CORSO DI LAUREA MAGISTRALE IN INGEGNERIA MECCANICA

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OPTIMIZATION OF PRODUCTION ACCORDING TO LEAN MANUFACTURING

A case of an Australian powder coating company

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Abstract

Global market competition grew up significantly in the last 50 years, especially in manufacturing industry, because of this in the companies arose the need to take counter-measures and innovate their manufacturing processes. Such initiatives have, in many cases, been aimed through the enforcement of lean manufacturing.
In a manufacturing point of view, is essential to underline all the production issues in order to reduce any waste and to increase the value add operation. To keep high level of competitiveness is required to preserve the productivity as high as possible in order to fully exploit the production capability.

In the light of the above the aim of this thesis is to establish strategies and engineering solutions designed to optimize the production processes in Djs Qualicoaters, an Australian powder coating company, case of this final project.
To reach this target, the production processes have been deeply analyse in order to underline the reason of production loss. Lean manufacturing and tools relating to it has been identify as useful instrument for the detection of aspects to improve and to decide which proposal best suits to the production needs.

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Summary

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List of Abbreviations

CGA: Colour Change Analysis

DTA: Downtime Analysis

JIT: Just-In-Time

NNVA: Necessary but not value added activities

NPA: Net positive value

NVA: Non-Value-Added activities

QCD: Quality, Cost and Delivery

TPS: Toyota Production System

VA: Value-Added activities

WIP: Work-In-Process

1 INTRODUCTION

This chapter presents a brief background of the company and the market relating to. After the problem formulation, the purpose of this thesis is stated, followed by research questions, research methodology and outline of the thesis.

1.1 Company and market overview

The core of this final project was entirely development at Djs Qualicoaters. Australian production spot, based on Sydney, of the DFV group. The field of application is the powder coating of aluminium extruded profile. The company and relating products are described in detailed in the chapter 3, the aim of this section is to characterise the company respect the market at hand. A powder coating company can be classified on the basis of resin type and application.

Resin type

On the basis of resin type employed for the production, the market is bifurcated into thermoplastic and thermoset. The company at hand employ thermosetting powder that are applied by a specialized spray process called electrostatic spray. The powder coating is applied by electrically charging the powder coating particles and applying them with a spray gun onto pre-treated parts in a powder application booth. The paint particles adhere to the parts until they can be cured in an oven, which permanently sets the coating on the part.

Application

On the basis of application, powder coatings market is segmented into automotive & transportation, architectural & furniture, appliances, consumer goods, and others. The field of application of DFV can be identified in the architectural and furniture as facade panels, window profiles, visible structural steel, and other building components.

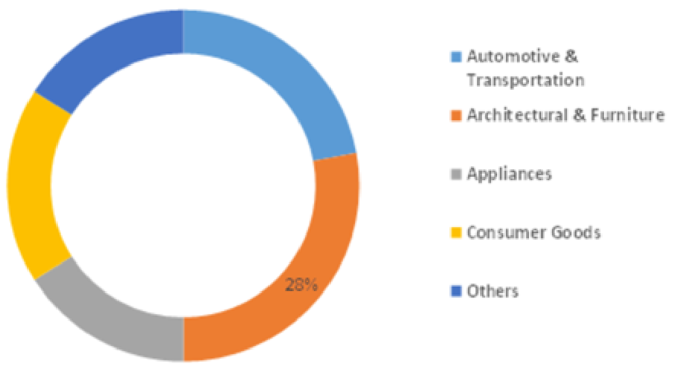

Figure 1 Global powder coating market share by application (2016)

As it possible to see from the figure above, the application of architectural & furniture is one of the most wide in the entire global powder coating marker running at 28%.

1.2 Problem formulation

Global market competition grew up significantly in the last 50 years, especially in manufacturing industry, because of this in the companies arose the need to take counter-measures and innovate their manufacturing processes. Such initiatives have, in many cases, been aimed through the enforcement of lean manufacturing.
It just begs the question, how could be possible that a circumscribed philosophy, arose more than 50 years ago in an automotive Japanese industries, has been included in universal applications from government to hospitality sector?
The answer is that the lean principles and its tools are useful to bring to light universal issues and to identify simple countermeasures. In a manufacturing point of view, is essential to underline all the production issues in order to reduce any waste and to increase the value add operation. To keep high level of

competitiveness arise the need to preserve the productivity as high as possible in order to fully exploit the production capability. One of the most useful tool to determinate inefficiencies in the production line lies in the Downtime analyses. This is as litmus test for the shop floor, DTA allows to identifies roots causes and bottleneck through the production processes. Another essential aspect in the daily tasks of a manufactory industry is undoubtedly the production planning. A flexible manufacturing can offer important advantages in terms of more efficient production, shorter throughput times, lower stocks and a higher quality of work.

1.3 Aim and research question

In the light of the above the aim of this thesis is to establish strategies and engineering solutions designed to optimize the production processes in the manufactory.

To reach this target the production processes have been deeply analyse in order to underline the reason of production loss. Lean manufacturing and tools relating to it has been identify as useful instrument for the detection of aspects to improve and to decide which proposal best suits to the production needs.

This thesis will answer the following questions in support of its research aim:

- *What are the root causes of downtime in the production line?*
- *How is possible to avoid DT or to mitigate the effects of these?*
- *What is the best strategy that allows a leaner and more flexible production planning?*

1.4 Methodology research

This thesis based its research method on both theoretical and empirical studies. A literature review helped define the problem.

Data was collected and processed during all the period from October 2018 to February 2019 at Djs Qualicoaters factory on a daily basis from Monday through Friday between 8.00 am and 4.00 pm. In the *chapter 4* for each analyse, the data gathering and data processing, have been described in detailed in order to provide to the reader a more straightforward lecture.

1.5 Report outline

This chapter summarizes all of the different chapters in the report and briefly explains the content in them.

- ***Introduction:*** In the Introduction chapter a brief background of the company Djs Qualicoaters and powder coating market is given along with purpose and objectives, methodology research and problem definition. This is described in the beginning of the Master thesis in order to make the reader more convenient with the following reading.
- ***Theoretic framework:*** The second has the aim to provide the reader with concepts and models relevant to this study. In the beginning of the chapter a frame of reference of the different models is included to give the reader an overview of the used philosophies and concepts.
- ***Empirics:*** This chapter focuses on identifying the current state of the factory, e.g. the work procedures in the factory today and the design of the current layout. The empirical data that have been gathered during the project is presented.
- ***Analyses and practical solution:*** The current state is analysed and possible improvement areas, in the investigated areas in the plant, will be highlighted in this chapter. This is followed by improvement proposals connected to each area. The proposals will be divided into short term and long term suggestions.

- ***Conclusion:*** In this chapter conclusions, regarding the result of the case study in relationship with the stated purpose and objectives of the Master thesis, are presented. Other findings during the study, which have not been addressed in the proposals, will also be presented as suggestions to future projects. Also answers to research questions and suggestions on further research are provided in this chapter.
- ***References***: This chapter provides a list of the literature that has been the foundation for this Master thesis.
- ***Appendix***: Supplementary information that goes more into detail in certain areas

2 THEORETIC FRAMEWORK

This chapter will provide information about the theoretical framework used in this thesis. Different concepts from well-established theories as well as more recent studies will be described and explored. The framework is built around the philosophies in Toyota Production System (TPS). Lean manufacturing is considered to be a western variant of TPS and is therefore included together with TPS in this particular framework. Furthermore, within lean manufacturing a few analysis tools are especially emphasized.

2.1 History of Lean

No new idea springs full-blown from a void. Rather, new ideas emerge from a set of conditions in which old ideas no longer seem to work. This was certainly true of lean production, which arose in one country at a specific time because conventional ideas for the industrial development of the country seemed unworkable [14] As Womack suggest a new philosophy idea of working rises to answer to specific request, TPS was born as a response to the needs of a Japanese automaker in crisis at the peak of mass production.

The Toyota Company was founded at a time when American automobile companies such as Ford and General Motors dominated the automobile field. Faced with the consequence of the second world war the Japanese economy starved for capital, TPS provided innovative solutions based on the reduce of wastes and continue improvement. [1].

The core at the origin of the TPS was the idea that the customary thinking of Cost + Profit = Sales Price was incorrect.

Instead, they believed that Profit = Sales Price – Cost. [7]

This new thinking drive Toyota to be focused on the management of costs. Eventually costs were interpreted as waste, and all varieties of wastes were targeted for elimination.

Unlike the mass production of a single product of GM and Ford, Toyota had to make a variety of vehicles on the same assembly line to satisfy its customers. Thus, the key to their operations was flexibility. This helped Toyota make a critical discovery: when you make lead times short and focus on keeping production lines flexible, you actually get higher quality, better customer responsiveness, better productivity, and better utilization of equipment and space. [9]

The origins of lean manufactory is strictly connected with TPS. The two are so closely knit that for many practitioners, Lean production and the Toyota Production System (TPS) are synonymous [13].

The term ‘Lean production’ was first used by Krafcik in 1988, and subsequently, Womack et al. of course used the term ‘Lean production’ to contrast Toyota with the Western ‘mass production’ system in the ‘Machine’ book. The name ‘Lean’ was born! [1]

2.2 The five Lean Principles

Figure 2 Five lean principles

The five Lean principles were developed by Womack and Jones in their book 'The Machine that Changed the World'.

The book emphasised Lean Enterprise rather than Lean Manufacturing; Lean can be used in systems not just in manufacturing. [1]. Here's some insight into the five principles.

2.2.1 *Identify value from customer point of view*

The critical starting point for lean thinking is *value.* Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time. Value is created by the producer. From the customer's standpoint, this is why producers exist [1]

The first principles could be synthetized in the expression “give the customers what they want”.

2.2.2 Value Stream Mapping

The next step to development lean thinking is to identify the entire value stream for each product (or family of product). Should be analysed all the process, step and movement of material necessary to have the finish product in the hands of the costumer. The asset is to bring out three different types of activities:

- *Value-Added activities* ***(VA):***
  Steps that unambiguously create value, which are unthinkable not to conduct in any future state model or scenario.
- *Non-Value-Added activities* ***(NVA):***
  Also called Muda (Japanese word for waste) are unnecessary activities which should be eliminate immediately because of increase cost without adding value to the product.
- *Necessary but not value added activities* ***(NNVA)****:*
  Operations that are essentially wasteful but may be necessary under the current operating procedures. To eliminate such operations, it would be necessary to make changes in the layout of the line or arrange for vendor items to be delivered unpackaged-none may be practical at the present time. [14]

2.2.3 Flow

Flow is defined as an uninterrupted movement of product or services through the system to the customer, it must be continuous and without blockages. For this reason is important to reduce as much as possible batch and queue, in this way is possible to reach a smooth and quick flow of information and production.

The first visible effect of converting from departments and batches to product teams and flow is that the time required to go from concept to launch, sale to delivery, and raw material to the customer falls dramatically. [13]

2.2.4 Pull

This step is maybe one of the most in contrast with the mass production system. The aim is to change the idea of a push system to a pull system, the demand of customers take the lead of production. This means the customer can “pull” the product from you as needed avoiding overproduction. As a result, products don’t need to be built in advance or materials stockpiled, creating expensive inventory that needs to be managed, saving money for both the manufacturer/provider and the customer.

2.2.5 Pursue perfection

Lean is more a dynamic system than static, this means that completed the previous four steps is required effort and vigilance to the perfection. The Lean thinking should be entrenched at every level of the production system, every employed has to be involved in implementing lean.
To point out the similarity between lean thinking and TPS, we can see that the concept of continuous improvement is strongly related with *Kaizen* one of the most important cornerstone of TPS, *Kaizen* is discussed in further detail in *chapter 2.7.2*.

2.3 Muda, Muri and Mura (MUs)

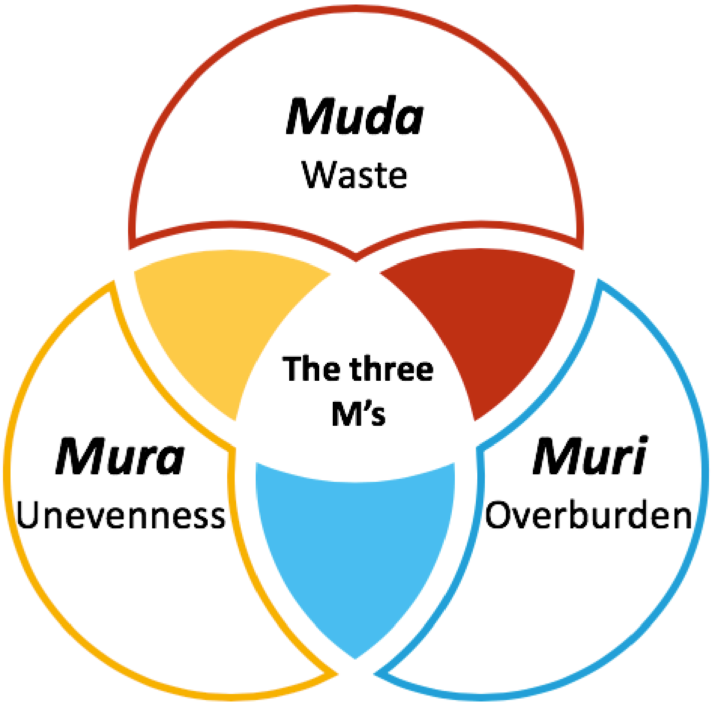

Figure 3 The three M's

Muda, Muri and Mura are 3 Japanese words often used together and referred to as the three MUs. These three concepts allow for a more complete understanding of Lean. [11].

- Muri means "overburdening" of workers and machines. Workers want to be able to enjoy their working life, and they should be willing to be a part of the improvement of company processes. The quality of work life should be enjoyable; ergonomics such as lighting, temperature, and comfort should be as work friendly as possible. Also, emphasis on safety in the work place is key. Workers should not be overburdened with work as this could result in stress and/or injury. Overburden leads to less efficient and low quality work done. Likewise machines can be pushed beyond their limits causing them to break down. Overburdening people and machines at the same time could result in accumulation of queues, which in turn would result in missing targets. [1].

- Mura means "unevenness", appears whenever a smooth flow of work is interrupted in an operator's work, the flow of parts and machines, or the production schedule.
- Muda The Japanese word Muda means "waste," but the word carries a much deeper connotation. Work is a series of processes or steps starting with various inputs and raw materials and ending in a final product or service. At each process, value is added to the product and then the product is sent on to the next process. The resources at each process—people and machines—either do add value or do not add value. Muda refers to any activity that does not add value.

Lean thinking identifies seven types of Muda also referred to as the seven waste. The table 1 shows some insight into seven waste according to Imai [8]

1. Transportation		
Description: It is the movement of materials which is not needed, because their chance to get damaged and deteriorated increases. Transport adds no value except the one in which product is delivered to customer and it is paid. Internal transports are purely waste.	*Root causes:* • Poor Layouts • Complex material handling systems • Large batch sizes • Multiple storage location	*Possible solutions:* Optimise the transportation of material setting up the next process as close as possible to the previous one.

2. Inventory		
Description: It involves the over existence of raw materials, WIP and finished goods in organizations. This is considered waste because of the excess of cost spend on them.	*Root causes:* • Bottleneck • Push logic production • Not continuous flow • Large batch sizes	*Possible solutions:* The warehouse layout as to be set up according to the real demand of customers. This Muda hides other waste as overproduction.
3. Motion		
Description: It happens when there are unnecessary movement of people and machines. Unnecessary motions may also be harmful from an ergonomics point of view.	*Root causes:* • Lack of standardisation • Inefficient layout and process flow	*Possible solutions:* A tool as 5s is helpful to provide a better arrangement of work tools, is also recommended to avoid the unnecessary motion.
4. Waiting		
Description: It is considered an enemy of flow, because materials and components do not move as a result of waste. Means time not used in production properly and leads to idle time. It can be due to a lack of material or information needed for next task.	*Root causes:* • Poor man/machine coordination • Time required to perform rework • Unreliable processes/quality • Long changeovers	*Possible solutions:* Could be avoid improving the continuous flow in order to reduce idle time as much as possible.

5. Over-processing		
Description: It means performing more work on a product than the customer is willing to pay for. Producing higher quality product than the customer asked, or carrying out unnecessary tasks.	*Root causes:* • No standardisation of best techniques • Unclear specification/ quality acceptable standard	*Possible solutions:* Optimise the value-add process in order to remove all the activities that don't bring value.
6. Overproduction		
Description: It means producing more than the customer wants, producing faster or earlier that what is required by the next process and producing overlarge batches.	*Root causes:* • Large batch sizes • Production based on forecast • Unstable schedules	*Possible solutions:* The philosophy of Just In Time (JIT) is the best way to avoid the Muda of overproduction. (JIT are discussed in further detail in chapter ….).
7. Defects		
Description: It involves any waste which involves costs related to delay, warranty and repairs. Produce defective products results in waste because wrong product has made and need to be corrected, mostly customer are not willing to pay for this.	*Root causes:* • Lack of standardisation • Untrained employers • Low Supplier quality • Lack of no-error system (Poka-yoke)	*Possible solutions:* Make "Right first time", every time a defect appear is necessary to understand the causes and standardise the solution.

Table 1 Description, root causes and possible solutions of the seven wastes

2.3.1 Banish Wastes

Lean and the its various tools are an efficient antidote to Muda, however the focus of lean implementation shouldn't be to identify and remove waste. Instead should be used the five principles to identify value, according to the customer, and make those value adding processes flow through the organization at the pull of the customer. This approach helped to make the value adding processes more efficient and causes the waste to literally "dissolve."

