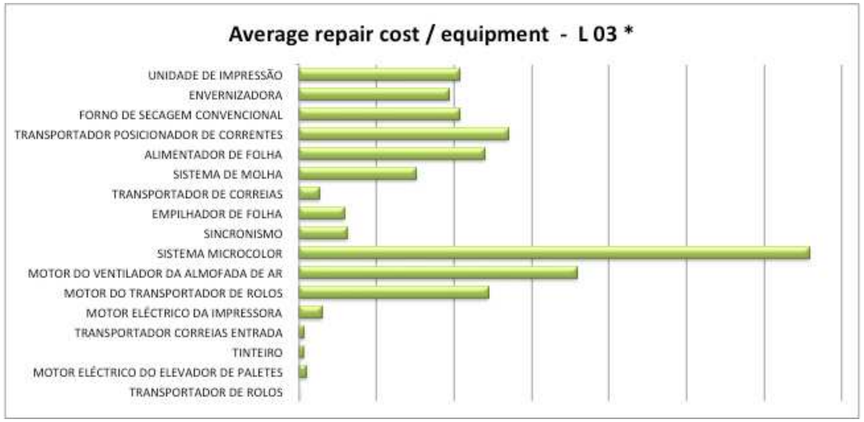


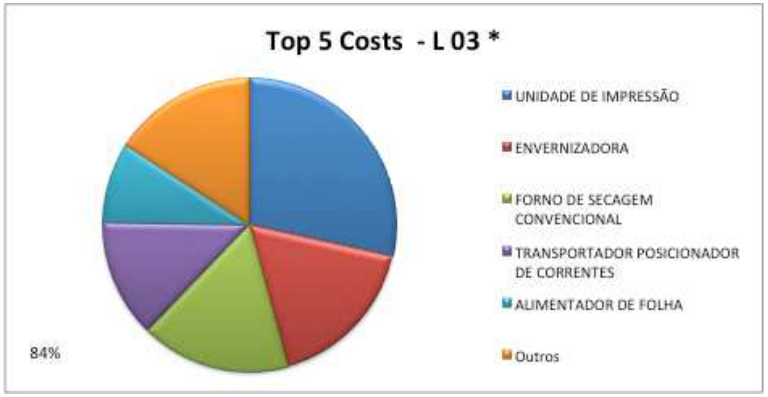


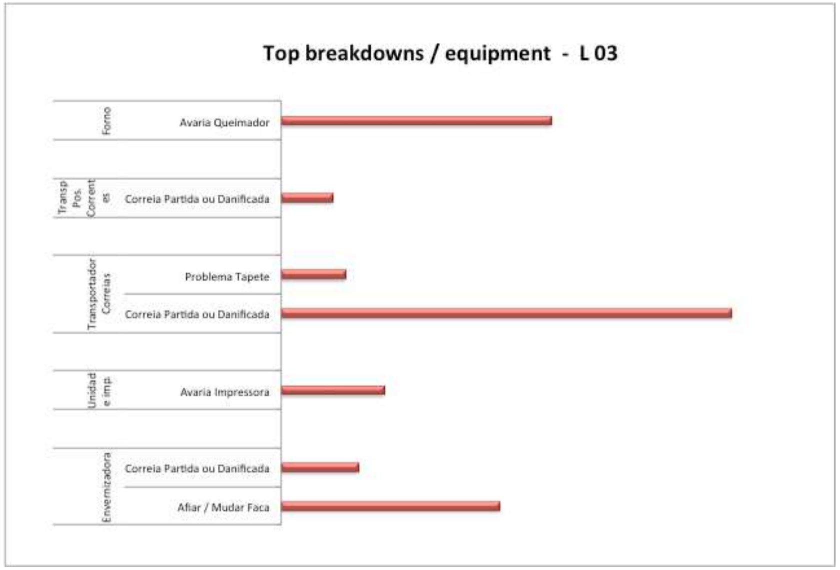


Production Line 03

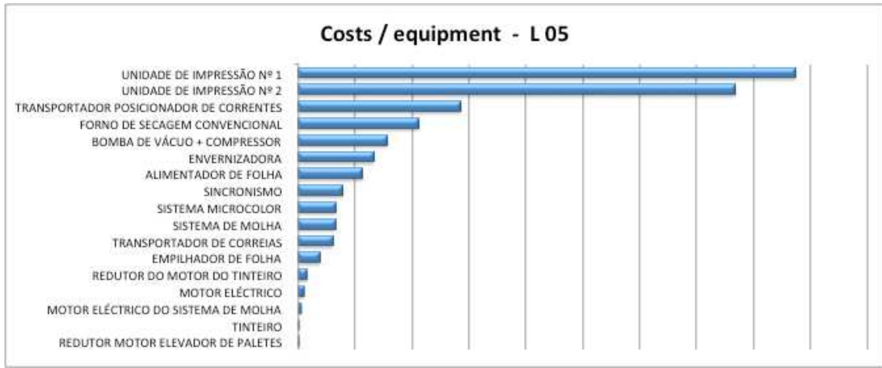


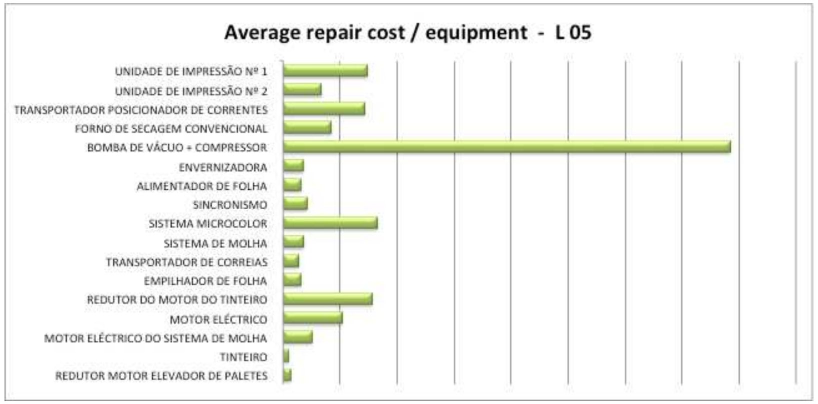


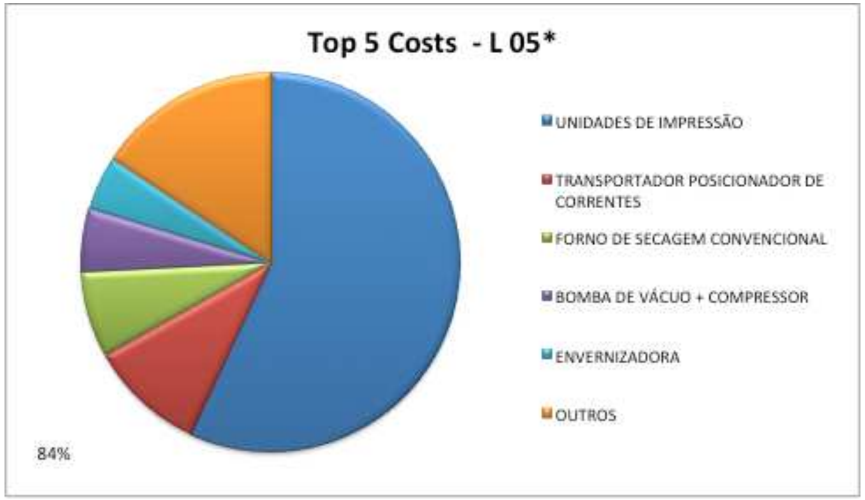


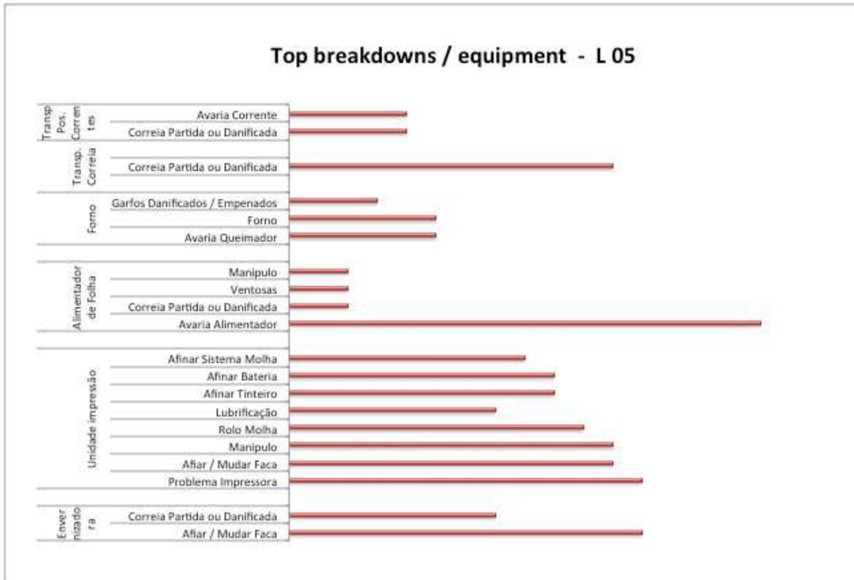


Production Line 05

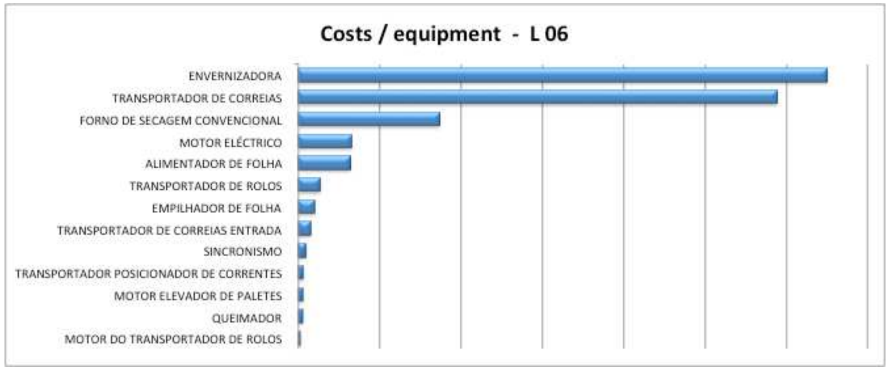


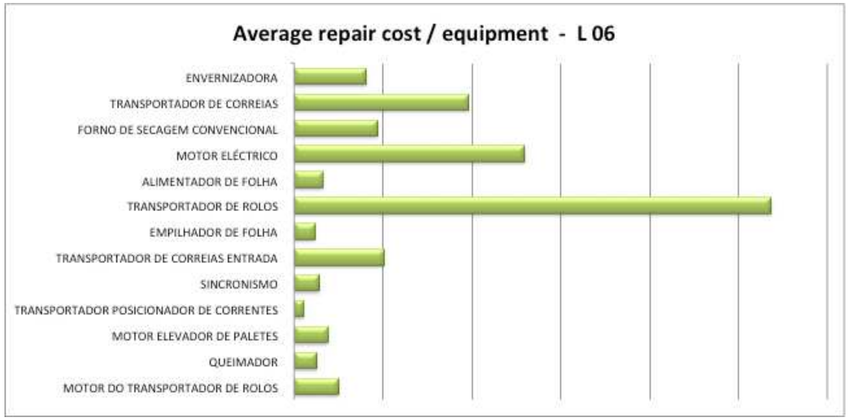


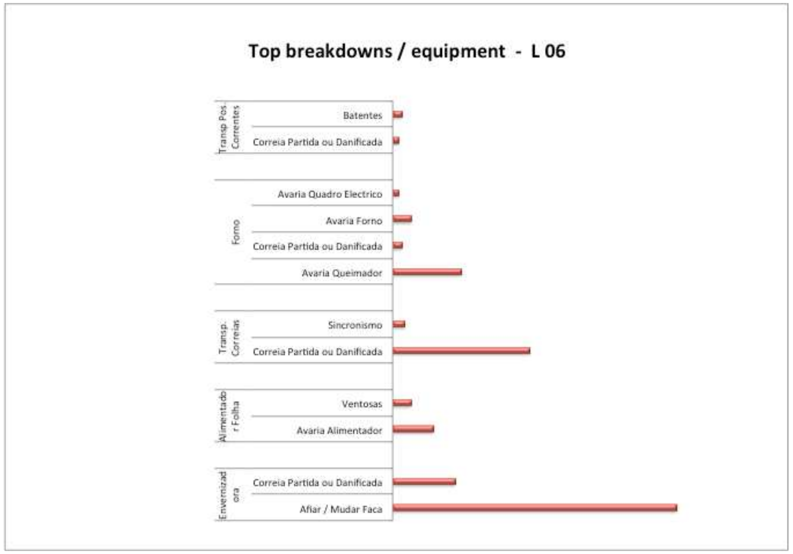




Production Line 06







ATTACHMENT B: Breakdowns and Root Cause Analysis

	LINHA 11 Avarias frequentes Descrição	O que avaria?	Porquê?	Pode ser prevenido?
Unidades de impressão	Distribuidor de tinta	Parafuso suporte do cilindro partiu; Cilindro que rebenta; Avaria Electrovalvula; Mudar Rolo 2		
		Parafuso		
	Avaria Sistema de Molha	Agua contaminada; Lixo na agua; Rolos danificados;	Má lavagem	?talvez?
	Mudar Rolo Bateria Mudar Rolo Molha			
	Problema Registo		Desgaste do Cilindro Folha Qualidade Material Velocidade	
Sistema Secagem UV	Avaria Lampadas	Problema Electrico micros excesso temperatura	temperatura da lampada 900ºC; temperatura da agua 160ºC	
	Avaria Obturadores	corrosão fugas	oxidação	?talvez? Utilização de outro fluido para refrigeração? Oleo?
Sistema de Molha	Avaria refrigerador	falta de agua permutador congelado		SIM, sistema de verificação de nível (tubo por fora da cuba, ou outro sistema de verificação de nivel)
	Avaria Sistema de Molha			
Transp Posicionador Correias	Correia Partida ou Danificada	Encravamentos		Manutenção

