POLITECNICO DI TORINO

Master's Degree in Mechanical Engineering

MASTER'S THESIS

Crane's Down-Time Analysis and Maintenance Implementation of a steel mill Company

The case of NLMK Verona S.p.A. Plant

Supervisor

Prof. Ing. Maurizio Schenone

Candidate

Edoardo Martini

S236163

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To my Family

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Summary

Abstract

This dissertation is the result of the Internship I took from April to July 2019 at the Maintenance & Technical Department of the Steel Company NLMK Verona Spa, the Italian branch of the Russian NLMK Group International, a group acknowledged among world leaders in the production of forged plates and ingots.

During that period, I had the chance of dealing with the ordinary maintenance activities of the production plant, an area which, in the current industrial reality, is achieving a growing strategic relevance for the process optimization and safety of both the plants and the staff.

Specifically, I had the possibility of assisting the Maintenance Manager of the handling equipment of the whole plant. Together with him, I could analyse the performances of the bridge-cranes in order to find out and possibly correct problems which may affect the efficiency and availability not only of the cranes but also, as a consequence, of the productive plant.

The specific target is that of eliminate the production losses through the reduction of the shutdowns of the plant/s as a result of the reduction of operative downtimes of all the cranes of NLMK Verona S.p.A.

Following what already stated and having had the opportunity of having access to the data related to stops for failure of the cranes in the semester January-June 2019, I could carry out a Downtime Analysis of the cranes in the whole plant in order to:

- Analyse and monitor the general situation of machine downtimes in the first semester 2019
- Find the most critical cranes of the plant, those cranes which have negatively affected the production due to times of standstill
- Compare the performance benchmarks of the first semester 2019 with the respective data of 2018 (considered acceptable by the Executive Board) and set the target for the year 2020
- Analyse and classify the nature and cause of the failures, their occurrence and length
- Find possible remedial actions, both technical or organizational, which may implement the present maintenance structure in order to constantly improve it with the aim of decreasing the production waste/losses due to the shutdown of the cranes handling systems.

The work has been divided into 2 parts.

The first chapters (from 1 to 3) aim at providing general information on industrial maintenance in order to better understand the basis of maintenance engineering and the basic aspects of proactive maintenance.

Then, after the presentation of the NLMK International Group, with a specific emphasis on the Verona plant, where I carried out my internship, and with a general description of the steel productive process, I will deal with the contents of my dissertation describing the 26 cranes of the plant together with their characteristics, functions and ordinary maintenance activities.

The second part of the work (chapters 4 to 6) deals with the analysis itself. First an analysis of the criticalities of the handling system of NLMK Verona has been carried out. This has been necessary in order to identify, through both technical and operational coefficients those cranes which are more stressed because of working conditions and those cranes which, in addition, represent a limit for the production, so as to be able to highlight those on which it seems advisable to focus my analysis.

In the last chapters (5,6) a Downtime Analysis on the gathered data has been carried out in order to examine the present situation of the firm, to find out problems or possible limits of the maintenance and define new targets.

Lastly, for various detected issues, solutions, improving suggestions and observations which may be helpful in reducing production losses caused by stops due to crane failures have be carried out.

1 Maintenance theory

1.1 Introduction

The current process of internationalization is forcing enterprises all over the world to constantly search for competitive advantages that will allow their positioning and permanence in international markets.

In this business context, the maintenance function is becoming a strategic factor for the competitiveness of organizations that have considerable investments in assets. In fact, adequate maintenance management is directly related to productivity, in order to optimize production and reduce overall operation costs, to customer satisfaction (Total quality = Customer satisfaction) and finally safety of employees and environmental protection.

In order to achieve global competitiveness, maintenance management must evolve from the traditional concept of prevention towards a new philosophy where knowledge, engineering and innovation constitute the necessary elements for effective implementation of improved maintenance.

In this context, therefore, the maintenance function must be able not only to prevent failures, but also to design, monitor and modify production systems, in order to reduce the total costs of plant breakdown through monitoring and continuous analysis of the historical trend of equipment, and incorporate the new technologies available.

To fulfil these goals, it is essential and desirable to develop a maintenance engineering unit within the organization that is able to design new production alternatives according to the Life Cycle Cost criterion and manage asset maintenance, so as to achieve continuous improvement of operating performance, according to PDCA (Plan Do Check Action).

The maintenance engineering staff must therefore be in direct support of the design processes and improvement of maintenance operations.

1.2 Maintenance in industrial plants

Whatever the entity, whether it be a machine, equipment or plant (production or service), has a natural tendency to age and wear with the passage of time, consequently decreasing its efficiency.

In this sense, maintenance can be seen as the "combination of all the technical, administrative and managerial actions, during the life cycle of an entity, aimed at maintaining it or bringing it back to a state in which it can perform the required function".

If in the past this function played an absolutely subordinate role with respect to production in all production realities, its current consideration has greatly increased, as each company has understood its strategic importance and how effective maintenance can achieve important economic, quality and safety outcomes.

The historical development of maintenance has followed the evolution of the industrial automation, with the most significant contributions that come from the siderurgical, chemical, petrochemical, nuclear and aeronautical sectors.