2.4 The fourteen principles of Toyota

TPS is not a toolkit. It is not just a set of lean tools like just-in-time, cells, 5S Kanban, etc. It is a sophisticated system of production in which all of the parts contribute to a whole. The whole at its roots focuses on supporting and encouraging people to continually improve the processes they work on.
Unfortunately, more and more often some joined-up thinking the misunderstanding that TPS is a collection of tools that lead to more efficient operations. The purpose of these tools is lost and the centrality of people is missed.
When looked at more broadly, TPS is about applying the principles of the Toyota Way. The initial focus was on the shop floor, but the principles are broad and, in fact, apply just as well to engineering and business service operations. [9]

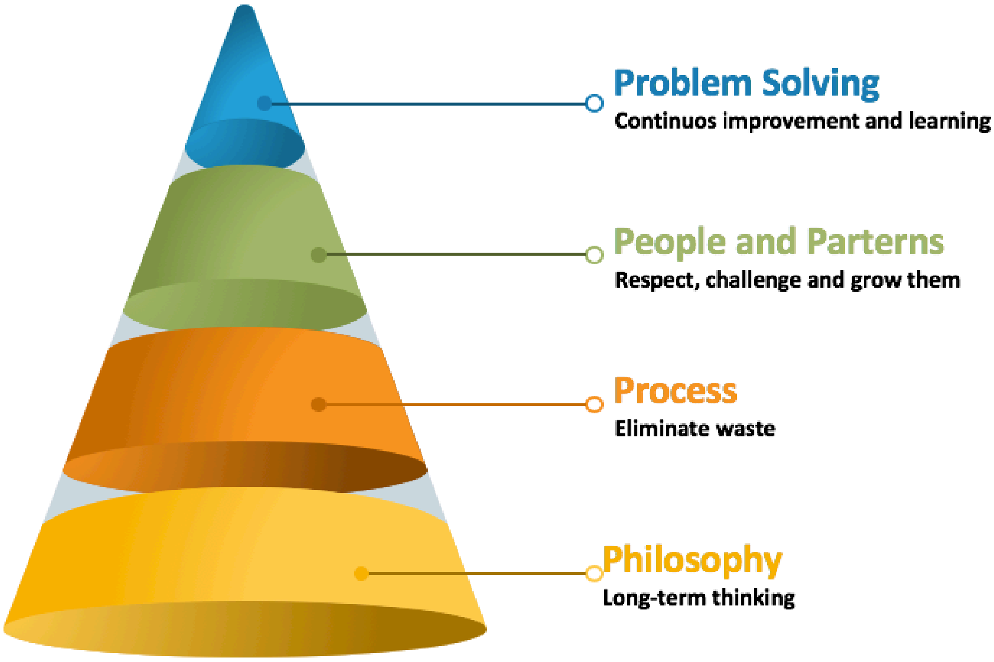

Figure 4 The pyramid of 14 Toyota's principles

This chapter provides a synopsis of the 14 principles that constitute the Toyota way. The principles are organized in four broad categories:

- Long-Term Philosophy,
- The Right Process Will Produce the Right Results (this utilizes many of the TPS tools)
- Add Value to the Organization by Developing Your People,
- Continuously Solving Root Problems Drives Organizational Learning. "

With the discussion of TPS principles can arise some similarity with The Five lean principle (discussed in the chapter 2.2), this is important to understand the strong connection between these two manufactory philosophy. Here's some insight into the fourteen principles according to Liker:

Long Term Philosophy

- *First principle:* **Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.**

Have a philosophical sense of purpose that supersedes any short-term decision making. Work, grow, and align the whole organization toward a common purpose that is bigger than making money. Understand your place in the history of the company and work to bring the company to the next level. Your philosophical mission is the foundation for all the other principles. Generate value for the customer, society, and the economy—it is the starting point. Evaluate every function in the company in terms of its ability to achieve this

The Right Process Will Produce the Right Results

- *Second principle:* **Create continuous process flow to bring problems to the surface.**
  Redesign work processes to achieve high value-added, continuous flow. Strive to cut back to zero the amount of time that any work project is sitting idle or waiting for someone to work on it. Make flow evident throughout organizational culture. It is the key to a true continuous improvement process and to developing people.
- *Third principle:* **Use "pull" systems to avoid overproduction.**
  Provide your downline customers in the production process with what they want, when they want it, and in the amount they want. Material replenishment initiated by consumption is the basic principle of just-in-time. Another cornerstone according to Liker is to minimize the work in process and warehousing of inventory by stocking small amounts of each product and frequently restocking based on what the customer actually takes away.
- *Fourth principle:* **Level out the workload (heijunka). (Work like the tortoise, not the hare.)**

Eliminating waste is just one-third of the equation for making lean successful. Eliminating overburden to people and equipment and eliminating unevenness in the production schedule are just as important.

- *Fifth principle:* **Build a culture of stopping to fix problems, to get quality right the first time.**

  Quality for the customer drives value proposition for this reason it's advisable to use all the modern quality assurance methods available. Develop a visual system to alert team or project leaders that a machine or process needs assistance.

  Jidoka (machines with human intelligence) is the foundation for "building in" quality.

- *Sixth principle:* **Standardized tasks are the foundation for continuous improvement and employee empowerment.**

  Use stable, repeatable methods everywhere to maintain the predictability, regular timing, and regular output of your processes. It is the foundation for flow and pull.

  Capture the accumulated learning about a process up to a point in time by standardizing today's best practices. Allow creative and individual expression to improve upon the standard;

- *Seventh principle:* **Use visual control so no problems are hidden.**

  Use simple visual indicators to help people determine immediately whether they are in a standard condition or deviating from it.

  Design simple visual systems at the place where the work is done, to support flow and pull.

- *Eighth principle:* **Use only reliable, thoroughly tested technology that serves your people and processes.**

Use technology to support people, not to replace people. Often it is best to work out a process manually before adding technology to support the process.

New technology is often unreliable and difficult to standardize and therefore endangers "flow." Reject or modify technologies that conflict with your culture or that might disrupt stability, reliability, and predictability. Quickly implement a thoroughly considered technology if it has been proven in trials and it can improve flow in your processes.

Add Value to the Organization by Developing Your People and Partners

- *Ninth principle*: **Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.**

  Do not view the leader's job as simply accomplishing tasks and having good people skills. Leaders must be role models of the company's philosophy and way of doing business. A good leader must understand the daily work in great detail so he or she can be the best teacher of your company's philosophy.

- *Tenth principle*: **Develop exceptional people and teams who follow your company's philosophy.**

  Create a strong, stable culture in which company values and beliefs are widely shared and lived out over a period of many years. Use cross-functional teams to improve quality and productivity and enhance flow by solving difficult technical problems. Make an ongoing effort to teach individuals how to work together as teams toward common goals. Teamwork is something that has to be learned.

- *Eleventh Principle*: **Respect your extended network of partners and suppliers by challenging them and helping them improve.**

  Have respect for your partners and suppliers and treat them as an extension of your business. Challenge your outside business partners to grow and develop. It shows that you value them. Set challenging targets and assist your partners in achieving them.

Continuously Solving Root Problems Drives Organizational Learning

- *Twelfth Principle:* **Go and see for yourself to thoroughly understand the situation (genchi genbutsu).**
  Solve problems and improve processes by going to the source and personally observing and verifying data rather than theorizing on the basis of what other people or the computer screen is reporting. Think and speak based on personally verified data. Even high-level managers and executives should go and see things for themselves, so they will have more than a superficial understanding of the situation.
- *Thirteenth Principle:* **Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.**
  Do not pick a single direction and go down that one path until you have thoroughly considered alternatives. When you have picked, move quickly but cautiously down the path.
  Nemawashi is a Japanese word referred to the process of discussing problems and potential solutions with all of those affected, to collect their ideas and get agreement on a path forward. This consensus process, though time-consuming, helps broaden the search for solutions, and once a decision is made, the stage is set for rapid implementation.
- *Fourteenth Principle:* **Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen).**
  Once you have established a stable process, use continuous improvement tools to determine the root cause of inefficiencies and apply effective countermeasures. Design processes that require almost no inventory. This will make wasted time and resources visible for all to see.

Once waste is exposed, have employees use a continuous improvement process (kaizen) to eliminate it. Protect the organizational knowledge base by developing stable personnel, slow promotion, and very careful succession systems. Use hansei (reflection) at key milestones and after you finish a project to openly identify all the shortcomings of the project. Develop countermeasures to avoid the same mistakes again. Learn by standardizing the best practices, rather than reinventing the wheel with each new project and each new manager.

2.5 The House of Lean

The representation of TPS principles as an "house" was developed by Taiichi Ohno, considered the father of TPS. There are several representation of these house that each one puts the accent to a different aspect but the core of the TPS remains the same.

In the figure below according to Liker is possible to see all the principle and tools necessary to reach the final target of best quality, lowest cost and shortest lead time. An house is strong only if the roof, the pillars and the foundation are strong. Each element of the house by itself is critical, but more important is the way the elements reinforce each other.

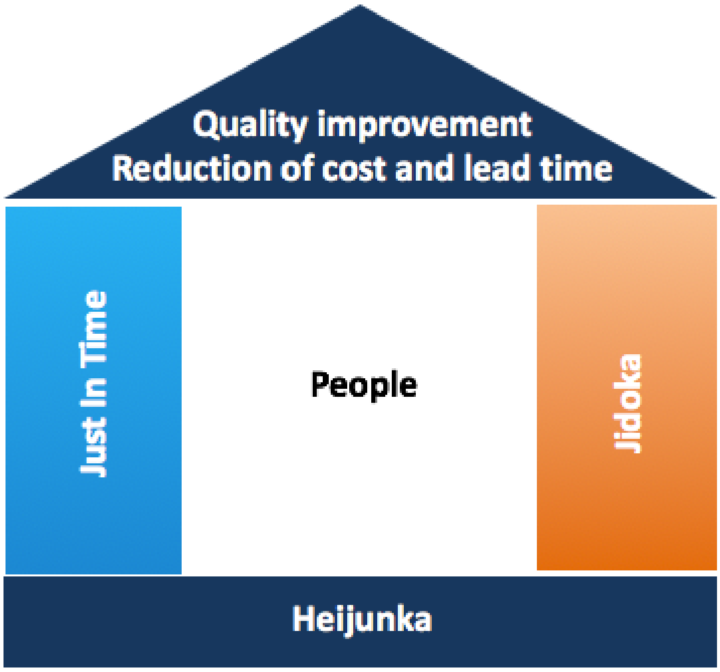

Figure 5 The Toyota Production System

1. Foundation: Toyota way Philosophy is the base to start the implantation of Lean, It's unthinkable to proceed an implementation without having stable and standardized processes. The cornerstone of stability lies in heijunka which means levelling out the production schedule in both volume and variety. A levelled schedule is necessary to keep the system stable and to allow for minimum inventory. Big spikes in the production of certain products to the exclusion of others will create part shortages unless lots of inventory are added into the system.
2. Pillars: The first pillar is JIT (Just In Time) that means removing, as much as possible, the inventory used to buffer operations against problems that may arise in production. The ideal of one-piece flow is to make one unit at a time at the rate of customer demand or takt (German word for meter). Using smaller buffers (removing the "safety net") means that problems like quality defects become immediately visible. This reinforces the second pillar of Jidoka, which halts the production process. This means workers

must resolve the problems immediately and urgently to resume production. [9].

3. Middle: People are in the middle of the house because only through continuous improvement can the operation ever attain this needed stability. People must be trained to see waste and solve problems at the root cause by repeatedly asking why the problem really occurs. Problem solving is at the actual place to see what is really going on (genchi genbutsu) [9].
4. Roof: The final asset of lean implementation is reflected in an improvement of quality and a strongly reduction of cost and lead time.

2.6 Visual Management

At the Gemba, abnormalities of all sorts arise every day. Only two possible situations exist in the Gemba: Either the process is under control, or it is out of control. The former situation means smooth operations; the latter spells trouble.
The practice of visual management involves the clear display of gembutsu – the actual product, as well as charts, lists, and records of performance, so that both management and workers are continuously reminded of all the elements that make quality, cost, and delivery (QCD) successful – from a display of the overall strategy, to production figures, to a list of the latest employee suggestions.
Thus visual management constitutes an integral part of the foundation of the house of Gemba [8].
Visibility, visual management and "control by sight" is a key theme in lean operations. Visual management should be integrated into 5S and standard work. In fact, visual management is the 'litmus test' for Lean – if going into any operation and find that schedules, standard work, the problem solving process, quality and maintenance are not immediately apparent, and up to date, there is an excellent chance is far off from Lean. [1]

2.6.1 Visual management add-on 5M

In the Gemba, management must manage the five Ms (5M): manpower, machines, materials, methods, and measurements. Any abnormality related to the 5M conditions must be displayed visually [8].

Following is same inside about the connection of 5M and visual management according to Imai:

- **Manpower (Operators):** The employee skills could be highlighted by a display in the Gemba that can show who is trained to do what tasks and who needs additional training.
- **Machines:** Jidoka and poka-yoke (mistake-proofing) devices should be attached in every process in this way the machine stops immediately after something goes wrong. This is a technique to keep tabs on what's happening. Metal housings also should be replaced by transparent covers so that operators can see when a malfunction occurs inside a machine.
- **Materials:** When a minimum inventory level is specified and Kanban (attaching a card or tag to a batch of work-in-process as a means of communicating orders between processes) is used, anomalies become visible.
- **Methods:** The work accuracy of employee is made clear by standard worksheets posted at each workstation. The worksheets should show sequence of work, cycle time, safety items, quality checkpoints, and what to do when variability occurs.
- **Measurements:** Trend charts should be displayed in the Gemba to show the number of suggestions, production schedules, targets for quality improvement, productivity improvement, setup-time reduction, and reduction in industrial accidents.

2.7 Lean Tools

2.7.1 Housekeeping 5's

The kaizen principle of 5S stands for five Japanese words that constitute good workplace organization. Today, practicing 5S has become almost a must for any company engaged in manufacturing. (Imai, 2010).
It's considered a cornerstone of TPS and Lean implementation that comprise a series of activities for eliminating wastes that contribute to errors, defects, and injuries in the workplace.
Companies that have implemented 5S have reported some of the following positive results:

- Improved communication and information sharing
- Lower accident rate (thus the safety has improved)
- The levels of product quality have improved
- Machine downtime has reduced [7]

Here are the five S's according to Liker:

1. Seiri (Sort): Sort through items and keep only what is needed while disposing of what is not.
2. Seiton (Straighten, orderliness) "A place for everything and everything in its place." "Arrange all items remaining after Seiri in an orderly manner."
3. Seiso (Shine, cleanliness): The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause machine failure.
4. Seiketzu (Standardize, create rules): Develop systems and procedures to maintain and monitor the first three S's.
5. Shitsuke (Sustain, self-discipline)—Maintaining a stabilized workplace is an ongoing process of continuous improvement.

Figure 6 The 5 S's

The Toyota Way is not about using 5S to neatly organize and label materials, tools, and waste to maintain a clean and shiny environment. Visual control of a well-planned lean system is different from making a mass-production operation neat and shiny. Lean systems use 5S to support a smooth flow to takt time. 5S is also a tool to help make problems visible and, if used in a sophisticated way, can be part of the process of visual control of a well-planned lean system [6].

2.7.2 Kaizen

Kaizen is one of Japanese the most recognized words. "Kai" means continuous and "zen" means improvement. It focuses on the fact that no process can ever be perfect and there is therefore always room for improvement.

Kaizen is the centre of many lean tools and techniques as, after implementation, they can continuously be improved upon. A less known word is 'kaikaku' which is a radical or revolutionary event, unlike kaizen that is an incremental event. Proponents of reengineering would be more likely to endorse kaikaku [1].

According to Mika is possible to line down three levels of kaizen:

- **Work operation kaizen**: involves changes done by the operator to his or her own machine or process, simply, cheaply, immediately, and with little impact on surrounding people or processes. It is the first choice to implement.
- **Kaizen equipment**: involves improvements made to a machine or piece of equipment, which requires more time, cost, and resources than a work operation kaizen, and it may affect other people and processes.
- **Process kaizen**: affects the complete manufacturing process, and may even affect all the equipment in a process. It may be done to greatly increase production capacity, incorporate engineering changes, or eliminate cost and time. Usually this type of kaizen is conducted when the plan is to develop cells and transform from batch to one-piece flow production [10].

Kaizen teaches individuals skills for working effectively in small groups, solving problems, documenting and improving processes, collecting and analysing data, and self-managing within a peer group. It pushes the decision making (or proposal making) down to the workers and requires open discussion and a group consensus before implementing any decisions [8].

Benefits: Kaizen events often eliminate the need for costly overtime by improving processes while collapsing lead times and dramatically reducing work-in-process. Other immediate results are a reduction in required floor space, reduction in labour, higher quality, faster service for customers, and improved profits. The flexibility of kaizen events makes them applicable anywhere in the plant, front office to back shipping dock. Wherever there is waste, kaizen can eliminate it [10].

2.7.3 JIT Just-In-Time

Just-in-time (JIT) is one of the two pillars of TPS (the other is Jidoka, built-in quality), without JIT is unthinkable to implement in any level the lean system.
Just-In-Time is based in Toyota's pull system. If JIT should be described by one sentence it is that JIT is the way of deliver the right items, in the right amount and at the right time. To be able to be responsive to customer demand, JIT is an essential part and it is applicable both internally and externally. Customers can be external but also internal inside the company, and should be provided with the same services as the external ones [9].
JIT is a set of principles, tools, and techniques that allows a company to produce and deliver products in small quantities, with short lead times, to meet specific customer needs. The power of JIT is that it allows you to be responsive to the day by-day shifts in customer demand, which was exactly what Toyota needed all along [8].
Just-in-Time is not a single technique that generates business success, it is the application of other production techniques, such as Kanban, reduced lot sizes of manufacturing, reduced delivery times, and increased quality of programs required to implement flexible manufacturing processes. Thus, JIT is described as a manufacturing system that strives for excellence through continuous improvement in productivity and the elimination of waste [4].

2.7.4 Kanban

Kanban is considered the Japanese term for visual control of the movement of materials and inventory throughout the plant. A Kanban is a card containing information that follows a product through each stage along its path to completion. These cards are used to control work-in-process (WIP), production, and inventory flow. A Kanban system consists of a set of these cards, with one being allocated for each part being manufactured [10].