Figure 57 - Critical analysis of breakdowns for L11

Envernizadora	Afiar / Mudar Faca	Tem que acamar	Mal afiada	Verificação da lamina apos afiar
	Correia Partida ou Danificada	Parte		
Alimentador Folha	Avaria Alimentador	Prob Electrico		
		Afinar		
	Ventosas	Ar Comprimido		
		Substituir cilindros		
Transportador Correia	Correia Partida ou Danificada			
Empilhador de Folha	Correia Partida ou Danificada	Correias		
	Avaria Descarregador	Batentes Esquadrias		
Forno	Avaria Queimador	Desliga		Limpeza? Incluir na MP
	Garfos Danificados / Empenados		Folha encrava	
	Avaria Forno	Tubagem para a inceneradora, Borboletas sujas		Limpeza? Incluir na MP
		Não liga Queimador		
		Velocidade inconstante, Esticadores de correntes do forno	Oleo no turbo, folga	Verificar Nivel na MP
	Avaria Quadro Electrico	Fusiveis, ...		
Transp Posicionador Correntes	Correia Partida ou Danificada	é raro		

Figure 58 - Critical analysis of breakdowns for L04

	LINHA 06 **Avarias frequentes** **Descrição**	**O que avaria?**	**Porquê?**	**Pode ser prevenido?**
Envernizadora	Afiar / Mudar Faca	Desgaste normal / depende do verniz verniz branco (fundo)		
	Correia Partida ou Danificada	Desgaste / Partir		
Alimentador Folha	Avaria Alimentador	Ventosas		
	Ventosas	Ajuste do ar / afinações		
Transportador Correia	Correia Partida ou Danificada	Correias partidas		
	Sincronismo	Correntes / eixo		
Forno	Avaria Queimador	Vai abaixo / não é avaria		
	Correia Partida ou Danificada			
	Avaria Forno	Velocidade inconstante, Esticadores de correntes do forno	Oleo no turbo, folga	
		Queimador / garfos empenados		usar a velocidade do ventilador como remedio
	Avaria Quadro Electrico			
Transp Posicionador Correntes	Correia Partida ou Danificada			
	Batentes	(e correntes tambem)		