In the siderurgical field, for example, in the context of the economic recovery after the Second World War, the fundamental aim was to produce on a large scale in the minimum amount of time, so that the availability of the machines was to take on primary importance, and consequently the concepts, strategies and technology of the Maintenance.

The chemical industry has provided a fundamental contribution to the development of the most sophisticated maintenance techniques, having to operate in the critical conditions of high pressures and high temperatures, with toxic materials. The high productivity requirements of the petrochemical industry have led to a high degree of automation and to the development of condition-based maintenance policies, linked to machine control and diagnostic techniques. Finally, the nuclear and aeronautical industries have promoted the application of reliability theories and probabilistic risk analysis, which have brought a fundamental contribution to the systematic study of failures.

In the transition from the industrial era to the post-industrial era, the need to maintain the efficiency of the plants prevails over the tendency to preserve them and the role of maintenance becomes crucial. The concept of maintenance comes to be associated with safety requirements, environmental protection, reliability, and the plants are beginning to be designed and manufactured on the basis of these requirements, which are now considered essential.

With regard to this sense, the development of the methods of maintenance engineering has contributed, in a significant way to provide a more appropriate description to maintenance activities.

1.3 Maintenance Engineering

The term Maintenance Engineering identifies the set of principles, techniques and procedures of managerial and organizational type that allow to approach the issue of maintenance from an engineering point of view, that is, based on the scientific principles of engineering and organization, with the aim of achieving significant improvements in terms of efficiency and effectiveness in the design, management, and control of maintenance.

Accordingly, the application within a company of the methods of maintenance engineering can lead to the creation of an organizational function in general called Maintenance Engineering.

It identifies the three main organisational macro-processes of maintenance

1. Maintenance Execution
2. Maintenance Management
3. Maintenance Engineering

The **Maintenance Execution** process receives operational orders from the Maintenance Management process and reports to it the progress of the same, as well as all information on preventive or breakdown interventions.

The **Maintenance Management** process generates a report of its activities concerning the organisation of interventions, from the planning phase to their finalisation, and sends it to the Maintenance Engineering function.

Lastly, the **Maintenance Engineering** process, using a set of techniques and support tools, has the task of deducing from the analysis of the data received, adequate proposals for improvement of maintenance activities, from a technical and managerial point of view. The deductions and plans made by the Maintenance

Engineering are then transferred as input to the Maintenance Management, which has the task of preparing the implementation.

1.3.1 The Mission of Maintenance Engineering

The maintenance engineering staff must, with its activities, develop a special focus on the context of the production process. Maintenance engineering is therefore increasingly seen as a specific and fundamental component of the entire production process, as it guarantees the continuity and quality of production, making plants and equipment available in compliance with company policies in terms of safety, quality and environment.

This way of thinking about production and all the other company functions in terms of processes involves all personnel in the production and maintenance of the plants. Unfortunately, still today in the production field there are situations of competition and opposition between production and maintenance, with the first interested in producing at any cost and the second forced to run after increasingly frequent and costly breakdowns.

All this turns into an engineering-oriented maintenance process, seen as an interconnection of human, technological and economic resources and systems aimed to achieve the common goal of improving results in terms of safety, efficiency, effectiveness and costs.

1.3.2 Activities and Goals

Lately, maintenance has rightly acquired the responsibility for the proper functioning and progress of the company, for this reason it is defined with greater precision within the production activity.

The person in charge of the maintenance service has assumed over time the role of manager, dealing both with the technical aspect, and both with financial and design aspects; in this way a new figure has been created within the company organisation.

The objectives and tasks that a maintenance manager is called upon to achieve and carry out can be defined as follows:

- Ensure the presence and proper functioning of safety and prevention systems against direct or indirect accidents to people or goods, and against dangerous environmental emissions.
- Managing company resources in order to minimise the costs deriving from the possible breakage and/or repair of technical assets used in production.
- Operate continuously in order to limit the deterioration of the performance of the machines.
- Training and educating employees to a safety use of machineries and making them responsible for the initial management of anomalies and faults in the plants.

The achievement of the objectives is related to the practical actions that the maintenance must put in place and manage in order to accomplish the task. Some actions can therefore be:

- To maintain the efficiency of a machine by implementing all corrective measures, both after a fault has occurred and to prevent a fault from happening.
- To organize and manage the necessary interventions and materials in terms of time, technical, productive, economical and human resources.
- To recognize and manage cases in which it may be necessary to use external experts, i.e. the use of structures and/or external personnel to solve problems of particular dimensional or technological importance.
- To continuously work on improving the technical equipment available through periodic reviews that ensure the correct degree of precision and through the evaluation of the case of replacement.
- To collaborate with all company functions involved in the process of installation, management and use of the machinery in order to collect as much information as possible to base intervention strategies.
- To manage the inventory, reorders and quantities of materials to be kept in stock.

The Maintenance Manager is, therefore, the interface between the operational team and the rest of the company. He must try to manage the staff in the best possible way and motivate them to achieve the objectives established. In this regard, the person in charge will have to solve certain problems concerning the size of human and technical resources related to the strategy adopted and the conditions of the operational environment and furthermore the determination of the spare parts procurement policies according to their criticality.