3 EMPIRICS

An overview of DFV group and Djs Qualicoaters Australian spot, products, and pre study is forwarded. A detailed description of the current process of production follows through the lean manufacturing tools. This description is a preparatory for the next chapter of analyses.

3.1 Company description

DFV is a company with 50 years of experience, an international leader in the field of industrial painting that specializes, in particular, in wood-effect. It's the only company in Italy to have all the necessary production technologies for the realization of these finishes on aluminium profiles and rolled sections.
DFV's mission is to paint aluminium profiles in a wide choice of colours, ranging from RAL (classic and special) to wood-effect decorations.

Figure 7 DFV logo

DFV guarantees a capillary and efficient distribution network: it counts on a large number of vehicles, all equipped with cantilevers, and on the quality of packaging to offer greater protection and safety to products during handling and transport. Moreover it ensures quick short delivery times (between 5 and 10 working days). Finally, a detailed order monitoring system allows customers to follow the processing steps through the online query of the order status [2].

DFV operates through 3 production sites located across the country (in Lecce, Agrigento and Venice) and abroad, with 2 plants located in Sydney and São Paulo.

Figure 8 Worldwide DFV

The case of this final project was developed in the Australian production spot called DJS Qualicoaters. The company founded in 1985 was acquired from DFV at the beginning of the 2018.

3.2 Product

The different products provided by the company can been classified manly in three categories: RAL paintings, powder on powder paintings and sublimation paintings. In the following is possible to see an overview about the characteristic and the technologies related to each product [2].

RAL PAINTINGS

The definition of RAL colours dates back to 1927, the year in which the collection that today is known as RAL Classic appeared: a choice of more than 200 colours. It follows that the range of colours achievable with RAL painting is wide. Nevertheless, in addition to the already numerous shades of the Standard range, there are the nuances of the Special collection, so that 200+ customization possibilities can be reached on the whole [3].

Figure 9 RAL paintings

- ***RAL STANDARD COLLECTION:*** These colours are obtained through a simple process consisting in coating the aluminium profiles in all the colour variants of the RAL chart through the use of thermosetting polyester powder paints. This type of finishes also includes textured, metallic and dotted finishes

- ***RAL SPECIAL COLLECTION:*** RAL Special is an evolution of the Standard RAL, a unique background colour collection that DFV makes available in numerous shades and for various uses. The special collection includes glossy, matte and rough colours and, among others, marble, antique, musk and rusticated effects.
- ***RAL CLASS 2:*** DFV employs Class 2 certified paintings (certified by Qualital) which guarantee high standards of quality and durability of the colour. Class 2 paintings are resistant to ageing, gloss loss and severe weather conditions. Class 2 colour finishes look like aluminium ones and offer a 15-year warranty period. They combine a modern design with exceptional durability performance. Thanks to their weather resistance characteristics, Class 2 paintings are recommended for applications in coastal areas, environments with a high level of humidity, pollution and high sunlight exposure.

POWDER ON POWDER WOOD-EFFECT DECORATION

The powder-on-powder decoration process ensures very high standards and great strength. The aluminium profiles are coated with a layer of powder that reproduces the wood’s veining using a special automatic applicator.

Figure 10 Example of Ezy coated profile

Ezy®: technology patented by DFV the first high-definition powder-on-powder wood-effect painting system capable of ensuring great aesthetic value and very high quality, in addition to homogeneous colouring on all sides of the profiles. The strong resistance to sunlight and weather conditions is obtained using only polyester powders, of which DFV knows every kind of application. Thanks to the scientific contribution of the Research and Development division, Ezy® is a constantly evolving system that allows creating as many as 20 elegant and high-resolution finishes suitable to enhance refined, composed and sophisticated taste.

- ***Ezy HD²:*** The new Ezy HD² high-durability finishes are obtained through the use of Class 2 approved powders, which guarantee a product life of 15 years under normal conditions of use and maintenance. DFV has obtained the prestigious Qualideco Class 2 certification for producing a product (Ezy HD²) that passed all the relevant tests thanks to the superior characteristics of the raw materials used and to the scrupulous respect of the Technical Guidelines of the brand at each processing stage. The Ezy HD² series ensures high performance of the painted product, namely: very high colour durability, excellent resistance to ageing, excellent barrier to the aggression of weather conditions, effective contrast to the loss of gloss.

- ***Effecta®:*** is the high-productivity painting system applied on a vertical plant. The high productivity of the plants and the rapid production times make the products processed with this technology more profitable, both in terms of cost-effectiveness and service effectiveness, ensuring fast and compliant deliveries on the entire range of 5 finishes. The high technology of the Effecta® system makes it possible to obtain an extremely high-quality product, highly resistant to weather conditions and, at the same time, guarantees maximum reliability and perfect balance between aesthetic value and cheapness.

SUBLIMATION PAINTINGS

In addition to powder-on-powder finishes, DFV offers a wide range of products with Sublimall decorations, obtained by means of the sublimation technique, which consists in performing a hot-stamping decoration of decorated supports that can be transferred onto aluminium profiles and rolled sections.

Figure 11 Example of Sublimall profile

- ***Sublimall:*** The main characteristics of the sublimated product are: four-colour reproduction, colour uniformity between different production batches, excellent graphic and aesthetic definition, 4-sided coverage, acceptable hardness and sufficient UV resistance [3].
- ***Electo®:*** is the latest addition to the wide range of wood-effect finishes created by the DFV Research and Development team. The wood effect is reproduced on the previously painted background profile, with the application of a film transfer that releases the decoration by hot-stamping thanks to the combined use of air void and high temperature. Compared to products processed with traditional sublimation, Electo® products have even more performing features, ranging from greater UV resistance to colour repeatability between different production batches.

3.3 Production chain

An overview of the plant as been described in this chapter, a more in-deep outline of the process unit follows in order to underline strengths and weakness of the production processes.

3.3.1 Plant overview

The following figure shows the shop floor CAD of the Djs Qualicoaters, two main areas can be identified:

- ***Ezy***: marked by a yellow rectangle, required for powder on powder process. In this area the wood decorations are made after a RAL colour layer.
- ***Cube***: marked by an orange rectangle. It is a vertical powder coating compact line that includes all the process unit required for the RAL coating. A more deep-in description of the different units has been presented in the following sub-chapter.

In the statement of this final project the Ezy area hasn't been taken into account in order to focus the research on the cube. Only the issues caused by Ezy process to the Cube in order to made the RAL base are analyse, e.g. Downtime described in the *sub-chapter 4.1.3.4*.

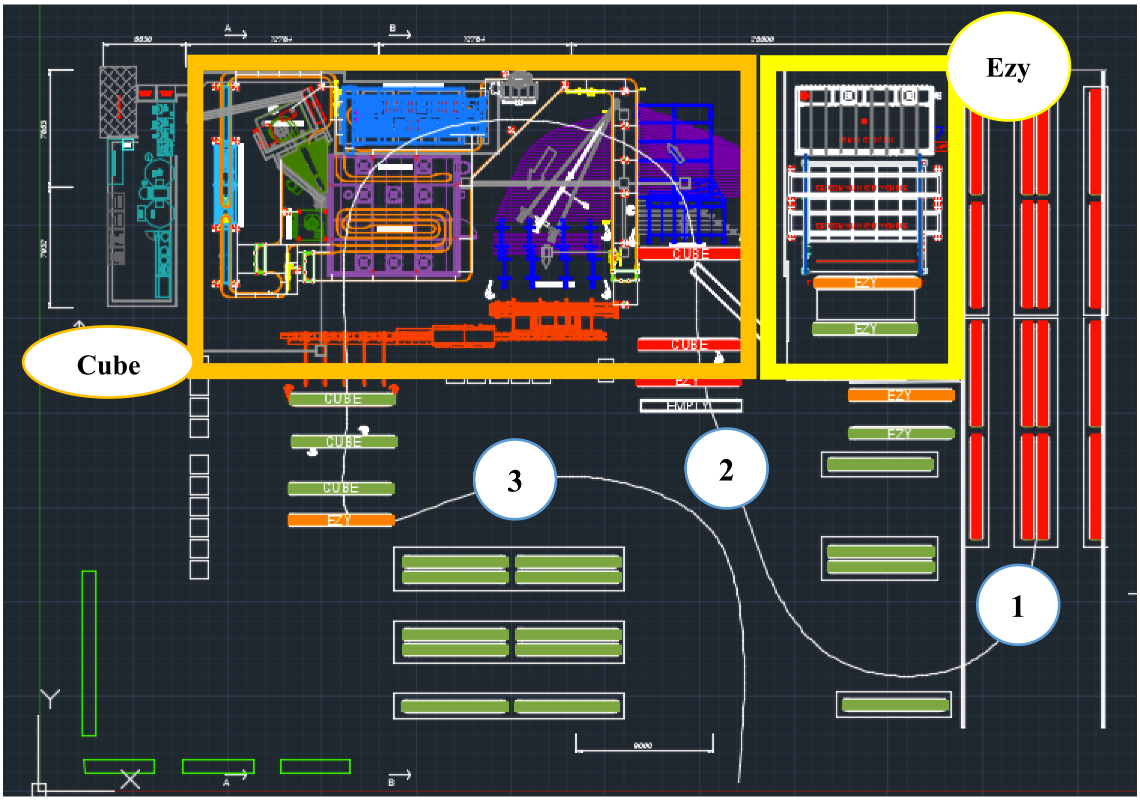

Figure 12Plant CAD

A spaghetti diagram enables a clear vision of the material flow throughout the plant. The image above shows the material route, that can be summarized as follow:

1. **Raw warehouse**: the first step of the route of raw approved material start into the warehouse, an employee handlings the bars by a forklift close to cube.
2. **Cube**: in this area there is the value added operation, through the units of the line the raw material has been coated and it is ready for the packaging operation.
3. **Dispatch**: subsequently the packaging operation, the batches of finished material are ready to be shipment the next day of the production.

3.3.2 Raw material Warehouse

The raw material is stocked in the warehouse, pending for the production process.

Figure 13 Raw material warehouse

As it possible to see from the figure above the warehouse is composed by cantilever where the bars are stocked. The first step is the approval process of the raw material, in which an employee check potential mismatch between the material received and the order processed. If it is present, e.g. different sizes of the intake batches or mismatch profiles, the production management department has to contact the client and figure out how to proceed.

The second step is the stock in the cantilever, currently from the intake of the raw material to the finished product dispatches a working week is guaranteed, for this reason an efficient warehouse management system is mandatory. It has been decided to match each cantilever to a different colour, in this way the handling operation is simplified and it is possible to save time and, in an lean manufacturing point of view, to avoid Muda of transportation and inventory.

3.3.3 Cube

This area is the core of the entire shop floor, it is where the value added is created. The figure below shows a detail of CAD represented the vertical powder coating compact line.

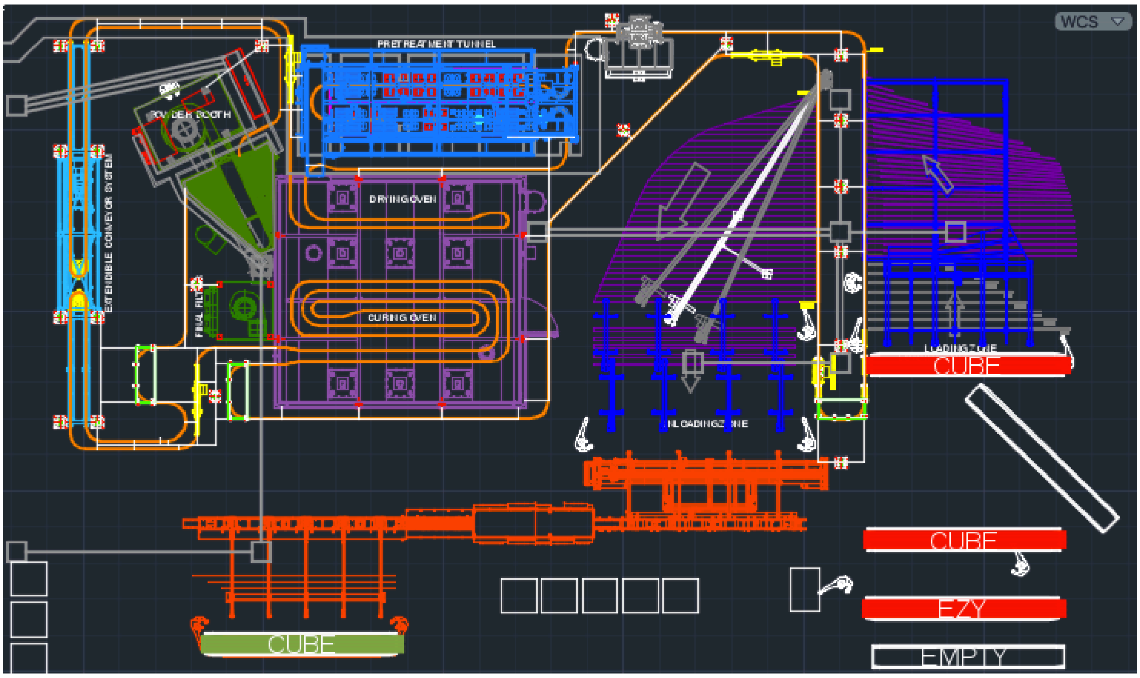

Figure 14 Cube CAD detailed

An overview of the benefits of the cube and a description of the different production unit is presented in the follow.

Cube benefits

Compared to the horizontal systems, the main advantages of vertical coating plants are the following [12]:

- Small space required
- Completely automated process

- Less workers need to manage the entire line
- Fast colour change that allows a higher flexibility
- Higher quality of the product thanks to a more efficient powder transfer that involves both a higher coat thickness uniformity and a reduction of percentage of powder wasted;
- Higher production: up to 450 profiles/h with the standard cube line vs 100÷150 profiles/h with an average horizontal line
- Low operating costs and low energy, water and electricity
- Integrated pre-treatment along the vertical plant

Load unit

Unit intended to the load of the aluminium extrusion profile. Subsequently the arrive of the raw material batches, the employee have to unpackaging each bars. The next step is to lay down the latter on the load bench, pierce one edge and connect it to the conveyor by an hook. The bars will arise vertically by the race of the conveyor. Four employees are required for this unit, one for the unpackaging operation, two for the load and pierce operation and the last one has task to insert the hooks to the conveyor.

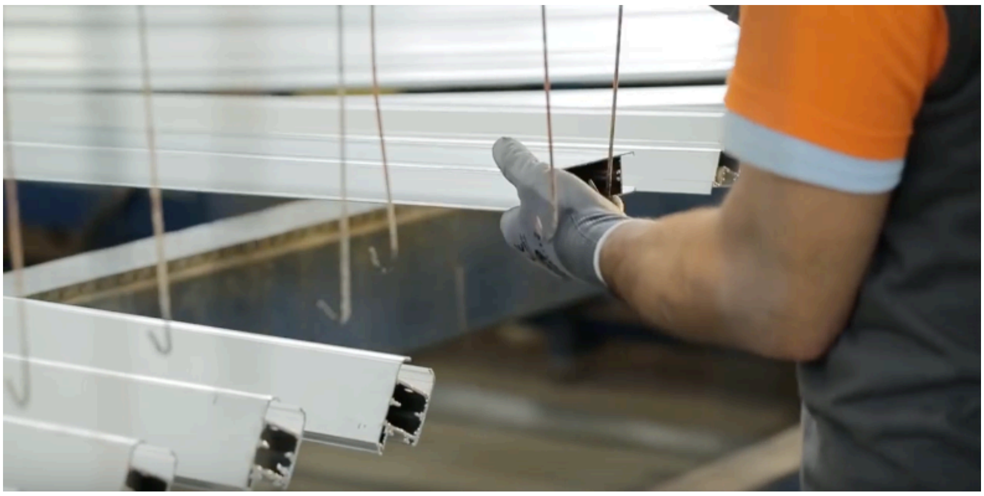

Figure 15 Load unit

Pre-treatment tunnel

Industrial produced profiles have an oxide layer as surface, which has built-in due to its natural growth during its formation dirt, moisture, oils, fat and process additives. This oxide layer is not suitable for the prevention of corrosion nor as an adhesive base for the following finish due to its inhomogeneity and the incorporated non-Aluminium materials. To insure the prevention of corrosion and optimal adhesion between the Aluminium base and the finish, the contaminated initial Aluminium oxide layer is removed down to the pure Aluminium alloy by the pre-treatment process.

In view of the above, subsequently the load operation and before the coating one, the bars connected required to go through the pre-treatment tunnel. The latter use the "cascade" technology, which gradually replaced the "spray" system since it grants reduced consumption of chemicals, due to the regular flow of the liquid along the profiles only few drops are generated and the drag out between two contiguous tanks is lower [12].

The step inside the tunnel can be divided as follow:

1. ***Cleaning:*** This is the first stage of the pre-treatment process and important. It is imperative that the component to be powder coated is thoroughly cleaned at this stage as dirty material will result in lower quality paint finish. A typical way of cleaning the component is with the immersion cleaning process in an acid etch cleaning solution.
2. ***Rinsing*****:** Rinsing of the components to be powder coated is carried out using a rinse typically at the same temperature as the cleaning process before. This is normally a rinse process using clean water.
3. ***Chromate pre-treatment*****:** The chromate process is widely used in polyester powder coating and it comprises a chrome phosphate process. The chromatin process ensures the best surface is available prior to polyester powder coating.
4. ***Second Rinse:*** A second rinse is carried out after the chromate treatment.

5. ***The Third Rinse Process:*** This process comprises another towns water rinse.
6. ***Final Rinsing process:*** This process is a demineralised water rinse. This rinse has had all the contaminants removed and is a pure water rinse to ensure that the surface is absolutely clean prior to polyester powder coating.