Figure 59 - Critical analysis of breakdowns for L06

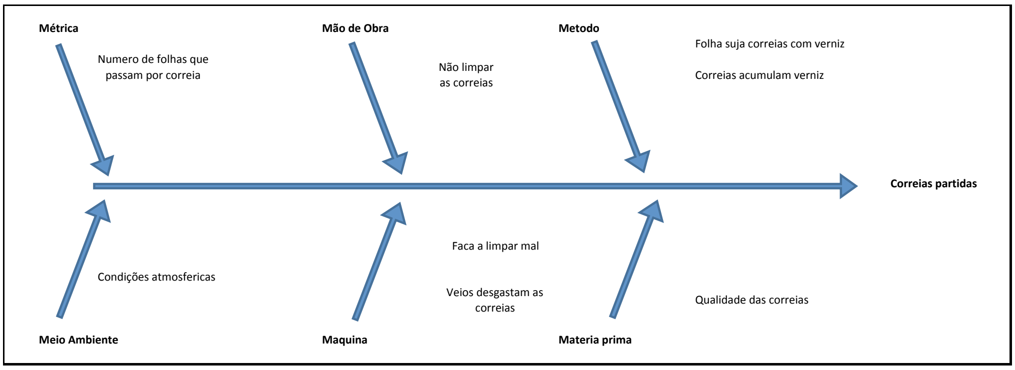


Figure 60 - Ishikawa diagram for broken belts' problem

ATTACHMENT C: One Point Lessons and Standard Operating Procedures

Referencing the CNC

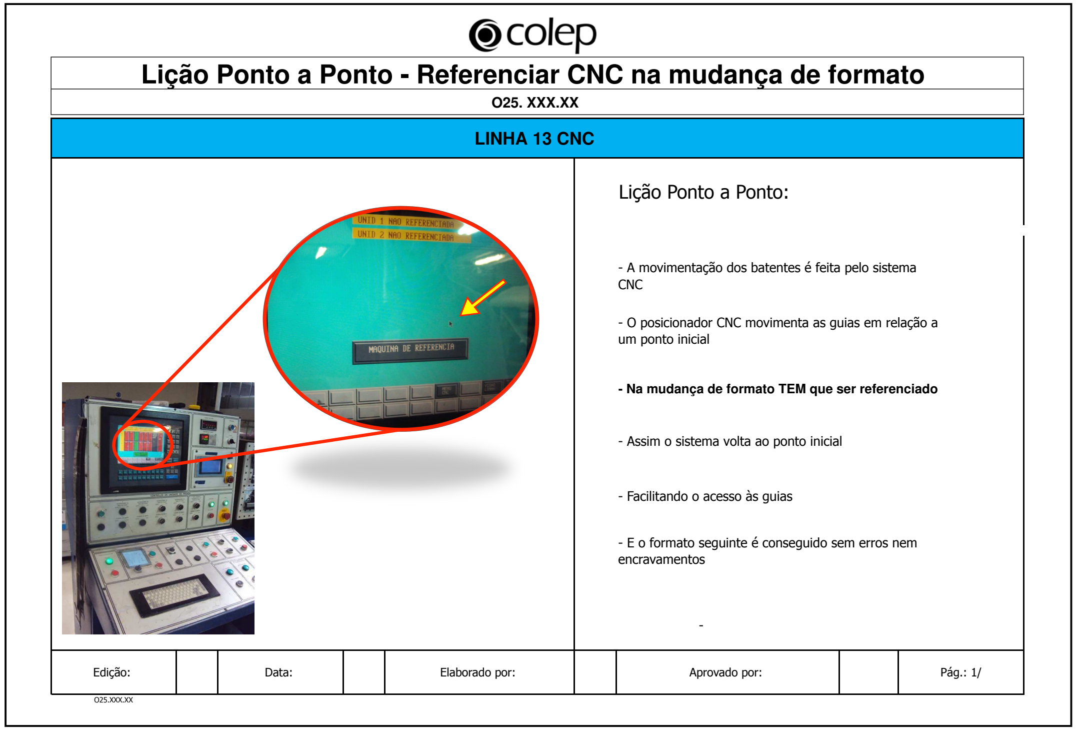


Figure 61 - One Point Lesson CNC

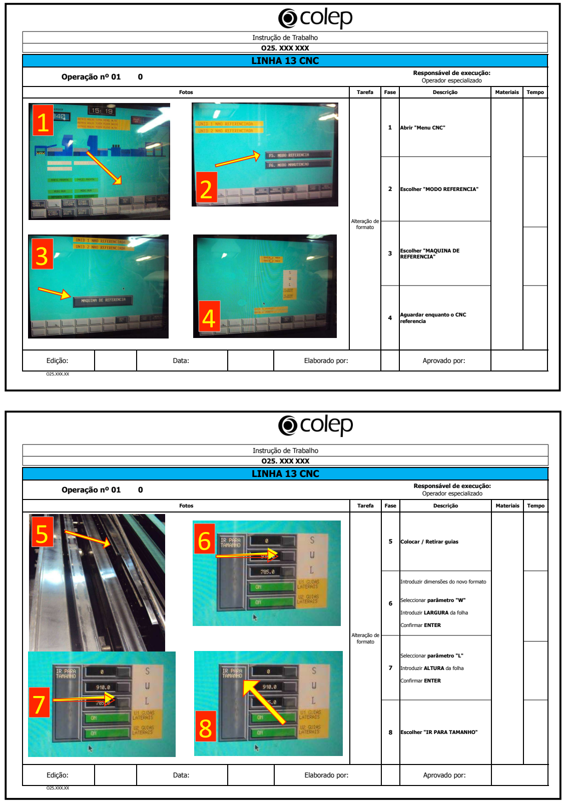
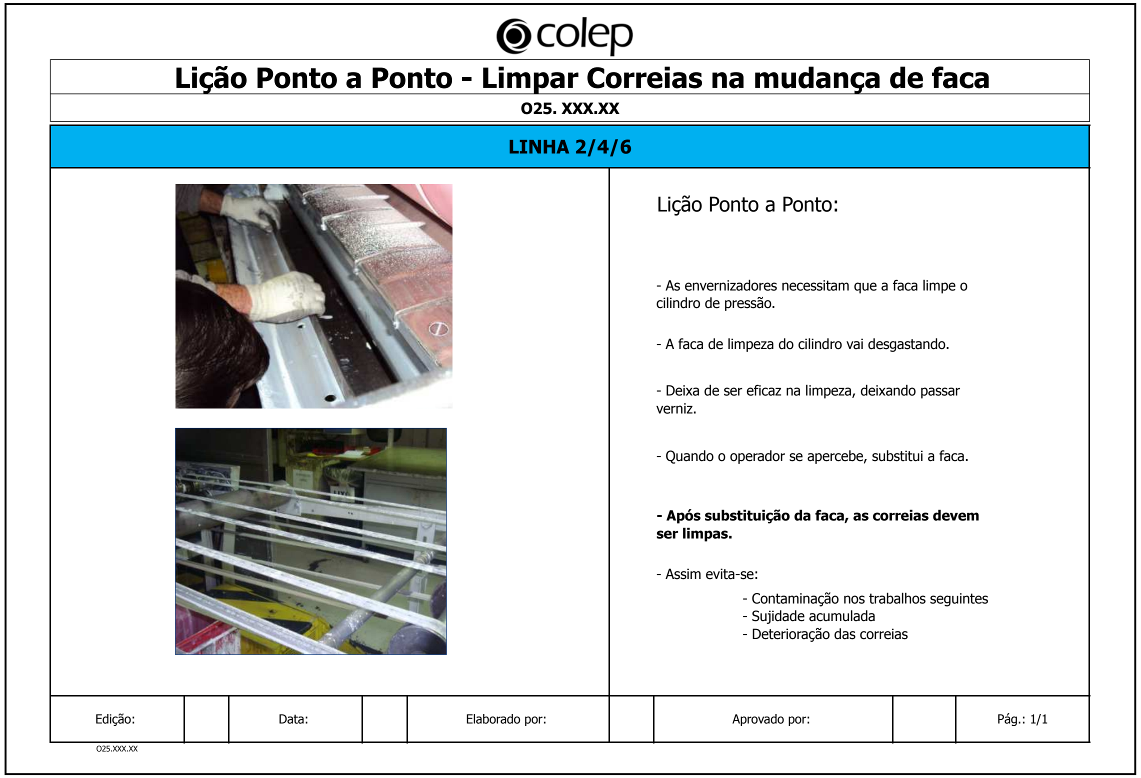