1.4 Evolution of maintenance models

To increase the availability of plant/machines, reducing downtimes and containing maintenance costs, it is essential to rationally define which is the appropriate maintenance strategy to adopt according to the type of system/machine, from both a technical and an organizational point of view.

A first step is to decide the maintenance policies to be adopted case by case to pursue their strategic objectives. In particular, to define:

- ❖ If and when it is convenient to carry out repairs only after a fault.
- ❖ If and when it is more appropriate to prevent faults by carrying out preventive maintenance operations.
- ❖ If and when it is appropriate to purchase instruments dedicated to monitoring the condition of the systems, to intervene when a significant change in a parameter, compared to normal operating conditions, occurs without waiting for the event to degenerate into a fault and the consequent plant stoppage.
- ❖ For which entities and maintenance activities it is advisable to research solutions to improve the existing situation.

Defining the maintenance policies therefore means deciding in advance the activities and the method of maintenance that will have to be carried out on the plant. In this way, they will not be the result of a simple randomness, but consequences of rational and conscious choices deriving from the in-depth knowledge of the plants, from the analysis of the faults (types of faults, distribution of the fault rate) and from economic evaluations relating to the cost of the life cycle of the equipment and plants that constitute the company's assets.

This awareness is acquired by answering a series of specific questions:

- ❖ What is the behaviour of a plant in case of a failure and what is the most appropriate type of maintenance to be adopted to control it?
- ❖ What is the comparison between the cost of maintenance, made as a result of the failure, and the cost of intervention made before the failure occurs?

- ❖ What are the costs and the advantages deriving from the introduction of possible improvements to the maintenance operation?

The different maintenance policies commonly adopted and applied to the different types of components, can be classified into the following categories:

- ❖ Corrective Maintenance;
- ❖ Preventive Maintenance;
- ❖ Predictive Maintenance;
- ❖ Proactive Maintenance;

1.4.1 Corrective Maintenance

Corrective Maintenance (or Run to Failure) simply consists of preparing and performing maintenance on a given unit after a failure has occurred, with the aim of restoring the functionality that the unit itself had before the failure occurred.

This maintenance strategy can still be considered a winning choice when applied to non-critical and/or low-cost machines. In fact, it is the maintenance strategy that requires lower costs and less organizational complexity. However, by adopting this strategy, the plant is mathematically exposed to a shutdown or reduced production regime, in each of the two cases affecting the plant's productivity. Moreover, the use of maintenance technicians is highly inefficient whereas the spare parts warehouse will necessarily have to be oversized in order to guarantee the promptness of the intervention in the event of a failure.

1.4.2 Preventive Maintenance

Preventive Maintenance is defined as any maintenance performed at predetermined intervals or in accordance with predefined requirements, and aimed at reducing the probability of failure or decline of the performances of an entity.

This is the most commonly used type of planned maintenance and its effectiveness is enhanced if the interventions follow criteria aimed at detecting signs of wear or degraded operation of the machinery. In fact, one of the aspects that can challenge the approach of intervention at predetermined time intervals, is the experimental evidence that most failures occur randomly, thus making this solution ineffective.

The policy is therefore based on the programmed replacement of a certain component of the machine that is still fully functional, with a new one, so as to prevent sudden decay. The programmability of the intervention allows a better organization of the work and makes it possible to manage the machine stop in a more convenient way.

Within this type of intervention, we can distinguish two intervention techniques characterized by a different method of determining the time intervals and by the different description of prescribed criteria.

1. **Condition-based Maintenance**
   In Condition based Maintenance, the interventions and criteria chosen for intervention are generally fixed for the entire useful life of the component or machine.
2. **Calendar-based Maintenance**
   In Calendar based Maintenance instead, the operations are determined on the basis of the historical nature of the previous activities. The MTBF (Mean Time Between Failures) analysis, i.e. the average time between two failures of the same entity, allows to prepare preventive intervention calendars based on a certain probability that the failure will not occur in the period of time between two successive replacements. Preventive scheduled maintenance is effective both from an economic point of view and in terms of machine availability. However, it is not convenient to apply scheduled maintenance techniques to components whose failure is difficult to predict as there is a risk of replacing the component during the useful life period.

The main activity of preventive engineering is the analysis of the causes of failure. It is not limited to simply implementing equipment with higher life expectancy or better lubrication systems, but goes into the analysis of each single fault that has occurred, going to discover the causes and pursuing the purposes of reducing the frequency of failures and the cost of the repairs.

The advantages of preventive maintenance in respect to corrective one are: by implementing preventive maintenance it is possible to reduce the number of failures, to optimize the use of maintenance staff and inventory. However, with such a strategy there is certainly an increase in the direct costs of maintenance and it must be taken into account that the interventions that this strategy imposes can themselves lead to failures.

1.4.3 Predictive Maintenance

Predictive maintenance is a particular type of Condition-Based Maintenance (C.B.M.). The main idea on which this maintenance is based is that a failure typically does not occur instantly but is the result of a deteriorating condition over time of a particular component.