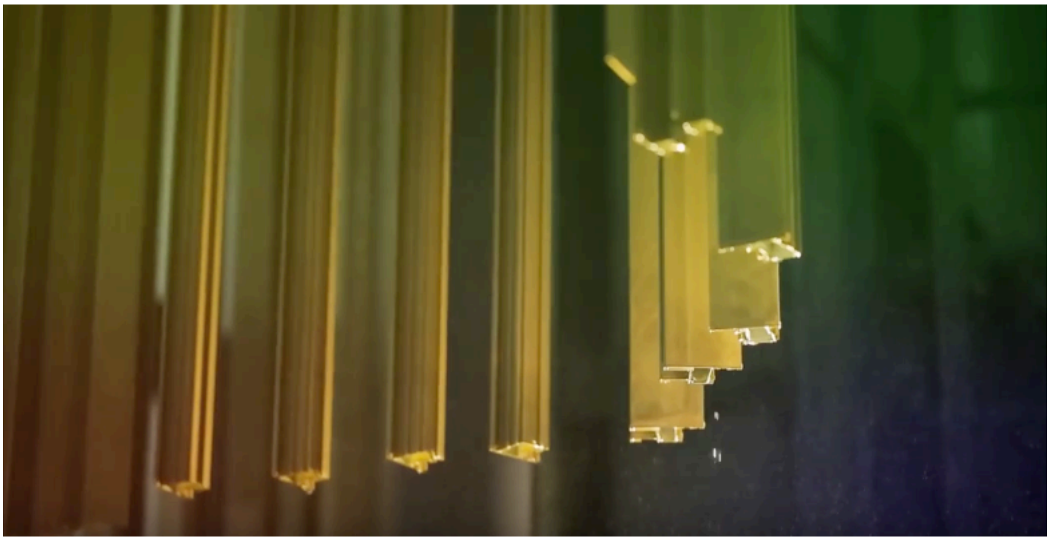

Figure 16 Pre-treatment tunnel

After these six steps, the pre-treatment of the bars is ended, the final result is showed in the figure above. It is possible to notice the different colour of the bars from the previous picture, in the load operation, the colour change from silver to yellow this is due to the chrome treatment.

Subsequently the tunnel the last step before the coating process is to go through the drying oven, The drying process is relatively quick achieving a metal temperature of not exceeding 100 degrees Celsius.

Booth spray

Subsequently the pre-treatment and dryer operation, the extruded aluminium profiles are ready to be coated by the desired powder.

The scheme of the booth spray is the represented in the following figure.

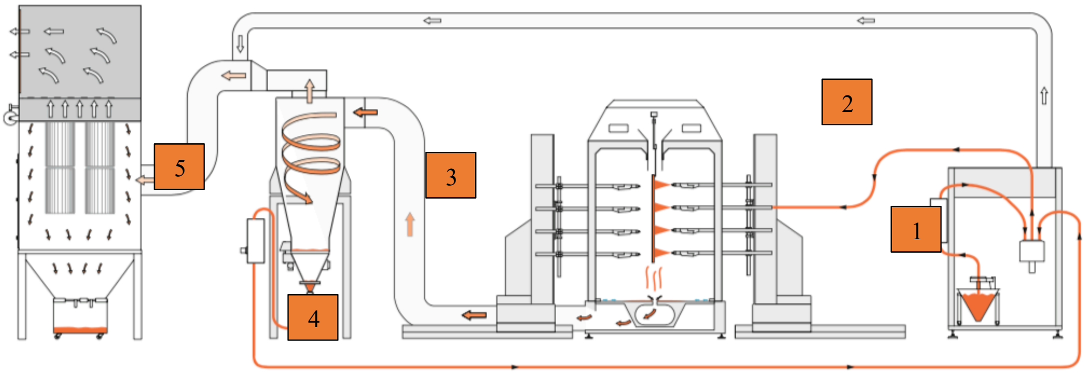

Figure 17 Booth spray system detailed [5]

The route of the powder can be summarised as follow, following the marked number in the figure above:

1. A desired powder bag can be placed in the fresh powder feed station. Injectors or pumps, hoses, guns and the recovery hose are automatically cleaned by powerful air blasts. The powder aspired from the bag go to fill the Opticenter.
2. From the Opticenter the flow of powder go to charge the different guns of the booth spray area
3. The extra powder ,which has not coated to the profiles, go from the aspiration of the booth spray area to the cyclone, tangential air movement within the trapezoidal design separates powder from the air stream and is proven efficient to 97%. Powder is recovered in the lower cone section of the cyclone.
4. The recovery powder go directly to feed the opticenter in order to be reused in the next profiles of the same colours.

5. The not recovery powder go through a final filter and it is considered the waste of the production because it cannot be reused.

Before the finished bars go through the oven, a last step is required. An employee shall linked up to by two by a clamps, as it possible to see from the figure below.

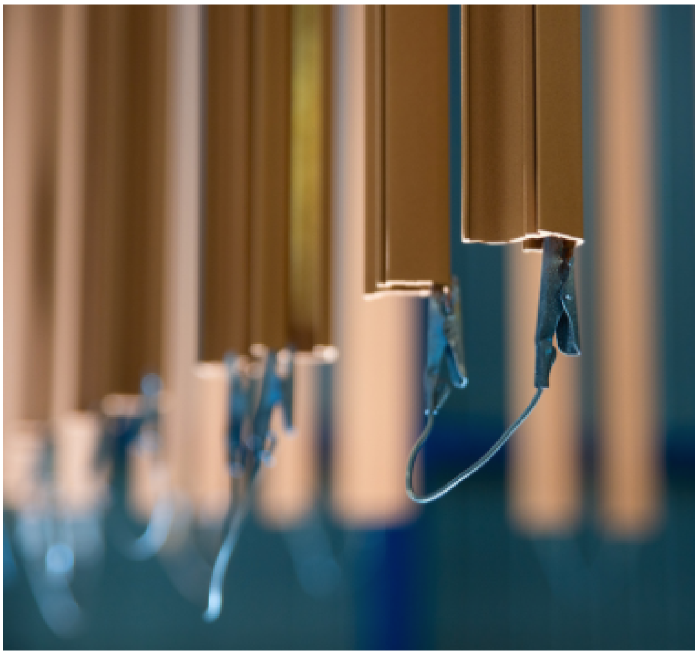

Figure 18 Example of clamps application

This procedures enable to avoid issues inside of the oven or in the route between the latter and the booth spray area, the profile could swing from the conveyor and impact to each other, removing the powder coated to the profile which it is not steel dry. The temperature of the oven depends on the powder, an average is around 180 degrees Celsius for the RAL and 100 degrees for the Ezy base.

Unload

Subsequently the exit of the bars from the oven the drying operation is terminated, the extruded aluminium profile are ready for the next step. Thanks to the inclined road of the conveyor the bars from vertical start to lay down to the unload bench in an horizontal way, as it possible to see from the figure below.

Figure 19 Unload operation

Once the bars are detached from the hooks the unload operation is concluded, the road of the unload bench proceeds close to the wrapping machine where two employee match an amount of bars that depends on the profile. A plastic film is inserted between each two profiles in order to avoid accidental damages.

The next step is the ride on the wrapping machine where the group of bars is compacted by a plastic wrap, this operation allows to block the relative movement of each bars.

The last phase is the packaging of the batch, two employee collect all the groups of bars outgoing from the wrapping machine and create the finish packaged batch. The packaging system is described in detail on the *chapter 4.1.6.2.*

Finished product

The final packed batches are stocked close to the loading bay pending to be loaded on the truck for the dispatch.

Figure 20 Finished batches

The figure above shows the final result of the packaging process and the batches ready to be shipped. The packaging is required in order to avoid accidental damages during the transportation.

4 ANALYSES

In this chapter the analyses and results achieved during the period in Djs Qualicoaters were exposed. Three different analyses have been conducted directly in the company, listed below:

- *Downtime analyse*
- *Powder consumption analyse*
- *Investment feasibility*

In a technical point of view the results achieved from the first two analyses bring useful feedback for production and pave the way for new implementations in the shop floor.
The last analyse shall examine, from an economic perspective, the cost and feasibility of an investment required to lead a practical solution to production issues.

4.1 Downtime Analyses

Downtime analysis (DTA) is an essential part of plant operations management as it provides a powerful tool which enables a better understanding of the underlying issues that affect plant availability and rate loss. DTA enables identification and quantification of lost production capacity by accurately collecting data and measuring actual overall output against theoretical or rated capacity.

4.1.1 Data gathering

For the DTA have been taken into account the working-day relating to the period 20/10/18 to 22/11/12.

The data referred to were gathering directly from the PLC of the booth spray area, for each stop of production, the cause and the responsible unit was detected. During the period mentioned, almost two hundred stops were collected and broken down in 5 different areas:

- Load
- Booth Spray
- Unload
- Failure
- Breaks

Subsequently data were processed by Excel, stops related to brakes haven't been taken into account because regularly scheduled.

The data have been taken daily into an excel sheet that refer to a single working day and then collected in an only file related to the entire period of study.
In the event that the conveyor requires to ride on backward, the amount of the stop is multiplied by two to consider in the DTA the time requires to the conveyor to came back in the previous position.

The following table give an example of the excel sheet gathering data for an entire working day of the plant.

DOWNTIME ANALYSIS							TOTAL PERIOD
N° stop	Time PLC	TIME ELABORATION			Downtime (sec)	Unit	Reason
1	00:01:16	00:01:16	1	16	76	LOAD	UNPACKAGING MATERIALS
2	00:03:02	00:01:46	1	46	106	LOAD	UNPACKAGING MATERIALS
3	00:10:13	00:07:11	7	11	431	OTHERS	DRYER
4	00:12:22	00:02:09	2	9	129	LOAD	MISSING MATERIAL
5	00:14:12	00:01:50	1	50	110	BOOTH SPRAY	POWDER LOADING
6	00:15:07	00:00:55	0	55	55	LOAD	UNPACKAGING MATERIALS
7	00:17:33	00:02:26	2	26	146	LOAD	UNPACKAGING MATERIALS
8	00:19:52	00:02:19	2	19	139	LOAD	MISSING MATERIAL
9	00:21:29	00:01:37	1	37	97	OTHERS	MISSING REASON
10	00:36:35	00:15:06	15	6	906	BREAK	TEA BREAK
11	00:37:47	00:01:12	1	12	72	BOOTH SPRAY	POWDER LOADING
12	00:39:33	00:01:46	1	46	106	BOOTH SPRAY	POWDER LOADING
13	00:41:02	00:01:29	1	29	89	LOAD	UNPACKAGING MATERIALS
14	00:42:45	00:01:43	1	43	103	LOAD	MISSING MATERIAL
15	00:43:43	00:00:58	0	58	58	LOAD	UNPACKAGING MATERIALS
16	00:45:34	00:01:51	1	51	111	LOAD	UNPACKAGING MATERIALS
17	00:47:45	00:02:11	2	11	131	BOOTH SPRAY	RECOATING
18	00:48:33	00:00:48	0	48	48	BOOTH SPRAY	RECOATING
19	00:52:13	00:03:40	3	40	220	BOOTH SPRAY	COLOR CHANGE
20	00:55:33	00:03:20	3	20	200	BOOTH SPRAY	COLOR CHANGE
21	01:35:33	00:40:00	40	0	2400	BREAK	LUNCH BREAK
22	01:36:58	00:01:25	1	25	85	BOOTH SPRAY	RECOATING
23	01:37:25	00:00:27	0	27	27	UNLOAD	WRAPPING MACHINE
24	01:42:17	00:04:52	4	52	292	OTHERS	OVEN
25	01:43:44	00:01:27	1	27	87	BOOTH SPRAY	RECOATING
26	01:44:41	00:00:57	0	57	57	BOOTH SPRAY	RECOATING
27	01:49:50	00:05:09	5	9	309	BOOTH SPRAY	COLOR CHANGE
28	01:58:56	00:09:06	9	6	546	UNLOAD	OVERLOAD
29	02:00:34	00:01:38	1	38	98	UNLOAD	WRAPPING MACHINE
30	02:01:20	00:00:46	0	46	46	UNLOAD	WRAPPING MACHINE
31	02:02:55	00:01:35	1	35	95	UNLOAD	WRAPPING MACHINE
32	02:07:00	00:04:05	4	5	245	UNLOAD	OVERLOAD

Table 2 Abstract of Downtime data

As can be seen below, the time related to the stop was taken from the GU of the PLC, for each stop the working pause was taken and collected into the excel.
On the column “time elaboration”, the time of a single stop was calculated as the difference between the value of the stop n+1 and the value of the stop n.

Figure 21 PLC screen

4.1.2 Data developed

The data concerning stops were compiled using a spreadsheet and drawn up into charts, this allows an easier feedback of the results.

UNIT ANALYSES			
UNIT	**TOT (sec)**	**TOT (min)**	
LOAD	4946	82,4	
FAILURE	15158	252,6	
BOOTH SPRAY	11868	197,8	
UNLOAD	9306	155,1	**TOT(hours)**
TOT	41278	688,0	11,47

Table 3 DT unit

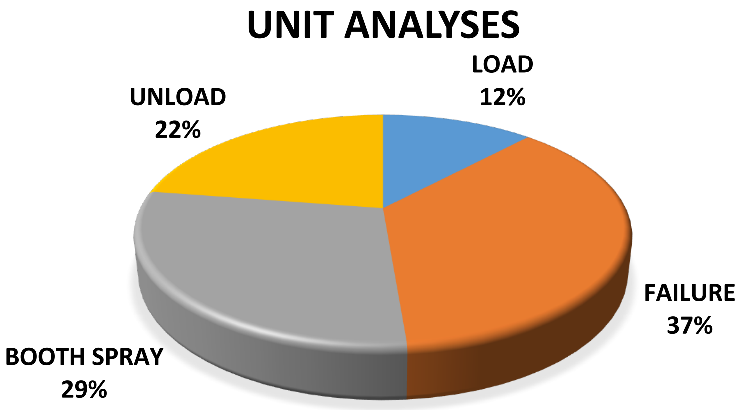

Figure 22 DT unit analyse

As is possible to see on the chart above, the main causes of DT are the failures in the plant, for this reason it was decided to proceed to two different analyses to understand the several root causes and take measures to avoid it. The two analyses mentioned-above are:

- Micro stoppage analyses
- Overall analyses

4.1.3 Unit overview

The following charts show the value of DT for each single unit, the vertical axe is represented by the sum of the minutes for each cause, the latter are represented on the horizontal axe.
In the following, the cause for each single unit have been analysed.

4.1.3.1 Load unit

- **Unpackaging materials:** Delay in the operation of unpackaging the cover of the batches of aluminium rods.
- **Materials lack:** Delay in the replacement of the empty batches with a plenty one.

- **Backlog drilling:** Overburden in the drilling operation of the material on the load bench
- **Hooks lack:** Delay in the sticking operation of the hooks on the conveyor

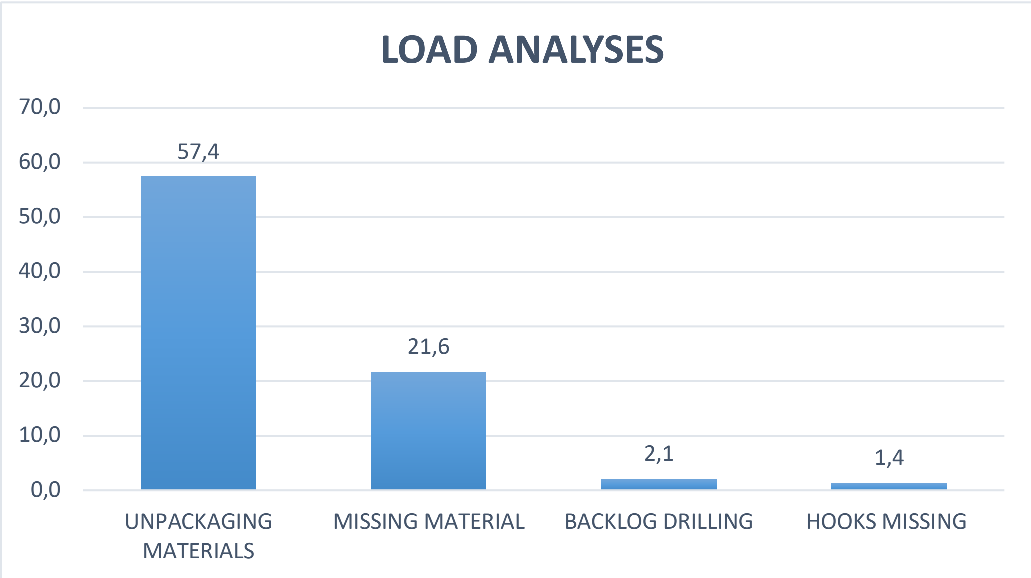

Figure 23 Histagram load unit DT

4.1.3.2 *Booth spray unit*

- **Recoating:** Operation needed to shoot out other powder to the same profile.
- **Aluminium test piece:** Rehearse of the powder before the operation of coating, necessary to test potential contamination of the powder
- **Colour change:** Usually operation breakthrough in masked-time but because of carelessness of the load unit could induce a DT of the plant
- **Powder loading:** When the batches of a single colour is widespread could happen that the several powder loading operations cause a DT necessary to continue the production.
- **Cleaning issues:** Likewise the operation of colour change, the latter should breakthrough in masked-time. This operation needs in total five

minutes, scheduling by free hooks in the conveyor, but could cause DT because of oversight of the employee.

- **Wrong powder:** Due to a carelessness of manpower and an inefficient disposal of powder box in the warehouse.
- **Clamp position:** Operation necessary before rods enter into the oven, typically due to an oversight of manpower.
- **Setting parameters:** Strictly related to recoating, it’s caused by peculiar profiles requiring long setting operation on the PLC.
- **Wrong proforma:** Due to an inconsistency between the proforma from the management and the material on the shop floor
- **Checking coating side:** Some profile require a different coating for each side, information contained on the proforma. For special profile could be difficult to underline the right side.