Figure 62 - Revised SOP for changing format

Belts Cleaning Procedure



colep

Lição Ponto a Ponto - Limpar Correias na mudança de faca

O25. XXX.XX

LINHA 2/4/6

Lição Ponto a Ponto:

- As envernizadores necessitam que a faca limpe o cilindro de pressão.

- A faca de limpeza do cilindro vai desgastando.

- Deixa de ser eficaz na limpeza, deixando passar verniz.

- Quando o operador se apercebe, substitui a faca.

- Após substituição da faca, as correias devem ser limpas.

- Assim evita-se:
  - Contaminação nos trabalhos seguintes
  - Sujidade acumulada
  - Deterioração das correias

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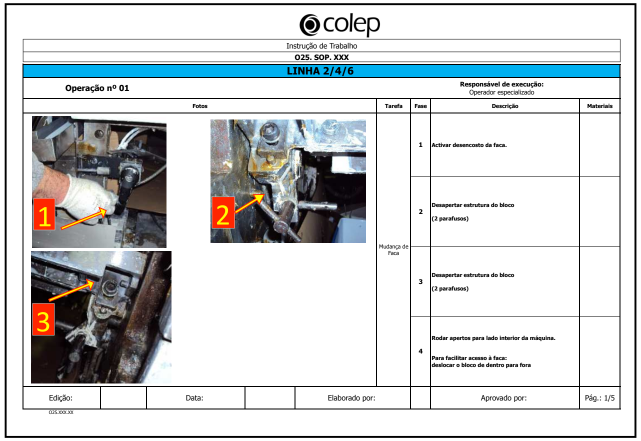

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Instrução de Trabalho

O25. SOP. XXX

LINHA 2/4/6

Operação nº 01

Responsável de execução: Operador especializado

Fotos	Tarefa	Fase	Descrição	Materiais
1, 2, 3	Mudança de Faca	1	**Activar desencosto da faca.**	
		2	**Desapertar estrutura do bloco (2 parafusos)**	
		3	**Desapertar estrutura do bloco (2 parafusos)**	
		4	**Rodar apertos para lado interior da máquina. Para facilitar acesso à faca: deslocar o bloco de dentro para fora**	

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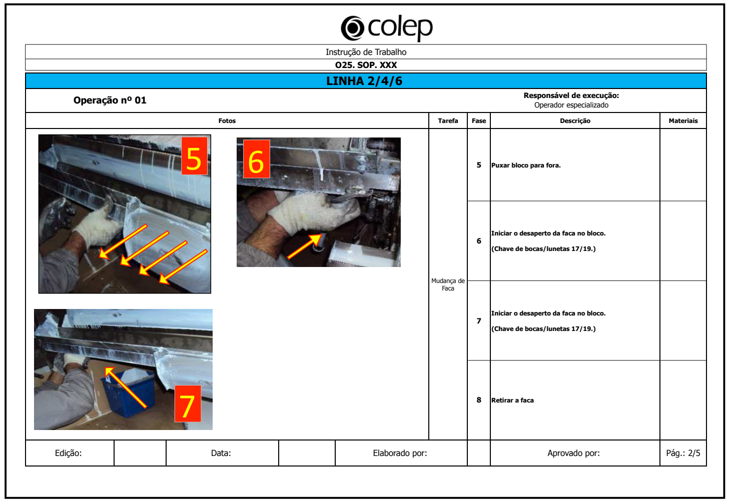
Figure 63 - One Point Lesson cleaning belts