The monitoring of some parameters can report anomalous operating conditions and therefore detect the necessity of an intervention. Clear symptoms of an unusual functioning are temperature variations, presence of wear particles in oils or an anomalous spectrum of vibrations. All these quantities can be easily measured and lead to the correct identification of the problem.

The predictive strategy is based on Condition Monitoring, i.e. the monitoring of certain conditions and/or indices considered crucial for the correct operation of the machine, in order to detect in advance conditions of incorrect operation or in any case conditions preparatory to a possible failure.

Once the detection has been carried out, there is a subsequent phase of analysis of the problem and planning of corrective interventions. Among the strategies introduced so far is the one that has the greatest potential from the point of view of maximizing uptime and reducing maintenance costs. This approach allows to conduct an accurate analysis that leads to the understanding of the root of the problem (which is not always possible by adopting, for example, corrective maintenance) and also to conduct inspections at very low cost.

It is useful to point out, however, that the implementation of such a strategy still requires a substantial initial investment if we consider all the equipment needed to monitor the parameters of interest and provide to the staff the knowledge necessary for the proper use of such equipment. Moreover, this approach requires a knowledge of the machine's behaviour based on the availability of historical data and trends that can be obtained reliably only after long detection times.

Some of the main predictive maintenance techniques commonly used are:

- Vibrational Analysis
- Thermography
- Tribology
- Noise analysis
- Visual inspections

1.4.4 Proactive Maintenance

The limit of predictive maintenance is that it would require the operator to be given an alert signal early enough to allow the necessary repairs to be scheduled. If the maintenance service does not respond quickly to the signal, the upcoming fault conditions may soon turn into those of impending failure.

Real benefits to deal with this problem can be achieved with another type of maintenance on condition: Proactive Maintenance, which takes place in advance of any damage related to a component or the performance of the system, with interventions aimed at avoiding the emergence of those conditions that may lead to deterioration of the system itself.

Basically, instead of monitoring the parameters, that indicate a potential failure and waiting for a certain alarm to plan the intervention, the purpose of the improved maintenance is to identify and correct the anomalous values that causes the failure.

1.5 The Total Productive Maintenance (TPM)

Productive Maintenance involves all the actions aimed at reducing the criticality of a system's performance (device, plant, etc.) and at improving its maintainability in order to increase its efficiency and reduce maintenance costs without increasing its capital value. This type of maintenance is achieved by using, in a suitably engineered way, all possible maintenance strategies in order to achieve the integration of maintenance functions through preventive activities, aimed at eliminating unexpected failures, monitoring activities and system improvement activities. The productive maintenance is therefore the sum of activities aimed both at restoring the functional and operational effectiveness of the assets and at improving this effectiveness, thus extending the useful life of the asset.

The evolution of productive maintenance is the Total Productive Maintenance (TPM), a technique developed in Japan at the Toyota Motor Company plants in the 1970s and 1980s.

TPM is an effort at the level of the entire company's technical and production organisation to improve the quality of the plants and guarantee their effectiveness:

- **Total**: Which competes with all and aims to eliminate any possible defect, anomaly and malfunction.
- **Productive:** That reduces causes of downtime and minimizes production problems.
- **Maintenance**: Which keeps plants in good condition of use and keeps production machines clean and functioning.

Total Productive Maintenance has the targets to achieve the Zero Product Defects, Zero Equipment Unplanned Failures and Zero Accidents. It sets out to achieve these goals by Gap Analysis of previous historical records of Product Defects, Equipment Failures and Accidents etc. Then through a clear understanding of this Gap Analysis (Fishbone Cause-Effect Analysis, Why-Why Cause-Effect Analysis, and P-M Analysis) plan a physical investigation to discover new latent failure (slight deterioration) during the first step in TPM Autonomous Maintenance called "Initial Cleaning". The five key elements for characterizing the TPM concept are as follows:

1 TPM strives for maximum equipment effectiveness.
2 TPM establishes a total system of preventive maintenance for the entire life of the equipment.
3 TPM includes participation by all sectors of the organization that plan, use, and maintain equipment.
4 TPM participation is from top management to the frontline staff.
5 Execution of TPM is based on Small Group Activity.

1.5.1 TPM in terms of Lean Production

The term "Lean Production" describes a philosophy that incorporates a set of tools and techniques to be used in the company processes to optimize time, human resources, activities, productivity, and at the same time to improve the quality level of products and services to the customer.

A company that produces with the criteria of lean production enhance the production system with the resources at its disposal and systematically eliminates all activities that do not create added value. In other terms, produces goods and services using the minimum quantity of everything: costs, time, space, human and financial resources, thus obtaining the following benefits:

- Reduction of cycle times.

- ❖ Reduction of inventories, raw materials and stored finished product.
- ❖ Reduction of semi-finished products in production.
- ❖ Reduction of production costs.
- ❖ Increase the company's production output.
- ❖ Improvement of delivery time.
- ❖ Increase in sales.
- ❖ Increase in productivity.
- ❖ Quality improvement.
- ❖ Growing profits.
- ❖ Increase safety and protection of operators and customers.
- ❖ Safe, ordered, clean and efficient working place.