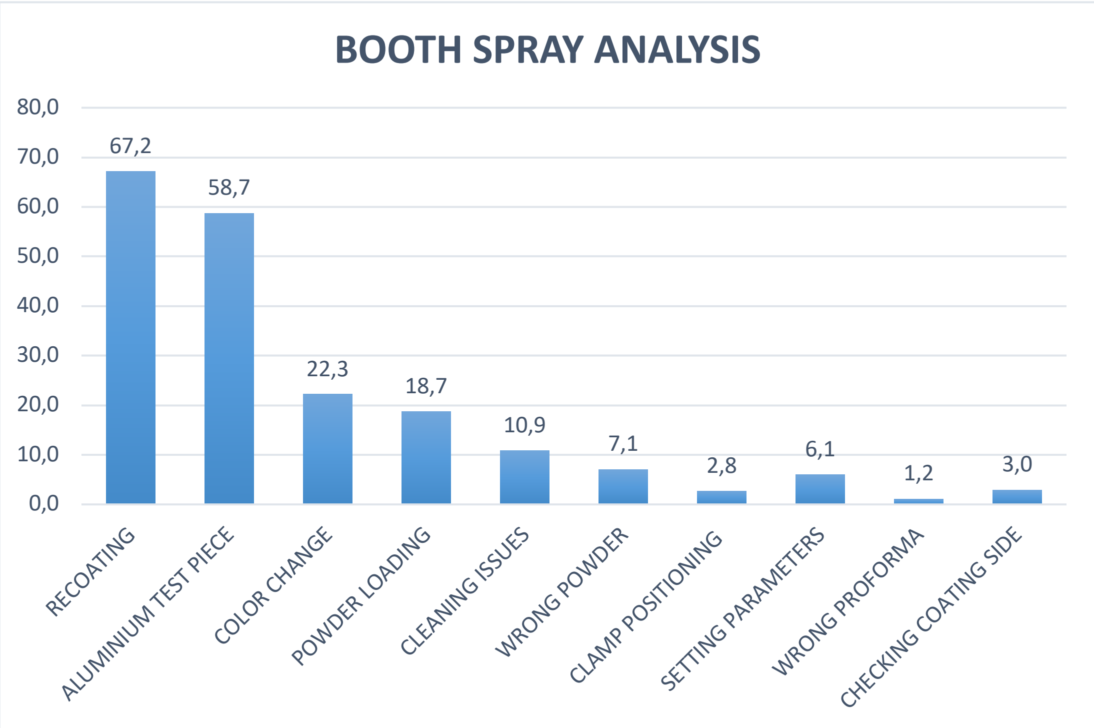

Figure 24 Histagram booth spray unit DT

4.1.3.3 Unload Unit

- **Wrapping machine:** Wide profiles might cause a block into the wrapping machine, this happen for batches consisting in not standard profile
- **Overload:** According to the analyses this operation is the bottleneck of the production, caused by an overload of material outgoing from the oven on the unload bench.

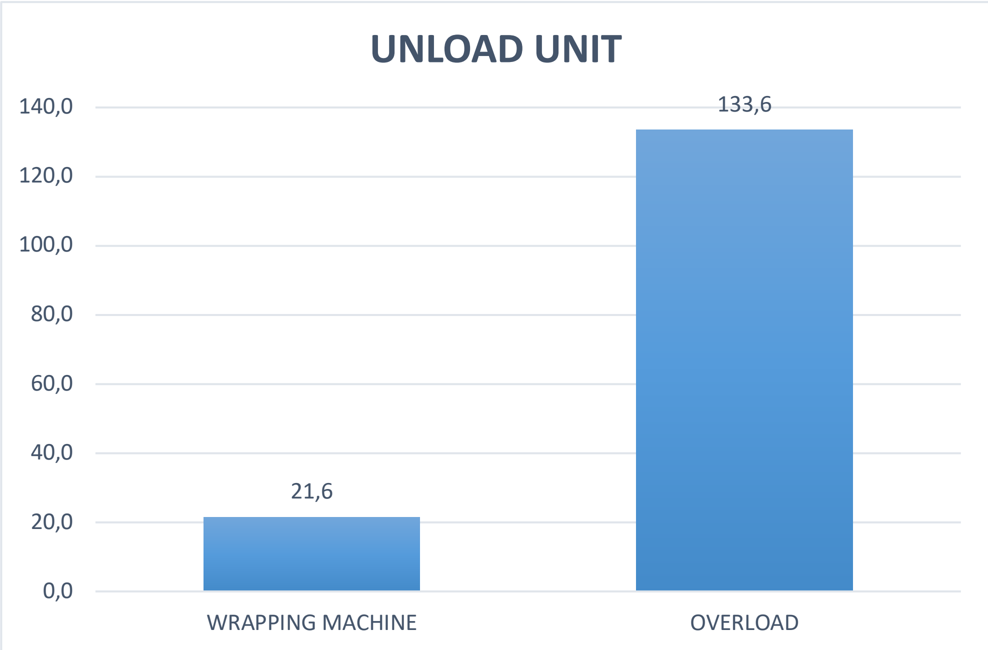

Figure 25 Histagram unload unit DT

4.1.3.4 Failure

- **Dryer:** Due to an deviation of the dryer temperature from the scheduled one, setting temperature is require to dry the material after the acid treatment
- **Software issues:** Caused by a faulty in the PLC software.
- **Oven:** Likewise the dryer failure, this breakdown is caused by a deviation of the oven temperature from the scheduled one. A steady oven

temperature is key importance for the production, otherwise defects might appear on the final product.

- **Fall bar:** Caused by a carelessness of employer on the load unit or faulty hooks.
- **Final filter:** Fundamental operation in order to reuse the recovery powder in the coating operation. DT due to an inefficacy of the filter, this cause contaminated powder.
- **Cyclone:** Strictly related to the final filter DT, the cyclone is connected to the latter. DT caused by an inaction in the powder separation procedure.
- **Power outage:** Due to an electrical malfunction causing the entire stop of the plant.
- **Demi pipe:** Plumbing emergency due to a pipe burst in the demineralised water recycling system.
- **Alarm inverter:** Due to a faulty in the power management system.
- **Injury:** Stop of production caused by accident which caused employer injury.
- **Lack of aspiration:** Faulty in the aspiration management system into the booth spray unit.
- **Burner:** DT related to the oven and dryer fault. Without the burner the firing operation is unable.
- **Valves:** Faulty in the Digital Valve Control system, this caused a mismatch while the opening and closing of the valves.
- **Compressor:** Failure in the air compressor management system, due to this faulting the powder shooting out is unable on the booth spray unit.
- **Check contaminated bars:** Stop of production caused by a contaminated batches from the oven, DT is requires to value all the option and decide to whether or not the production of the batches under discussion.

- **Team meeting:** DT due to a team meeting in order to establish specific procedures.
- **Ezy:** Strictly related to oven faulty, is caused by a faulty in the temperature control system of the oven. For Ezy material the oven temperature shall be set lower than RAL material.

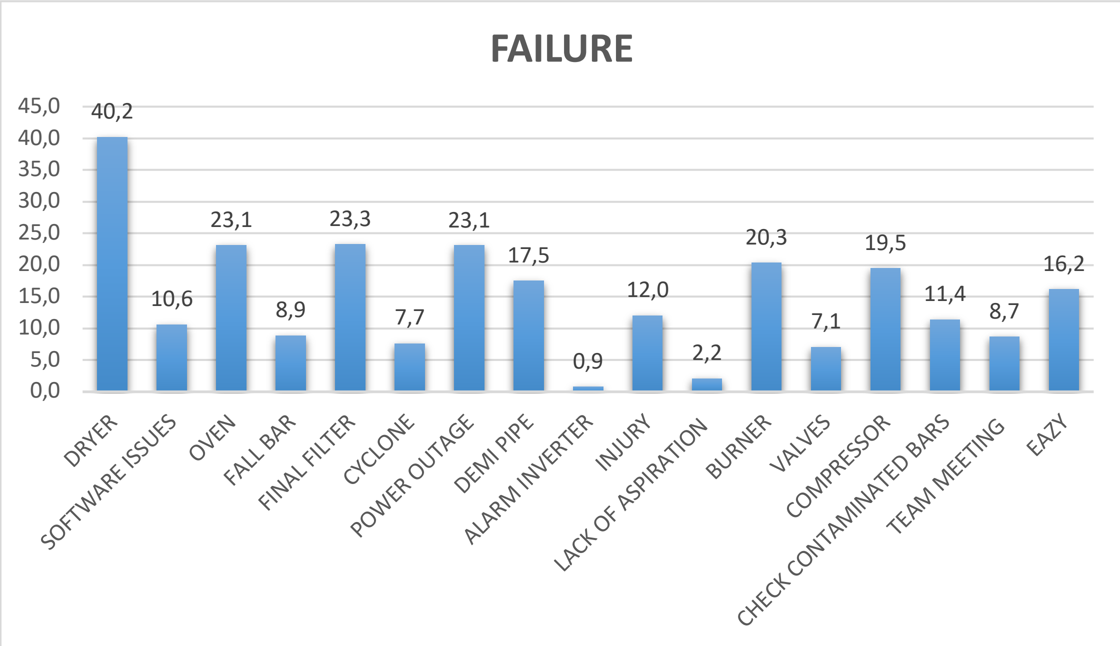

Figure 26 Histagram failures DT

4.1.4 Micro stoppage Pareto analyses

In the following analyses are taken into account only the micro stoppage related to the three principal industrial unit:

- Load
- Booth Spray
- Unload

All the data concerning the production unit have been collected and developed into spreadsheet. The cause of DT for each unit have been collected in increasing order of the amount of the stop.

Subsequently the percentage of each single stop cause has been calculate as:

$$\%_n = \frac{Value_n}{\sum_{i=1}^{t} Value_i}$$

After the collection of each single cause percentage, the cumulative has been calculated by the formula:

$$Cumulative_n = \%_{n-1} + \%_n$$

The value of the last cumulative shall be 100% otherwise the calculation is incorrect.

The table below shows the spreadsheets regarding the developed of the data.

MICRO STOPPAGE ANALYSES				
REASON	**TOT(sec)**	**TOT(min)**	**%**	**CUMULATIVE**
OVERLOAD	8013	133,6	30,7%	30,7%
RECOATING	4031	67,2	15,4%	46,1%
ALUMINIUM TEST PIECE	3522	58,7	13,5%	59,6%
UNPACKAGING MATERIALS	3444	57,4	13,2%	72,8%
COLOR CHANGE	1335	22,3	5,1%	77,9%
MISSING MATERIAL	1294	21,6	5,0%	82,8%
WRAPPING MACHINE	1293	21,6	5,0%	87,8%
POWDER LOADING	1123	18,7	4,3%	92,1%
CLEANING ISSUES	651	10,9	2,5%	94,6%
WRONG POWDER	426	7,1	1,6%	96,2%
SETTING PARAMETERS	363	6,1	1,4%	97,6%
CHECKING COATING SIDE	181	3,0	0,7%	98,3%
CLAMP POSITIONING	166	2,8	0,6%	98,9%
BACKLOG DRILLING	126	2,1	0,5%	99,4%
HOOKS MISSING	82	1,4	0,3%	99,7%
WRONG PROFORMA	70	1,2	0,3%	100,0%

Table 4 Miscostoppage data

The results of the analyses are represented below as chart, the first one is an histogram organized on a downward path.

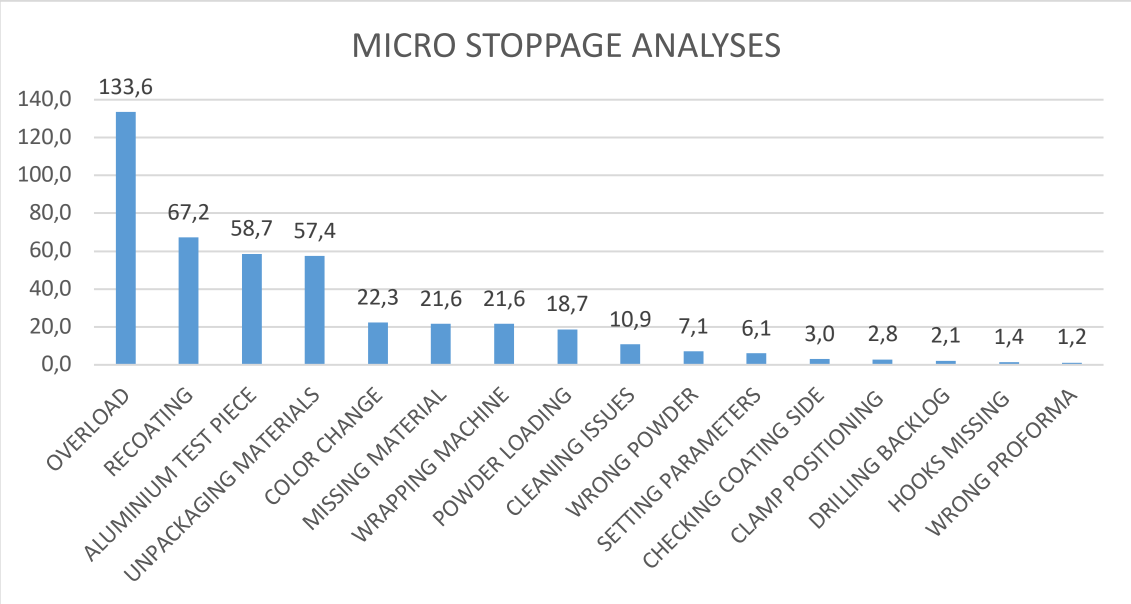

Figure 27 Histagram miscrostappage DT

The second chart is represented below, the vertical axe is composed by the value of the cumulative, instead on the horizontal axe can be found the cause of DT.

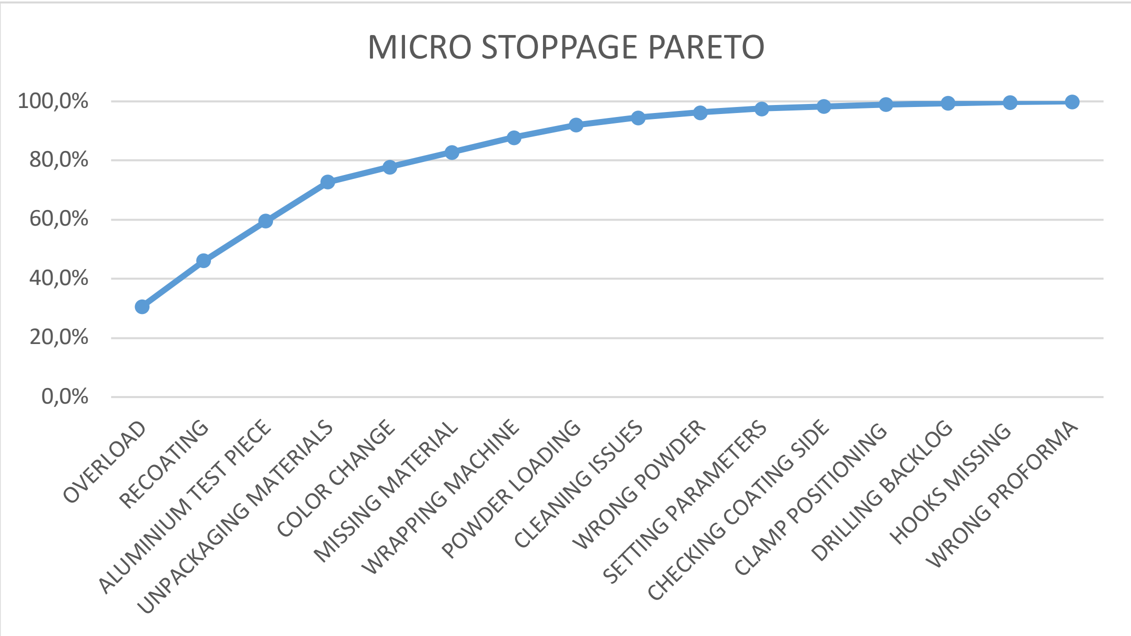

Figure 28 Microstoppage Pareto result

According to Pareto analyses rules the causes of DT have been divided in three different groups:

- **Group A** composed of 5 causes, hence the 80% of the total amount of DT is reached from the 30% of the total causes. These are the critical causes of DT in the plant for this reason more attention must be placed for research of practical solution.
- **Group B** covering the value of DT from 80% to 95% and made up by 5 causes, namely the 30% of the total causes.
- **Group C**, the last 5% of DT is due to 6 causes corresponding to almost the 40% of the causes.

4.1.5 Overall analyses

In the following statement, unlike the micro stoppage analyses, the failure are taken into account. Data have been processed in the same way of micro stoppage analyses.
The table below shows the spreadsheets regarding the developed of the data for the current analyses.

OVERALL ANALYSES				
REASON	**TOT(sec)**	**TOT(min)**	**%**	**CUMULATIVE**
OVERLOAD	8013	133,6	19,4%	19,4%
RECOATING	4031	67,2	9,8%	29,2%
ALUMINIUM TEST PIECE	3522	58,7	8,5%	37,7%
UNPACKAGING MATERIALS	3444	57,4	8,3%	46,1%
DRYER	2411	40,2	5,8%	51,9%
FINAL FILTER	1396	23,3	3,4%	55,3%
OVEN	1388	23,1	3,4%	58,6%
POWER OUTAGE	1386	23,1	3,4%	62,0%
COLOR CHANGE	1335	22,3	3,2%	65,2%
MISSING MATERIAL	1294	21,6	3,1%	68,4%
WRAPPING MACHINE	1293	21,6	3,1%	71,5%
BURNER	1220	20,3	3,0%	74,5%
COMPRESSOR	1170	19,5	2,8%	77,3%
POWDER LOADING	1123	18,7	2,7%	80,0%
DEMI PIPE	1050	17,5	2,5%	82,6%
EAZY	973	16,2	2,4%	84,9%
INJURY	722	12,0	1,7%	86,7%
CHECK CONT. BARS	685	11,4	1,7%	88,3%
CLEANING ISSUES	651	10,9	1,6%	89,9%
SOFTARE ISSUES	635	10,6	1,5%	91,4%
FALL BAR	532	8,9	1,3%	92,7%
TEAM MEETING	524	8,7	1,3%	94,0%
CYCLONE	460	7,7	1,1%	95,1%
WRONG POWDER	426	7,1	1,0%	96,1%
VALVES	424	7,1	1,0%	97,2%
SETTING PARAMETERS	363	6,1	0,9%	98,0%
CHECKING COATING SIDE	181	3,0	0,4%	98,5%
CLAMP POSITIONING	166	2,8	0,4%	98,9%
LACK OF ASPIRATION	130	2,2	0,3%	99,2%
BACKLOG DRILLING	126	2,1	0,3%	99,5%
HOOKS MISSING	82	1,4	0,2%	99,7%
WRONG PROFORMA	70	1,2	0,2%	99,9%
ALARM INVERTER	52	0,9	0,1%	100,0%

Table 5 Overall analyse data

The histogram below show a representation of the data as histogram.