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Instrução de Trabalho

O25. SOP. XXX

LINHA 2/4/6

Operação nº 01 — **Responsável de execução:** Operador especializado

Fotos	Tarefa	Fase	Descrição	Materiais
	Mudança de Faca	5	Puxar bloco para fora.	
		6	Iniciar o desaperto da faca no bloco. (Chave de bocas/lunetas 17/19.)	
		7	Iniciar o desaperto da faca no bloco. (Chave de bocas/lunetas 17/19.)	
		8	Retirar a faca	

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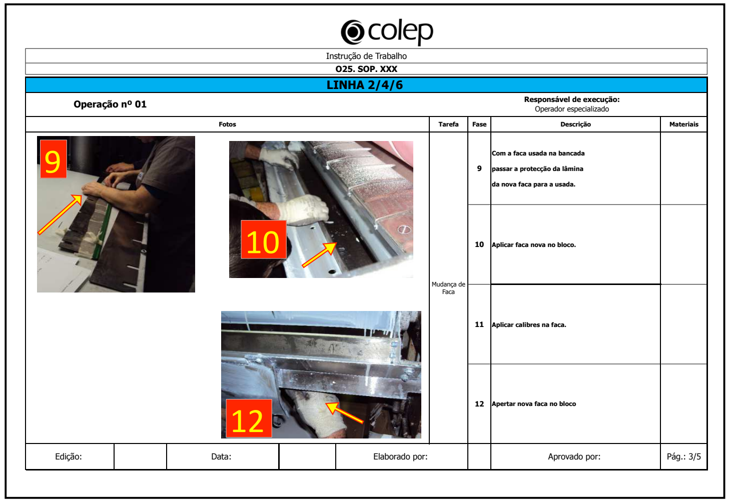

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Instrução de Trabalho

O25. SOP. XXX

LINHA 2/4/6

Operação nº 01 — **Responsável de execução:** Operador especializado

Fotos	Tarefa	Fase	Descrição	Materiais
	Mudança de Faca	9	Com a faca usada na bancada passar a protecção da lâmina da nova faca para a usada.	
		10	Aplicar faca nova no bloco.	
		11	Aplicar calibres na faca.	
		12	Apertar nova faca no bloco	

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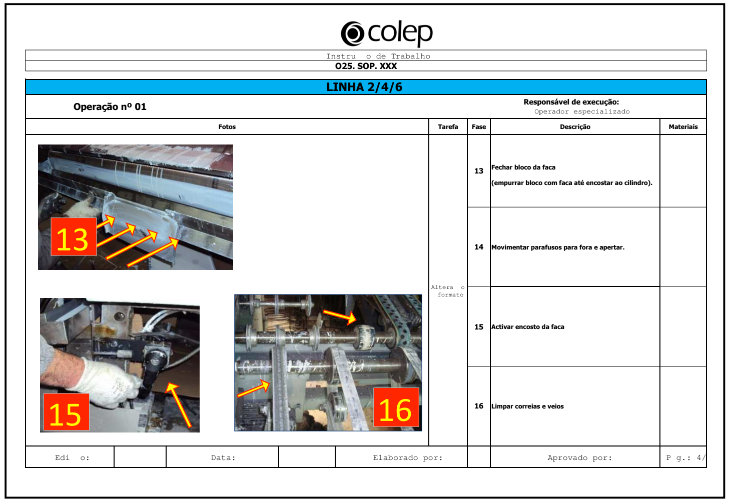

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Instru o de Trabalho

O25. SOP. XXX

LINHA 2/4/6

Operação nº 01 — **Responsável de execução:** Operador especializado

Fotos	Tarefa	Fase	Descrição	Materiais
	Altera o formato	13	Fechar bloco da faca (empurrar bloco com faca até encostar ao cilindro).	
		14	Movimentar parafusos para fora e apertar.	
		15	Activar encosto da faca	
		16	Limpar correias e veios	

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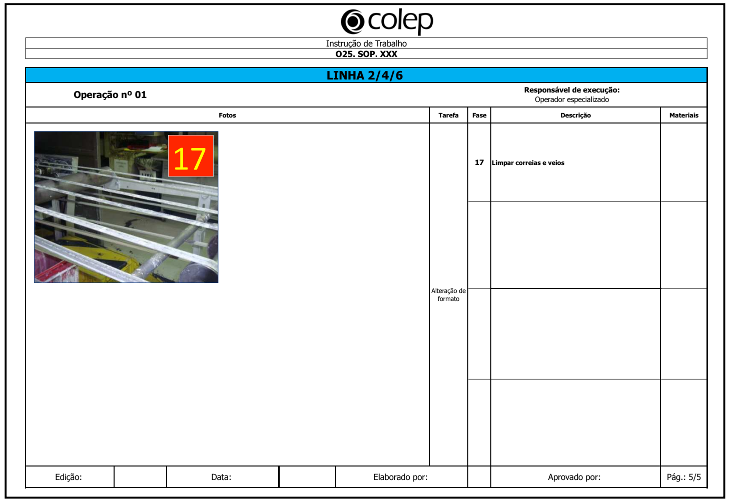