Lean Production, as an integrated system with others (quality, economic and financial, etc.) starts with typical business plan targets, to be used as specific improvement projects, with a particular focus on the production and delivery of the product/service. In fact, the application of a Lean Production system does not differ much from the application of a quality management system: the objectives at the business level are transformed into specific activities for the processes in order to reduce, if not eliminate, the 6 major losses of industrial plants.

Therefore, the objective of the TPM is to reduce these losses. These are:

- ❖ Breakdown losses;
- ❖ Setups & adjustments losses;
- ❖ Losses from idling and micro-stoppages.
- ❖ Losses due to speed loss.
- ❖ Start-up and reduced yield losses.
- ❖ Losses due to quality defects and reparations.

Figure 1 TPM 6 Big Losses

Equipment failures/breakdown losses are the time losses and quantity losses caused by defective products. Set-up and adjustment losses are defined as time losses resulting from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item. Idling and micro-stoppages losses occur when the production is interrupted by a temporary malfunction or when a machine is idling. Reduced speed losses refer to the difference between equipment design speed and actual operating speed. Reduced yield losses occur during the early stages of production from machine start up to stabilization. 6. Quality defects and reworks are losses in quality caused by malfunctioning of production equipment

The first two losses are known as down time loss and are used to calculate availability of a machine. The third and fourth are speed losses that determine the performance efficiency and the final two losses are considered to be losses due to defects in the products.

1.5.2 The 8 Pillars of TPM

The Japan Institute of Plant Maintenance propose the introduction of TPM program is based on the implementation of a series 8 pillars of TPM in a systematic way to optimize plant and equipment efficiency by crating perfect relationship between man and equipment. The figure 2 represents the structure of TPM.

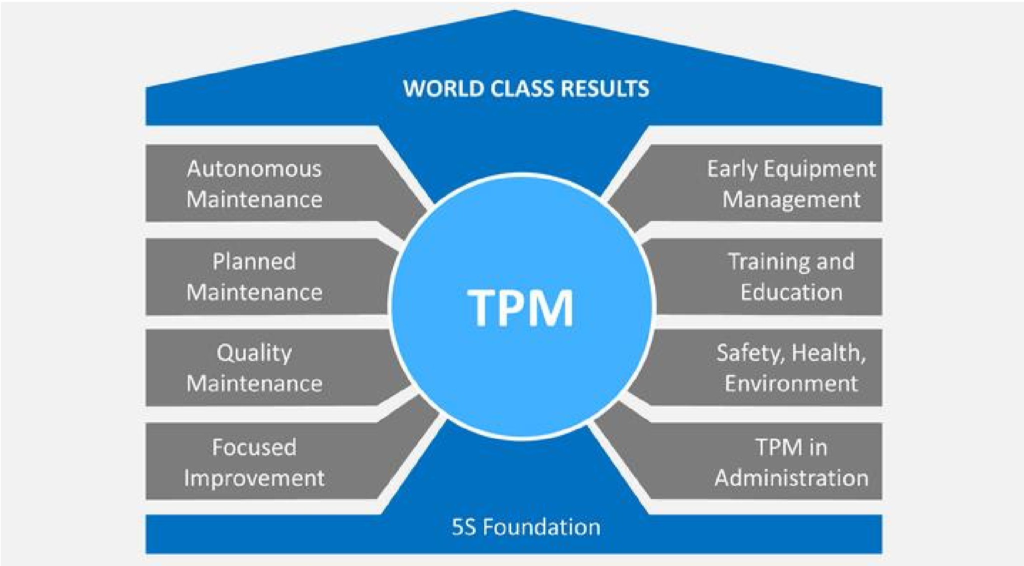


Figure 2 The 8 TPM Pillars of Maintenance

The 8 fundamental principles of the TPM methodology are presented below.

1. **Focused Improvement**
   Focusing on trying to solve problems starting from a detailed analysis and creating dedicated working groups involving all levels.
2. **Autonomous Maintenance**
   It is based on the involvement of employees dedicated to production systems. It seeks to enable the operator to perform self-maintenance on the machine to reduce machine downtime due to degradation and negligence.
3. **Planned Maintenance**
   It is aimed at defining the inspection and control standards and maintenance activities necessary to define the maintenance program and improve performance to achieve high availability and reliability.
4. **Quality Maintenance**
   It is the set of methodologies with the aim of preventing the appearance of defects increasing the overall quality of the products.
5. **Training and Education**
   Establishes and manages the training activities of the company in a standardized way and involving the entire staff.
6. **Safety, Health and Environment**
   It supervises the management procedures of the company with the environment (Environmental Control and Corporate Safety) and integrates the regulations to the internal procedures.

7. **Early Equipment Management**
   Defines standards for design at all levels.
8. **TPM in Administration**
   It links administrative and production activities and extends the contents of the TPM to all company functions.

TPM bases its pillars on the 5S's method, an approach that helps to make the workstation clean and in order, by carrying out simple and frequent improvement actions. The name comes from the 5 phases in which the method is implemented and the concept it is to define a place for each thing to keep everything in the right place.