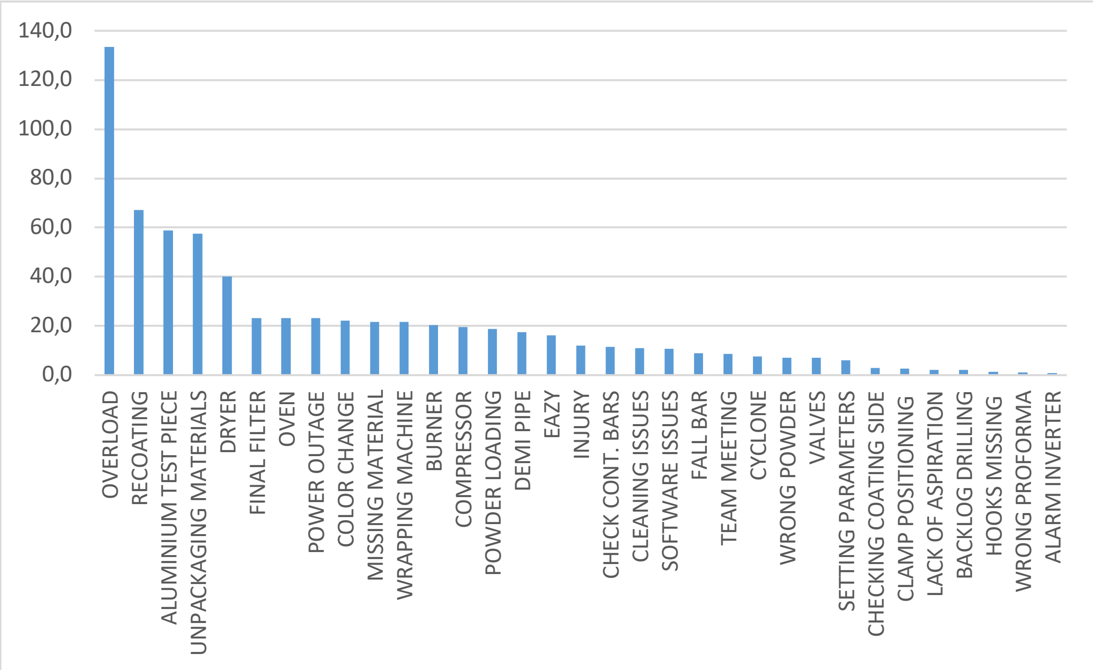

Figure 29 Histagram overall DT

The following chart is a representation of the Pareto analyses, it is noticeable that the trend is different from the micro stoppage analyses. In particular the 80% of total DT is reached by more causes than the first analyses.

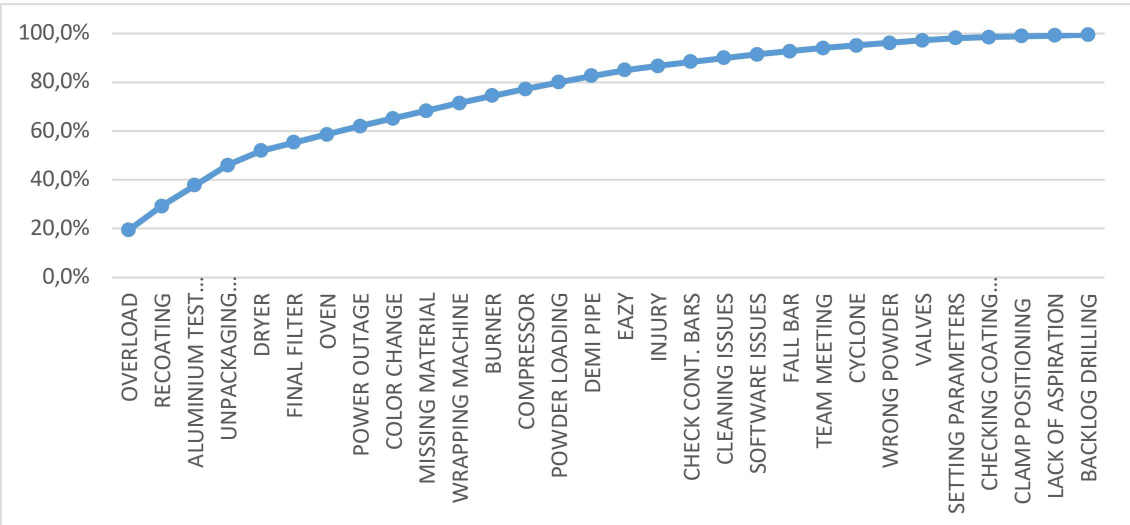

Figure 30 Overall DTA Pareto result

Likewise the micro stoppage analyses, the causes have been divided in three different groups:

- **Group A** composed by twelve causes, corresponding to the 40% of the total causes. The 80% of DT is reached by the causes of this group.
- **Group B** covering the value of total DT from 80% to 95% and made up by 9 causes, namely the 30% of the total causes.
- **Group C** the last 5% of DT is due to 9 causes corresponding to 30% of the causes.

4.1.6 Practical solution

In this section the countermeasures of DT have been exposed, it is noted that the aim of this final project is not to conduct a FA rather than to identify the causes of DT in the production unit.

Furthermore from the results of the micro stoppage analyses and the overall analyses it is clear that the first four causes are the same.

For this reason additional emphasis has been placed to the practical solution of the unit process according to lean manufacturing.

The solution for the following causes of DT have been discussed in the next subchapters:

- Failure
- Overload
- Recoating
- Aluminium test piece
- Unpackaging

4.1.6.1 Failure

The failure, by definition, cannot be expected nevertheless solution for the main failure causes of DT have been implemented.
A fishbone diagram is represented below that sums up the principal causes of DT regarding failure.

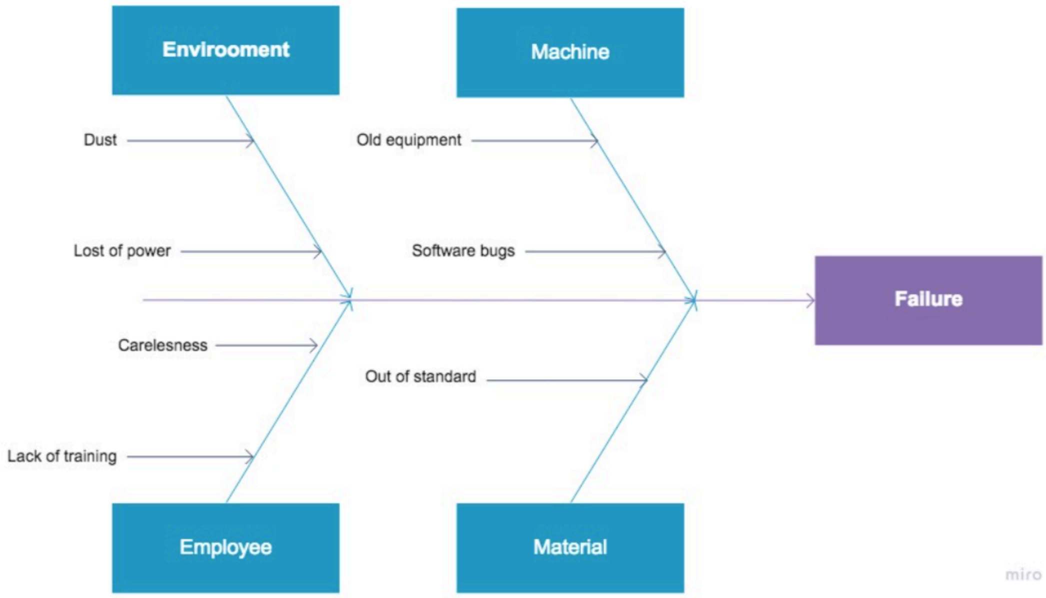

Figure 31 Fishbone failures

The practical solution implemented are described below for each causes of the group A of the analyses.

- **Oven and dryer:** causes strictly connected to each other, the main reason of DT is a deviation of the temperature due to a carelessness of the employee or a bugs in the temperature management system.
  For this reason a warning signal have been installed on the top of the PLC. Every time there is an incongruity between the setting and the real parameters, e.g. temperature or Ph of the treatment, an acoustic and visual signal is activated.
  This signal allows the employee to suddenly take the countermeasures in order to restore the normal function of the plant.

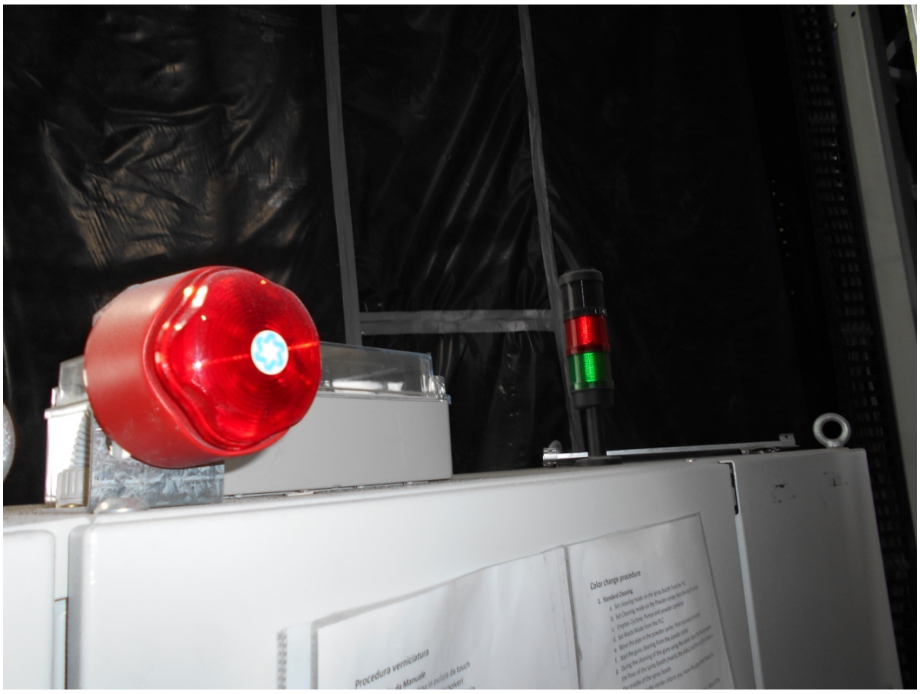

Figure 32Warning signal in the shop floor

The figure above shows the warning signal, implemented directly into the factory. This solution has allowed to prevent DT in the production.

- **Compressor**: In order to avoid any faulty in the air compression system, a new compressor has been installed on the factory.

  On the picture below is possible to see the new compressor, before the replacement with the old one.

Figure 33 New compressor

Regarding the other causes of DT, related to the failure, it was decide to improve the maintenance and to implement new procedures in order to avoid the faulty in the factory, e.g. reduce the period of the final filter cleaning.

4.1.6.2 Overload UNLOAD UNIT

According to the results of the analyse, this cause of DT is the bottleneck of the production, namely it's a point of congestion in a production system that occurs when workloads arrive too quickly for the production process to handle.
Due to an overload of material outgoing from the oven on the unload bench. Employee are not able to dispose of all the material because of a slow speed in wrapping and packaging operation of the finished products.

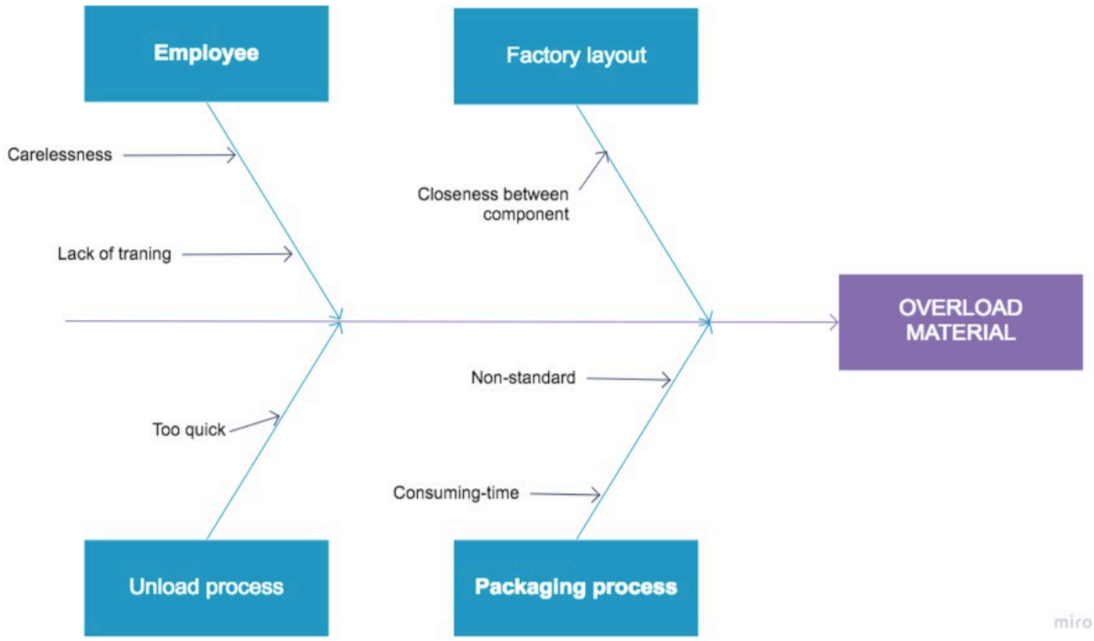

Figure 34 Fishbone unload unit

In the figure above is possible to see the fishbone chart regarding the overload material. In the following statement the roots causes and the possible solution have been exposed.

LONG TERM SOLUTION

To avoid the overload of the material, a long term solution is to increase the unload benches this would enable a longer buffer. In this way employee would have more time to dispose of all the material without the urgency to stop the ride of the conveyor.

The development of this solution requires an adjustment in the layout of the shop floor because of the closeness of the wrapping machine to the unload benches. For this reason the development of this solution has been postponed to the end of the current year, period during which the factory renewal will be held in.

Figure 35 Unload bench and wrapping machine

The figure above shows the unload benches and the wrapping machine, marked, it is possible to notice the closeness between this two components.

SHORT TERM SOLUTION

Due to the limitation in the layout of the factory, a short term solution has been implemented. The roots idea is too improve the packaging operation by changing the packaging system.

- **Current packaging system** composed by wood bases where the finish product is lied down, two side cleats in order to avoid the translation and one top side requires to cover the batches. The finish frame is blocked by a plastic closer.
  This system is very time-consuming because the dimension of the side cleats change for each single batches hence it requires an employee who

have to take the measure of the final batches and proceed to the cutting operation of the side cleats.

The figure above show an example of the current packaging system, this kind of packaging is requires for the forklift handling.

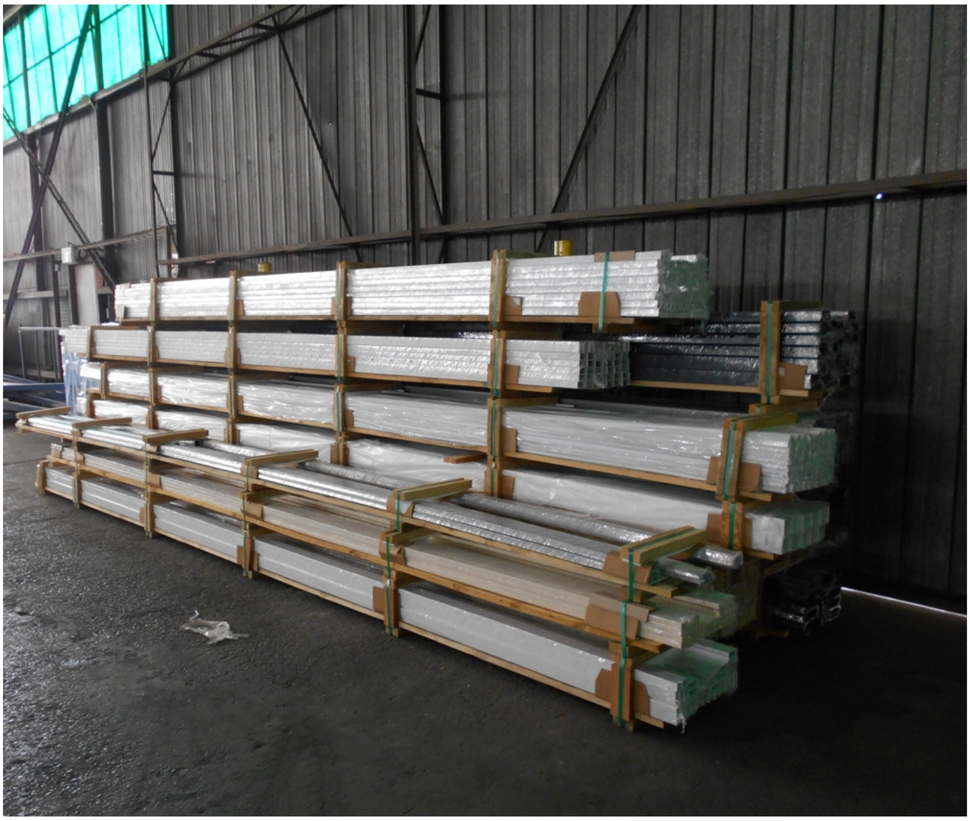

Figure 36 Current packaging system

- **New proposed packaging system:** Unlike the current disposable system the new one is composed by reusable plastic frame called K-PAK. There are several advantages of using the K-PAK system.