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Instrução de Trabalho

O25. SOP. XXX

LINHA 2/4/6

Operação nº 01 — **Responsável de execução:** Operador especializado

Fotos	Tarefa	Fase	Descrição	Materiais
	Alteração de formato	17	Limpar correias e veios	

Edição:		Data:		Elaborado por:		Aprovado por:	Pág.: 5/5

Figure 64 - Revised SOP for changing knife

ATTACHMENT D: List of Common Breakdowns for Drop Down Menus

Convencional

Alimentador	Ventosa	Desgaste	#1
	Braço da ventosa	Partido	#2
	Detector dupla espessura	Avariado	#3
	Cilindro Ar comprimido	Desafinado	#4
Correias	Partida	Entrada do forno	#5
		Saída do Forno	#6
		Alimentador	#7
		Descarregador	#8
	Danificada	Entrada do forno	#9
		Saída do Forno	#10
		Alimentador	#11
		Descarregador	#12
Descarregador	Partido	-	#13
	Avariado	-	#14
	Desafinado	-	#15
Envernizadora	Faca	com Desgaste	#16
Folha	Manchar	-	#17
	Riscar	-	#18
	Torcer	-	#19
	Tremer	-	#20
Forno	Garfos	Danificados	#21
		Empenados	#22
	Queimador	Avariado	#23
		Desafinado	#24
	Ventilador	Avariado	#25
		Desafinado	#26
Impressora	Bateria	Avariada	#27
		Desafinada	#28
		Mudar Rolo	#29
	Sistema Molha	Avariado	#30
		Desafinado	#31
	Tinteiro	Avariado	#32
		Desafinado	#33

Figure 65 - List of conventional lines' common breakdowns

Ultravioleta

Alimentador	Ventosa	Desgaste	#1
	Braço da ventosa	Partido	#2
	Detector dupla espessura	Avariado	#3
	Cilindro Ar comprimido	Desafinado	#4
Correia	Partida	Alimentador	#5
		Entre Unidades	#6
		Descarregador	#7
	Danificada	Alimentador	#8
		Entre Unidades	#9
		Descarregador	#10
Unidade de Impressão	Distribuidor de tinta	Avariado	#11
		Mudar Rolo	#12
	Bateria	Desafinado	#13
		Mudar Rolo	#14
	Problema Registo	-	#15
	CNC	Avariado	#16
	Sistema de Molha	Mudar Rolo	#17
		Água Contaminada	#18
Sistema Secagem UV	Lâmpada	Partida	#19
		Fundida	#20
	Obturador	com Fuga	#21
		partido	#22
	Micro	partido	#23
Sistema Molha	Refrigerador	Avariado	#24
		Falta água	#25

Figure 66 - List of ultraviolet lines' common breakdowns

ATTACHMENT E: Preventive Maintenance Procedures Revision

Bm	Bi-monthly	60	days
Tm	Trimestral	90	days
Sm	6-monthly	180	days
An	Annual	360	days

Ultraviolet Lines

	Previously	Revised
Line 11		
LUBRICATE SPECTRAL MECHANISMS	Sm	Sm
INSPECT SPECTRAL COMPONENTS	Sm	Bm
Line 13		
LUBRICATE SPECTRAL MECHANISMS	Sm	Sm
INSPECT SPECTRAL COMPONENTS	Sm	Bm

Figure 67 - PM Procedures revision UV lines

Conventional Lines

	Previously	Revised
Line 2		
CLEAN BURNER NOZZLE AND BURNER CHAMBER’S IGNITER	Sm	Sm
CLEAN EXAUSTION VENTILATORS	An	Sm
CLEAN OVEN FORKS	An	Sm
Line 3		
CLEAN BURNER NOZZLE AND BURNER CHAMBER’S IGNITER	An	Tm
CLEAN EXAUSTION VENTILATORS	An	Sm
CLEAN OVEN FORKS	Sm	Sm
Line 4		
CLEAN BURNER NOZZLE AND BURNER CHAMBER’S IGNITER	Sm	Tm
CLEAN EXAUSTION VENTILATORS	An	Sm
CLEAN OVEN FORKS	An	Sm
Line 5		
CLEAN BURNER NOZZLE AND BURNER CHAMBER’S IGNITER	Sm	Sm
CLEAN EXAUSTION VENTILATORS	An	Sm
CLEAN OVEN FORKS	An	Sm
Line 6		
CLEAN BURNER NOZZLE AND BURNER CHAMBER’S IGNITER	Sm	Tm
CLEAN EXAUSTION VENTILATORS	An	Sm
CLEAN OVEN FORKS	An	Sm

Figure 68 - PM Procedures revision CV lines