Figure 3 The 5S Principles

The following steps are identified:

1. **SEIRI** (Separating): To remove from the workstation everything that is not necessary (materials, equipment, tools) and to define the frequency of utilization of what is defined as "useful" in production. To accomplish this first activity, an area called "Quarantine Area" is organized, in which all the articles present in the area under examination must be placed, each one labelled with a tag that shows its usefulness.
2. **SEITON** (Ordering): To define a place for each material, equipment or instrument, so that everyone can immediately be aware of where to find everything, so to eliminate the time necessary to search for instruments and material.

3. **SEISO** (Cleaning): To remove dust, material debris and component waste from the work area in such a way that the area is cleaned, inspected and any sources of dirt and problems with the workstation identified.
4. **SEIKETSU** (Standardise): To plan and define inspection and cleaning activities in order to maintain the order achieved in the previous steps.
5. **SHITSUKE** (Maintain): Once the periodic activities have been scheduled, it is necessary to ensure that they are carried out and use any feedback to continuously improve the workstation standards.

2 NLMK Group and NLMK Verona S.p.A. plant

2.1 Introduction

The consultant to whom I turned to be directed to a company that, beyond the specific and primary objective of realizing my thesis, also gave me the opportunity to live a training experience potentially useful for my professional future, agreed that the great limitation of the Italian production system compared to other European countries is given by the scarcity, almost lack of large companies.

Large companies, both in size and organizational structure, are "schools" for the entire Italian system, characterized instead by a myriad of small, very small and micro-enterprises (one-man companies), inevitably focused exclusively on production, thus excluding fundamental aspects such as research, innovation, training, product development and markets, etc. It is therefore important for the country to have large companies because these have investment capacity, promote technologies, look to the future, but above all are schools of management.

These were the reasons that led me to ask for and obtain the opportunity to do my internship at a multinational company, which in addition to all the above-mentioned also adds the positivity arising from the presence in many areas of the world with the content of multicultural and intercultural that follows.

NLMK Int.l, a Russian multinational with a significant production and marketing unit in Italy, has been considered by me an important opportunity for my short and longer term goals.

2.2 NLMK Int.l Group

NLMK Group is a leading international manufacturer of high-quality steel products with a vertically integrated business model. Mining and steelmaking are concentrated in cost-efficient regions; finished products are manufactured close to the company main customers in Russia, North America, and the EU.

Figure 4 NLMK Logo

Thanks to self-sufficiency in key raw materials and energy, coupled with the technological superiority of production capacity, NLMK is one of the most efficient and profitable steelmakers in the world. NLMK has a diversified product mix, ensuring a leading position in local markets and sales effectiveness

NLMK Group is the largest steelmaker in Russia and one of the most efficient in the world. It is the only Russian company among TOP 20 leading global steelmakers. As shown in Figure 5, NLMK Group operates over 20 production facilities in Russia, the United States, Belgium, Denmark, Italy, France and India with total annual production capacity of over 20 million tonnes.

The company's headquarters is in Lipeck, a city about 500 km south-east of Moscow, and covers an area of 27 square kilometres.

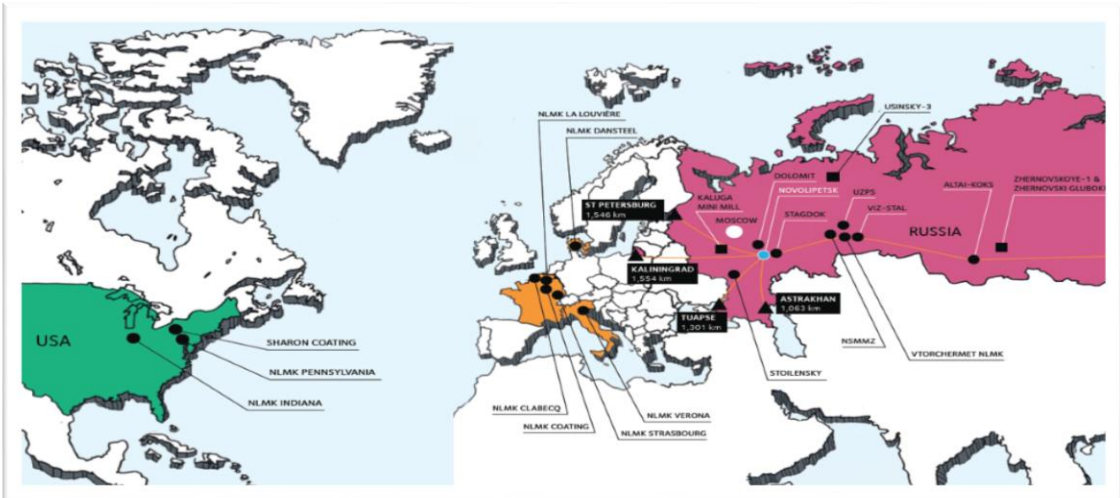


Figure 5 NLMK Map of Assets

It has more than 60,000 employees with a total production of over 22 million tons and a revenue close to 8 billion US$ It is present in Europe with 5 production units (including one in Verona, Italy) for a total production of

2.2 million tons, in Russia with 11 production units for a total production of 16 million tons and in the USA with 3 production units for a total production of 2.2 million tons. Furthermore, it is listed in the Moscow Stock Exchange.