  The packing operation would be quicker thanks to the adjustable side uprights that provides the flexibility to pack extrusions in different bundle heights.

  Other than the time-saving aspect, this system requires an employee fewer because it’s not require the cutting side cleats operation.

Furthermore from an environmental point of view, the reusable system is an advantages rather than the disposable one.

Figure 37 K-Pak packaging example

The figure above shows a practical example of the K-PAK system, one k-pack should be placed every one meter of the bar length. It is possible to stack up to 5 batches and lift them by a forklift.
Regarding this new system an economical analyses have been developed in the next chapter in order to evaluate the costs and the advantages of the investment.

It is possible to find many aspect regarding lean manufactory philosophy about this new packaging system, for example:

- **Standardisation:** underpins the lean manufacturing philosophy and thanks to K-PAK is possible to implement the standardisation trough the factory.

- **Waste banish:** One of the aim of the lean manufactory is to identify the NVA and eliminate these in order to highlight the VA. From this point of view the cutting operation of the cleats sides could be consider a Muda.

Other than a NVA task this operation could be counter-productive for the production because the dust produced by the cutting operation could contaminate the bars freshly coated.

4.1.6.3 Recoating

Cause of DT regarding the booth spray unit, due to operation that requires to shoot out additional powder to the same profile, caused by a lack of penetration on the profile.
The fishbone chart below show the main causes of this subject.

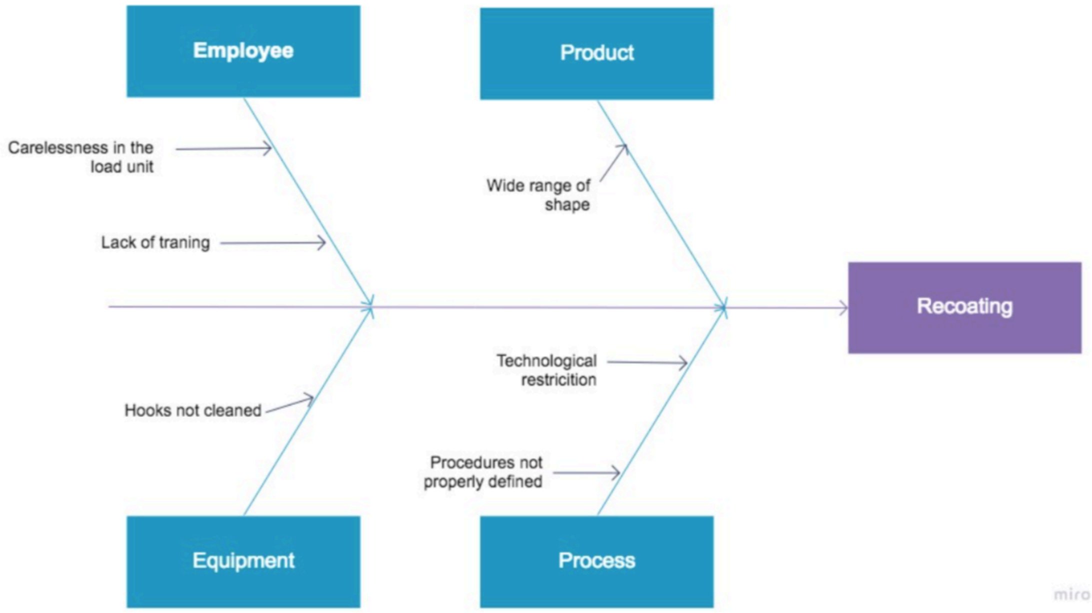

Figure 38 Fishbone recoating

Australian market is characterised by a wide range of aluminium extrusion profile. In particular profile the powder has trouble to penetrate inside, for this reason the employee of the both spray must stop the production and adopt countermeasures.

This problem is caused by the formation of an electrical arc on the profile, positively charged, that reject the powder, negatively charged. Parameters from the PLC shall be set in order to avoid this situation, e.g. increasing the amount of powder shouted out from the guns or decreasing the voltages.

Another aspect that influence the conductivity of the aluminium extrusion profile is the hook, bars are hanging up on the conveyor by hooks. It should be specified that the bars are positively charged by the conveyor so the hooks play a dual role, physical connection between bars and conveyor and it also allow to positively charged the bar.

Hence that a not cleaned hooks leads to a conductivity leaks which hampers the powder coating of the profile.

The figure below show an example of typical hooks used in the factory.

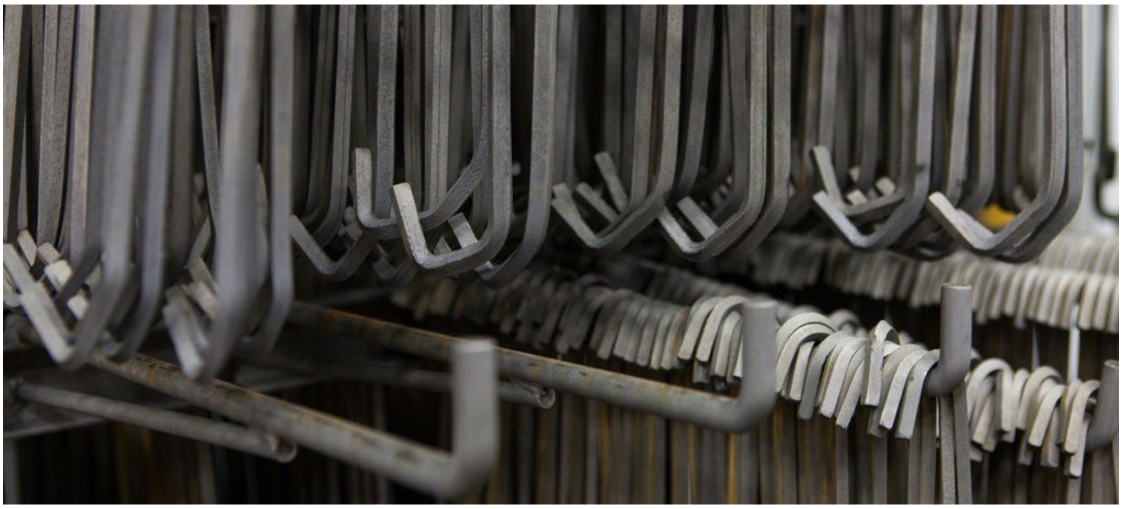

Figure 39 Example of hooks

Another reason that caused the recoating DT is the employee carelessness of the load unit. Different profile are load on the conveyor in the same batches colour, for this reason the employee of the booth spray unit needs to stop the production to change the setting of the PLC to adapt the powder spray to the profile.

To sum up the three roots reason that caused downtime and their solution can be identified in:

- **Technical restriction**: Solution based on matching the profile with the best setting parameters of the PLC. Namely the aim is to create a directly match, each critical profile is matched with a pre-set program. In this way the employee of the booth spray unit does not require to stop the production and find the best mix of parameters.
- **Hooks:** Actually hooks are cleaning up by acid, new improved procedures have been implemented regarding the method and the time of the cleanliness.
- **Employee:** More attention has been demanding to load unit regarding the load sequence in the same colour batches.

4.1.6.4 Aluminium test piece

Likewise the recoating DT, aluminium test piece concerns the booth spray unit. Special attention has been paid to avoid powder contamination problem, for this reason before the powder loading on the opticenter an aluminium test piece is produced.

Every time a powder box is required for the production, an employee shall cover a rectangle shape aluminium piece by the powder at hand. The test piece is dried by a high temperature blow dryer and analysed trough a microscope. This allow the employee to decide if the powder is contaminated, in this case the box is rejected and It is necessary to open a new box to proceed to the production.

The figure below shows an example of aluminium test piece, as it is possible to notice from the figure, it is hard to match the piece to the powder box.

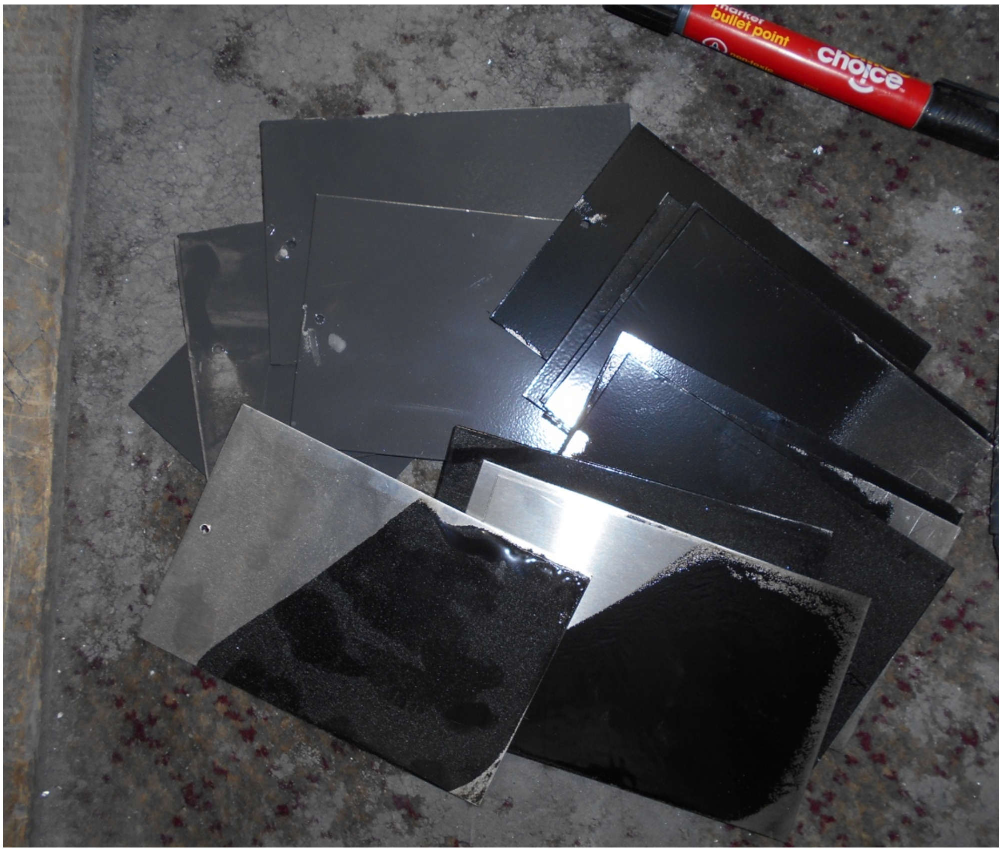

Figure 40 Test aluminium pieces

The procedures is slow and chaotic, for this reason in a visual management point of view, it was decided to implement a new leaner procedures.

In according to the production scheduling, the specific amount of every different powder colour is withdrawn from the warehouse and carried close to the Opticenter. Subsequently in line with the scheduling chronological order, the powder shall be analysed, as described above, and collected in an airtight plastic packet and attacked on the box at hand.

This allow the booth spray employee to directly view the result of the test without the need to claim to the test operator.

Figure 41 Test piece passed

The figure above and below show two different example of this procedure. As it is possible to see the colour, date and the results of the test have been reported on the packet.

With this data the booth spray employee has all the information to understand which box is ready to load and which it is rejected.

Figure 42 Rejected test piece

The figure above show a negative outcome of the test. The contaminated piece occurs as an uniform base of the colour at hand with scattered spots of a different colour. In this specific case, the base is a Pearl white gloss but the test piece presented black spots and for this reason the employee decided to reject the box. Causes of contamination could be identified in:

- **Environmental**: Due to the dust pollution in the factory not finished box in the warehouse can be contaminated.
- **Faulty powder batches**: It is possible that an unopen box present contamination, in this case the responsibility is of the powder production company.

4.1.6.5 Unpackaging

Due to the load unit, this DT refers to the delay in the operation of unpackaging the batches of the raw material.

Figure 43 Example of raw material packaging

The figure above shows an example of raw material in the warehouse. In line to the production scheduling an employee carries the correct batches by the forklift close to the load batches.

This particular coverage is necessary from the supplier to avoid accidental damage during the transportation.

The employee from the load unit has to uncover each bar and load to the benches, this operation is seriously time-consuming.

The solution that was implemented to avoid this DT cause is to increase the load batches this would enable a longer buffer for the drilling and hooking up operation.

Unlike the overload solution, this one has been already implemented without the needs of a re layout of the shop floor.

4.1.7 Conclusion

To sum up, DTA was an important tool to arise issues in the production on the shop floor. The data processed and the results achieved bring key information about the performance of the plant and allow to identify process which have to be improved.

Practical solution have been identified in all of the production unit in order to avoid or decrease the cause of DT, some of these have been already implemented bringing optimal results.

In line to the lean manufacturing principles, the results achieved from the analyses allow to reduce wastes as Muda, described in the *chapter 2.3,* and to introduce procedures in according to visual management, discussed in the *chapter 2.6.*

4.2 Colour change analysis

In their strive for success in competitive markets, manufacturing companies have to payed special attention in flexibility, the importance of an efficient production planning is taking more and more influence in the internal company policy.

The aim of this analyse is to bring results helpful for the production planning in order to reduce to reduce the colour change during the production and all the issues that it brings.

4.2.1 Data gathering

For the CGA were taken into account the data regarding the entire year of production, namely from January 2018 to December 2018.

Data were collected directly from the production management system and exported in Excel as spreadsheet, almost two thousand value have been analysed regarding each batches related to the same colour.

Proforma	Load day	Load time	Unload day	Unload time	Code colour	Num. of piece	Square meter
281813	02/07/18	61506	02/07/18	115124	ZSGY4DM	8	7,68
281821	02/07/18	63247	02/07/18	115524	ZSGY4DM	26	57,17
281814	02/07/18	63649	02/07/18	120218	ANNY3AM	7	7,49
281805	02/07/18	64505	02/07/18	122909	SHLY3DS	3	9,78
281817	02/07/18	72207	02/07/18	122919	DUNY3DS	26	66,24
281797	02/07/18	74040	02/07/18	135317	WLBY3AM	2	11,46
281818	02/07/18	80438	02/07/18	140626	VPSY3AS	76	114,21
281810	02/07/18	83235	03/07/18	62743	DMOY4DM	303	628,11
281796	02/07/18	95538	03/07/18	73552	UCHY4AM	1	2,429
281806	02/07/18	101317	03/07/18	80600	CHRY3DS	8	17,2
281820	02/07/18	101526	03/07/18	81321	CHRY3DS	47	111,59
281819	02/07/18	110610	03/07/18	82903	ZCHY4DS	49	183,29
281811	02/07/18	110621	03/07/18	84313	ZCHY4DS	425	1149,02
281807	02/07/18	131942	02/07/18	132000	SHLY3DS	14	14,68
281812	02/07/18	133820	03/07/18	110022	ZCHY4DS	20	25,64
281816	02/07/18	133926	02/07/18	133952	DUNY3DS	37	86,83
281809	02/07/18	140135	03/07/18	112136	BTPK3AS	150	101,4
281808	02/07/18	142317	03/07/18	114751	BTPK3AS	395	415,67

Table 6 Example of spreadsheet gathering data CGA

The table above shows and example of the collected spreadsheet data. As it possible to see all the information about the production are reported. The following is a general description of the relevant information contained in the spreadsheet:

- **Proforma:** unique code related o the production batches. In each proforma are collected all the batches with the same profile and colour.
- **Code colour:** Single code that leads information as supplier, colour, conductivity and granulation.
- **Number of piece:** number of the same profile of the same batches.

- **Square meters:** Surface of the bars that has to be coating, unlike the Italian that consider the weight of the material in Australia the main information to communicate with suppliers and clients is the surface.

It should be noted that the number of piece is linked only to the same profile and not to the production batches. An example to understand the difference between this two definitions is on the first two lines of the table 7 sets out below:

Proforma	Load day	Load time	Unload day	Unload time	Code colour	Num. of piece	Square meter
281813	02/07/18	61506	02/07/18	115124	ZSGY4DM	8	7,68
281821	02/07/18	63247	02/07/18	115524	ZSGY4DM	26	57,17

Table 7 Detailed spreadsheet gathering data CGA

In this two cases is possible to see that the proforma is different but the code colour is the same. That is because the proforma is referred to the raw material batches, but in an optical production this two batches do not require a change colour operation by the booth spray unit because the code colour is the same.
In this case the employee from the load unit shall leave ten free hooks between the two batches, by allowing thus the employee from the booth spray unit to set the value of the PLC in according to the new profile.

4.2.2 Data processing

Subsequently the collection of the data, the latter were processed in spreadsheet by a Pivot table. Data have been sorted by colour, hence different profile coated by the same colour have been placed together.
An example of the first lines of the spreadsheet is represented below:

Colour	SQM
Duratec MONUMENT Satin	43649
PRECIS BLACK INK 20YR	25165
PEARL WHITE Gloss	17641
Duratec Monument Matt	14985
MONUMENT - Satin	12468
BLACK Satin (Akzo)	10965
Eternity CHARCOAL PEARL Satin	10107
Precious- SILVER PEARL KINETIC	7810
MONUMENT matt- D2015	7792
Duratec CHAMPAGNE MATT KINETIC warranty	7581
Electro BLACK ACE (20KG)	7298
SURFMIST Satin	7018
Precis Dark Bronze	6750
Ultriva CHARCOAL Matt - D2015	6574
BLACK Matt	6335

Table 8 Pivot table data processing DTA

The entire analyse cover a range of colour amounting to 193 different colour, collected in decreasing order of SQM.

It was decided to processed data by SQM rather than the number of piece because the revenue of the company is calculated related to the SQM and not related to the number of piece.

The code of the colour has been also replaced by the name of the powder in order to have a more intuitive analyses.

4.2.3 Powder analyse

Data were subsequently processed in spreadsheet and a Pareto analyse have been conducted in order to divide all the different powder in three categories.

The steps conducted to process data are the same to those described above in the chapter 3.1.4.