The Group vertically integrated business model ensures control over all stages of the production process; from mining, processing steel, to manufacturing high value-added steel products. Service centres and trading companies ensure steady, just-in-time supply and a high standard of customer service in more than 70 countries around the world.

2.3 NLMK Verona S.p.A.

The present work of thesis has taken shape during an internship carried out by the candidate at NLMK Verona Spa, the Italian subsidiary of NLMK Int.l Group. Precisely, along with DanSteel (Denmark) and Clabecq (Belgium) production facilities, forms the NLMK Europe Plate division.

In Figure 6 it is represented the international organization of the Group.

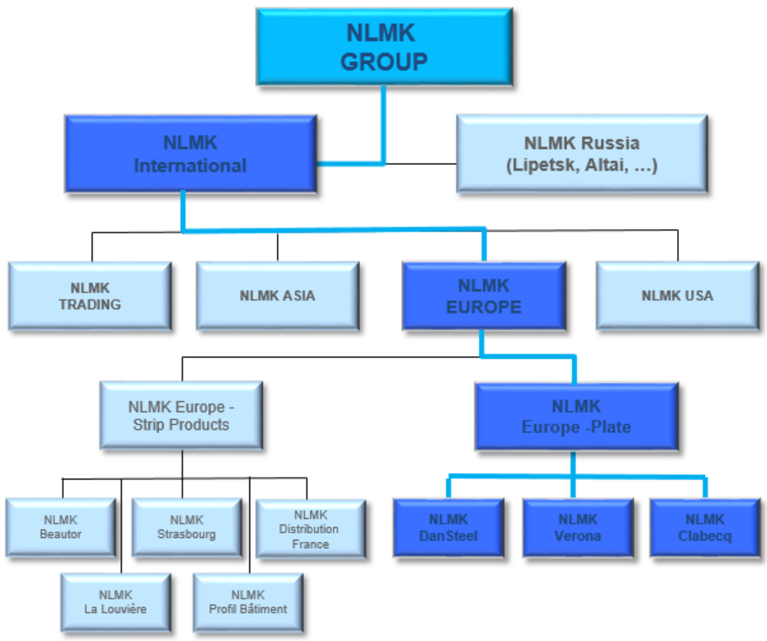


Figure 6 NLMK International Organization

NLMK Verona is a state-of-the-art smelting and rolling mill focusing on production of plate steel, forgings and ingots. The plant is renowned for the quality of its plates and its unrivalled flexibility when it comes to the production of various formats. Its production capacity is 450.000 tonnes of products a year and the enterprise employs almost 300 persons.

About two thirds of NLMK Verona products are sold in Italy with the remainder being sold mainly within Europe. However, sales to Asia and the Americas are constantly growing too.

The main market-sectors are many, among them we find: Oil&Gas, energetic, automotive, nautical, energy, civil constructions, pressure vessel and more.

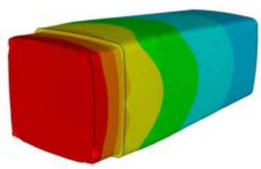
2.3.1 Products

NLMK Verona is able to produce most of the steel grades required by the market. The products provided can be grouped manly in three categories:

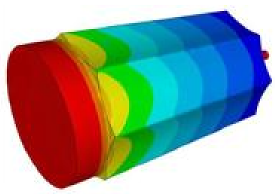
1. **Forging ingots:**
   The ingots can be produced by pit casting in various forms and each type is chosen according to the final use. NLMK offers to the market four types of formats and the weight can vary from 5 tons up to 120 tons. The formats available are:

   - Round ingots:

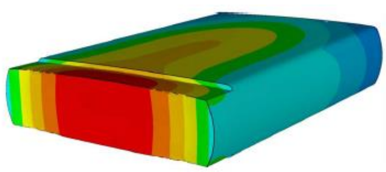
   - Square ingots



   - Polygonal ingots



   - Slab ingots



2. **Forged & Rolled plates:**
   One of the most niche products characterised by excellent surface quality are forged and laminated slabs. This is possible thanks to the presence of forge and rolling mill arranged in series along the same production line, thus minimizing death time between the processes of forging and rolling, it is therefore possible to optimize production and give the product its valuable mechanical characteristics.
   The slabs are available with a thickness ranging from 150 mm up to 1000 mm and a width up to 2900 mm.
3. **Continuous casting slab plates:**
   Thanks to the continuous casting facility present in the plant it is possible to produce slabs with variable thickness, from 15 mm to 250 mm and width up to 3000 mm.

2.3.2 The Production chain

In this chapter a more detailed overview of the plant is been described, in order to better understand the facility subdivision into production areas. A more in-deep outline of the process unit follows.

Since production chain follows three macro step the whole production area, of approximately 40.000 m^2, has been subdivided into three integrated facilities. The three department are:

- ❖ Steel Mill Dept.
- ❖ Rolling Mill Dept.
- ❖ Heat Treatment & Finishing Dept.

In Figure 7 it is presented the overall layout of the production area and how the respective departments are subdivided.