Colour	SQM	% SQM	CUMALATIVE
Duratec MONUMENT Satin	43649,048	0,1197	11,97%
PRECIS BLACK INK 20YR	25165,82	0,0690	18,87%
PEARL WHITE Gloss	17641,654	0,0484	23,71%
Duratec Monument Matt	14985,064	0,0411	27,81%
MONUMENT - Satin	12468,191	0,0342	31,23%
BLACK Satin (Akzo)	10965,944	0,0301	34,24%
Eternity CHARCOAL PEARL Satin	10107,454	0,0277	37,01%
Precious- SILVER PEARL KINETIC	7810,425	0,0214	39,15%
MONUMENT matt- D2015	7792,868	0,0214	41,29%
Duratec CHAMPAGNE MATT KINETIC warranty	7581,497	0,0208	43,37%
Electro BLACK ACE (20KG)	7298,113	0,0200	45,37%
SURFMIST Satin	7018,974	0,0192	47,29%
Precis Dark Bronze	6750,889	0,0185	49,14%
Ultriva CHARCOAL Matt - D2015	6574,47	0,0180	50,95%
BLACK Matt	6335,919	0,0174	52,68%
Eternity CITI SILVER PEARL Matt	5815,496	0,0159	54,28%
Zeus SILVER GREY Matt	5490,064	0,0151	55,78%
BLACK Satin DULUX (Nightsky)	5331,788	0,0146	57,25%
Zeus BLACK Matt	5241,274	0,0144	58,68%

Table 9 Abstract of the processing data CGA spreadsheet

The table above shows an abstract of the data spreadsheet, as it possible to see the percentage of the SQM has been calculated for each colour in order to establish the cumulative.

Subsequently data have been represented in a graph, which can be seen from annex A, the three classes are underline by different colour.

4.2.4 Results

The results of the analyse allows to create three different classes of powder, in line to the Pareto analyse are presented in the following:

- **Category A**: composed by 39 colours, it means that the 80% of the entire annual production is reached by 20% of the colour.

- **Category B**: the other 15% of production is generated from 53 colour, namely the 30% of the total colour used in the year
- **Category C**: the last 97 colours, almost the 50% of the total colours produced in the year, cover only the 5% of the entire production.

This classification has been useful to identify a proposed strategic plan in according to the sales team. Has been decided a policy for each category regarding delivery time, pricing, minimum amount as follow:

Proposed strategic plan				
Category	**N° of powder**	**Price**	**Minimum amount**	**Delivery time**
A	20	standard	not present	1
B	46	standard	present	2
C	127	overcharge	present	2

Table 10 Proposed strategic plan

The three categories have been also reorganised in order to promote the category A, the colours from different categories are often very similar, the distinction is only on the powder supplier or the granulation of the powder.

Thanks to the proposed strategic plan the planning of production should result easier because the minimum amount of B and C shall ensure a decrease of the change colour issue, cause of DT in the plant discussed in the *chapter 3.1.4*.

4.2.5 Conclusion

To sum up, the result achieved from the powder consumed analyse in the period from January 2018 to December 2018 brings several results. A classification of more than 190 different powder has been possible thanks to the analyse at hand, this leads a new proposed strategic plan that will bring an easier production planning and a decrease of the colour change in the shop floor.

An another important implication of the analyse is also reflected in the warehouse management system. Currently the orders for the powder are managed day by day, this means that, one time the production planning for the next day has been established, the orders for the required powder can be drawn up. An order submitted before the 12:00 shall ensure that the powder at hand will arrive the next day, in line to lean manufacturing principle as JIT described in the *chapter 2.7.3.* Thanks to results achieved from the analyse, the importance of some colour have emerged, in line with this a minimum stock of the powder constituent the category A has been taken into account in order to avoid issues as possible contaminated powder or delay in the shipment of the powder.

In the period at hand, in line to the analyse and through the application of lean manufacturing tools, e.g. housekeeping 5's described in the *chapter 2.7.1*, it has been possible to reduce the powder warehouse by more than 20%.

4.3 K-pak analyse

When it comes to packaging aluminium extrusions, the annual costs of single use disposable timber packaging materials, and consequential waste issues, has become a major burden on the industry as well as the environment.

Moreover a new packaging system was required to consider because of production issues, as it has been described in the *chapter 3.1.6.2*.

The product that allows to develop the new packaging system is the follow:

Figure 44 Example of K-pak

It composed by four plastic mountable pieces:

- Base: which can be also installed on the conveyor in order to load all the bars directly on the k-pak. It has been designed in order to be handles by a forklift
- Two lateral brackets: required to block the lateral movement, the height of the latter is adjustable in order to fit different rods dimension.

- Top cover: It connected to the lateral supports and close the batches, it is necessary to block definitely the batches. On the top of the cover there is a piece that allows the stack of multiple k-pak.

The aim of this analyse is to test the feasibility of the investment, a cost analysis and all the several tools used are describes in the following.

4.3.1 Cost analysis

In the following is possible to see the cost of the two different packaging system. It noticeable that the economical unit used in the entire analyse is the Australian dollar, for this reason every time the symbol "$" has been used it refers to A.U.D.

CURRENT PACKAGING SYSTEM

The costs related to the required material of the current packaging system have been collected and organized in table which is presented in following:

MATERIAL COST CURRENT SYSTEM			
PRODUCT	**COST ($/n)**	**PIECE (n/w)**	**TOTAL ($/w)**
Clear Tape	1,75	12	21
Bundling film	4,05	22	89,1
Spiral Machine	22,07	30	662,1
Plastic closer	68,5	1	68,5
Styrofoam	0,22	551	121,22
Wood Bases	15,4	27	415,8
Cartons cover	9,72	65	631,8
Top cover	0,65	128	83,2
Lateral brackets	2,7	11	29,7

Table 11 Material cost current system

In Australia salaries and payments are provided weekly, for this reason all the cost in the analyse are defined to a period of a week.

On the table 10 in blue are marked the unnecessary components thanks to the new packaging system, the total saved material cost amount to: 528,9 $/week.

Besides the material cost, also the cost of manpower have to be taking into account for the analyses, in this specific case one employee. The following table shows the total cost saved by the new system:

TOTAL COST SAVED	
TYPE	**COST ($/w)**
Material	528,7
Manpower	865

Table 12 Total cost saved by the new packaging system

It follows that the total cost saved per week is 1393 $

NEW PACKAGING SYSTEM

The minimum purchase batch of K-Pak amount to 2000 pieces with a price per unit of 35$. For the initial outlay of the investment has been considered, as well as the cost of the units, also the cost of a warehouse, necessary to store all the units. For the warehouse has been considered three shelves, one for each piece constituent the final product.

In the following table is possible to see what was said earlier:

INITIAL OUTLAY K-PAK			
PRODUCT	**PIECE (n)**	**COST ($/n)**	**TOTAL ($)**
K-PAK	2000	35	70000
Shelves	3	300	900

Table 13 Initial outlay for the investment

It is concluded that the entire initial outlay for the investment of the packaging system amount to 70900 $.

4.3.2 Payback method

From the data collected in the previous chapter is possible to proceed to the feasibility of the investment, the first tool is the payback method.
It has been considered for the analyse as:

- **Cash inflow:** cost saved from the new packaging system amount to 5574,8 $ constantly per month.
- **Cash outflow:** the initial outlay of the investment regarding 2000 units and the shelves.

The following table shows an abstract of the spreadsheet used for the analyses.

PAYBACK METOD		
Months	**Cash flow**	**Cumulative**
0	-70900	-70900
1	5574,8	-65325,2
2	5574,8	-59750,4
3	5574,8	-54175,6
4	5574,8	-48600,8
5	5574,8	-43026
6	5574,8	-37451,2
7	5574,8	-31876,4
8	5574,8	-26301,6
9	5574,8	-20726,8
10	5574,8	-15152
11	5574,8	-9577,2
12	5574,8	-4002,4
13	**5574,8**	**1572,4**

Table 14 Payback method

From this it follows that the payback period amount to 13 months because is the first positive value on the cumulative column.

The limit of the Payback method is that it disregards the time value of money. Simply, it is determined by counting the number of years it takes to recover the funds invested.

The time value of the money is the idea that money today is worth more than the same amount in the future due to present money is earnings potential. Therefore, if an investor has been payed in the future, it must include an opportunity cost. The time value of money is a concept that assigns a value to this opportunity cost.

The value obtained of 13 months is so short that can be considered a positive marker for the feasibility of the investment but, with the limitations of the payback method, it can be viewed as an additional point of reference in a capital budgeting decision framework.

In the view of the above, a net positive value analyse has been conducted in the following.

4.3.3 Net positive value method

In order to provide a complete feasibility analyse of the investment, an additional tool has been used, the Net Positive Value method (NPV)

NPV is defined as the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project, in this case NPV is used to analyse the profitability of the K-Pak investment.

The following formula is used to calculate NPV:

$$VAN = -K_0 + \sum_{t=0}^{n} \left(\frac{1}{1+i}\right)^t \cdot \Delta F_c + \frac{E_n}{(1+i)^n}$$

In this equation:

- $\boldsymbol{K_0}$**:** Cash outflow due to the investment amount to 70900 $

- $\boldsymbol{n}$**:** Product life, in line to the manufacture's specs is 5 years
- $\boldsymbol{i}$: Discount rate or return that could be earned in an alternative investment, namely is the opportunity cost. In this case it has been considered to 2% which is the average rate of the Australian bonds
- $\boldsymbol{\Delta F}$: Difference between the net cash inflow and outflow during a single year of n. Likewise of the payback method it was consider as net cash inflow the cost saved from the current packaging system, instead the outflow is not provided so it can be considered zero. It follow that the value of ΔF is 66897 $ per year.
- $\boldsymbol{E_n}$**:** Residual value of the products, in this case is void because the option to sell the residual products has not been taken into account.

In the following is presented the table required for the NPV:

VAN METHOD		
n	**$(1/(1+i))^n$**	**NPV for year**
0	1	-70900
1	0,980	65585,9
2	0,961	64299,9
3	0,942	63039,1
4	0,924	61803,0
5	0,906	60591,2

Table 15 NPV method

The final value is the sum of each line of the last column that amount to 244419 $. A positive net present value indicates that the projected earnings generated by the investment, in present dollars, exceeds the anticipated costs, also in present dollars. It is assumed that an investment with a positive NPV will be profitable, and an investment with a negative NPV will result in a net loss. This concept is the basis for the Net Present Value rules, which dictates that only investments with positive NPV values should be considered.

4.3.4 System limitation

On the current packaging system, in the best-case scenario, it is possible to recover only the wood bases, for the analyses this aspect has been included in the cost analyse.

For this reason the value added from the proposed packaging system respect the current one is the reusability. It follows that particular attention must be paid in the development of the recovery K-Pak system. It is necessary to introduce a tracking for each K-Pak in order to know where is and when it will be recover.

The possibility of a not completely recovery has been taken into account in order to estimate which is the acceptable rate loss of the product and which is the limit value. In the following analyses has been analysed the impact of different weekly rate loss value. From the production management system has been calculated the value of the packs delivered in a week that amount to 60 packs, considering an average of 5 K-Pak for each packs, it follows that the weekly use of K-Pak reaches the 300 units. The following chart show the impact of the product loss.

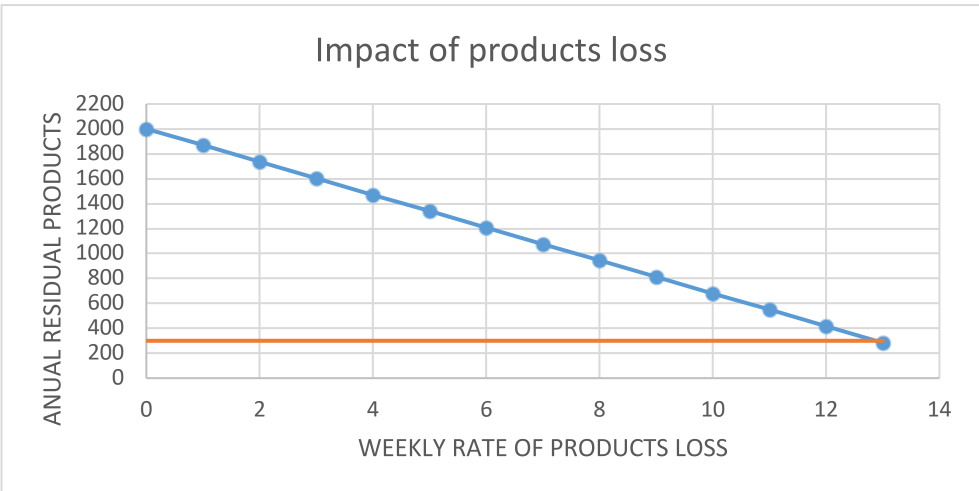

Table 16 Impact of K-pak loss on the investment

On the graph above in orange is marked the critical value for the production of residual K-Pak, the value has been considered as the amount of K-Pak necessary for a week, as above, amount to 300 units. It has been decided to consider this value as critical because the shipments of a new batch of K-Pak requires one week. On blue is marked the annual residual products, an example of the computation is presented below.

Example of 10% weekly rate of products loss

Every week 300 units must be used, it follows that for 10% of weekly rate of product loss the amount of K-Pak missed in a year amount to 1320 units, considering 11 months of production in a year.
The initial amount of K-Pak is 2000 units, namely the minimum purchase batch, it means that in one year the residual units are 680, value higher than the critical of 300 units.
The intersection between the two lines in the previous chart is for 13% of the rate, it concludes that the critical value of rate is 13% for week.

4.3.5 Conclusion

To sum up, the results achieved from the payback method and the NPV were found as a positive marker for the feasibility of the investment.
It is possible to conclude that the investment can be considered profitable as far as the weekly rate of product loss does not exceed the value of 13%. For this reason special attention must be paid to monitor the flow of K-Pak between the company and the clients.

5 CONCLUSIONS

The aim of this thesis was to establish strategies and engineering solutions designed to optimize the production processes in Djs Qualicoaters according to lean manufacturing.

Particular attention has been paid in the plant productivity, in DTA has been identified a key tool which provides a powerful instrument that enables a better understanding of the underlying issues that affect plant availability and rate loss.

The results achieved from DTA enables to answer of the first two research questions:

What are the critical root causes of downtime in the production line?

In line to DTA the roots causes of plant stoppage have been identify, the results achieved also allows to detect the bottleneck of the entire production. Almost 200 different DT have been analysed during the period at hand, that allows to categorise the causes in 16 production unit types plus the failure DT.

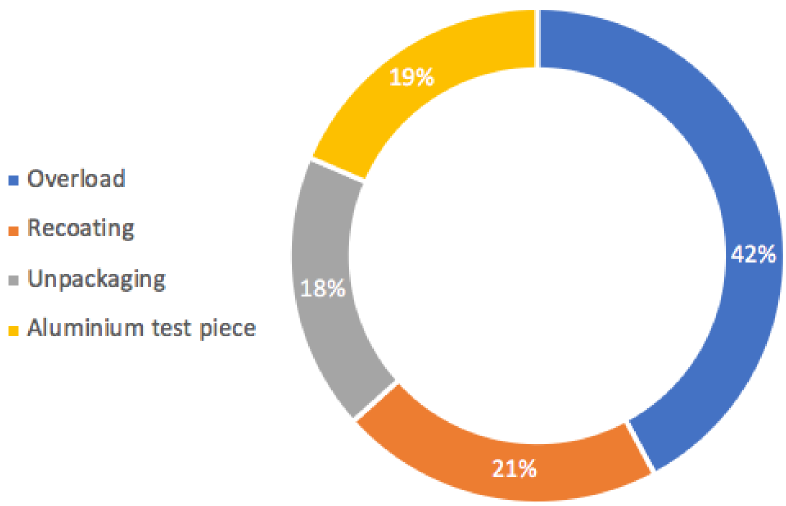

Figure 45 Four majors causes of DT in production units

The figure above shows a representation of the four major causes of DT, running at almost 75% of the total production DT. As it possible to see, more than 40% is caused by a single type. We can conclude that the bottleneck of the production is, without doubt, the overload operation, due to the Unload unit. It follows the second question and related answer.

How is possible to avoid DT or to mitigate the effects of these?

Subsequently the identification of the roots causes of DT, practical solutions have been detected through every production unit in order to avoid or decrease the stoppages through the plant. In this point of view, lean manufacturing and its principles have proved to be crucial in the establishment of practical solution designed to face DT.

In the light of the above, long term and short solution have been implemented in all the shop floor. For critical DT, like the unload operation which as be proved as the bottleneck of the production, the feasibility of the investment for the future solution has been analysed, leading to meaningful results.

An essential aspect in the daily tasks of a manufactory industry is undoubtedly the production planning. A flexible manufacturing can offer important advantages in terms of more efficient production, shorter throughput times, lower stocks and a higher quality of work. In the following is presented the third and last research question.

What is the best strategy that allows a leaner and more flexible production planning?

The result achieved from the CGA brings several results. A rating of almost 200 different powder has been possible thanks to the analyse at hand, this leads a new proposed strategic plan that will bring an easier production planning and a decrease of the colour change in the shop floor.

To sum-up, the final aim of this thesis was to optimise the production in order to keep high level of competitiveness in a more and more challenging market. To achieve the final target, a detection of production issues has been proved necessary, these was possible by a deeply study of the production processes through all the factory. The next step was to detect the possible solutions to the issues at hand, well-established theories features of lean thinking as visual management, standardisation, JIT and 5's Housekeeping have been implemented in all the solutions. In so doing, these would not only help to avoid singular problem, but they will establish key procedures for prevention of future plant stoppages or overall themes.

Furthermore, several ancillary gains have been encountered by the results achieved from the analyses drawn up during the period at hand. CGA has allowed, other than reaching the main goal, to develop a better powder warehouse management system. As regards the DTA paved the way for the implementation of future tools as Keep Performance Indicator, an example could be the Overall Equipment Effectiveness that, as well of the production rate loss, take into account the quality of the products, making it a valid indicator for future production management choices.

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7 APPENDICES

Annex A: Pareto CGA