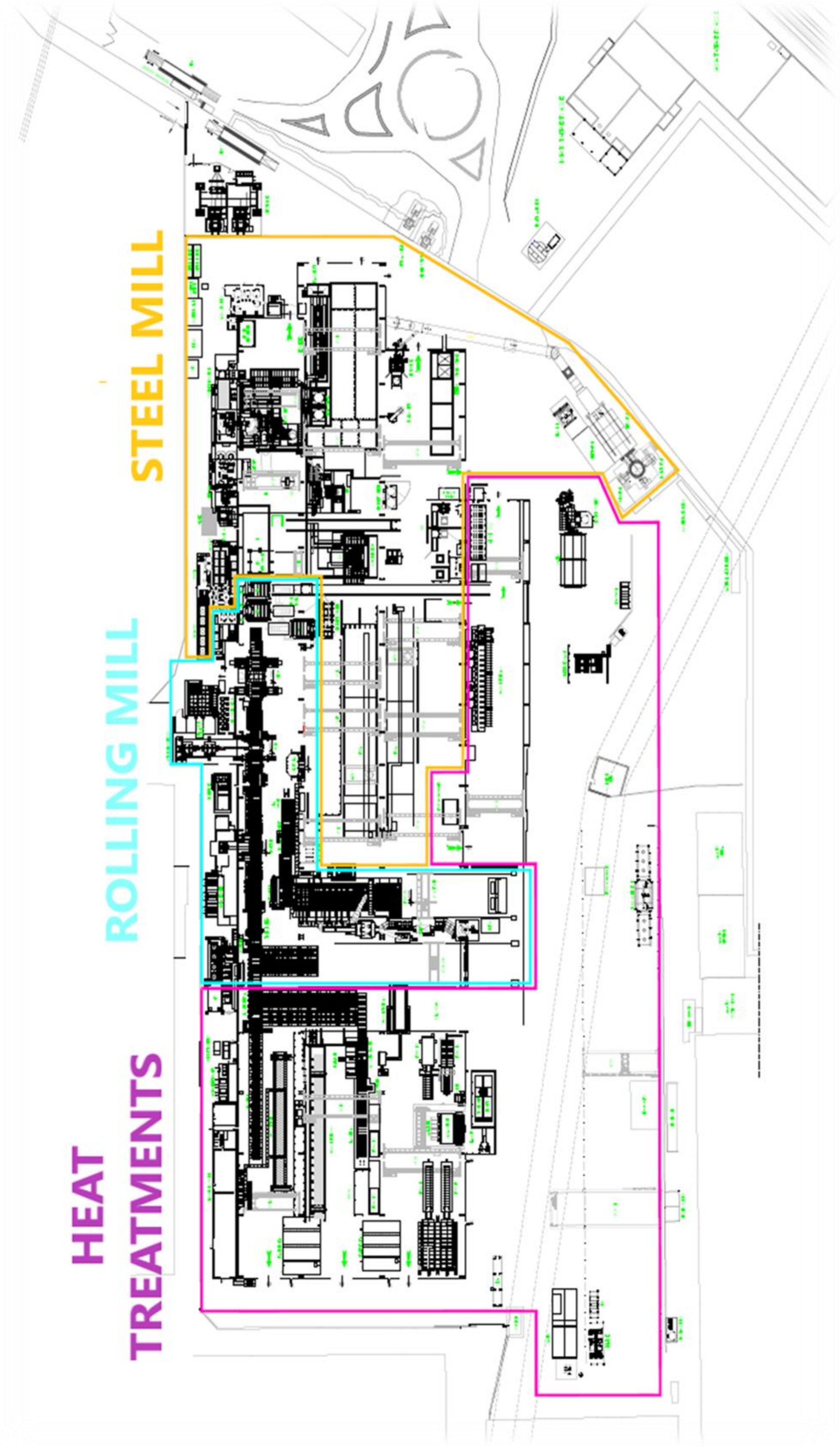


Figure 7 NLMK Department's Subdivision

2.3.3 The Steel Mill Dept.

The Steel mill department is the first step of steel manufacturing and the hearth of NLMK Verona. The smelting line is equipped with:

- An 80 tons Electric Arc Furnace (EAF).
- 2 Ladle Furnaces (LF1, LF2) for secondary metallurgy.
- A Vacuum Degasser Furnace (VD) for hydrogen/nitrogen stripping and cleanliness.

This smelting line is able to serve three different production lines with two different production processes. In fact, two lines are used for pit casting, respectively called Pit Casting 1 and Pit Casting 2, while in the third line it is possible to produce by continuous casting.

A 100% Italian domestic scrap containing low tramp elements it is given to the plant, after passing the company control system including a radiation-based control by portable spectrometer is stored in the scrap yard.

Scrap is taken from the park by using two bridge-cranes and deposited into special baskets which, by sliding on rails, are positioned near the melting furnace. Once loading of the furnace is complete, the steel is melted by means of an electric arc (EAF). In this phase the scrap is completely transformed into a liquid steel bath at a temperature of about 1700 °C.

Figure 8 LF1 Furnace

Once the ladle has been tapped, it is placed in the ladle furnace (LF1 or LF2), where the liquid steel is heated to the ideal processing temperature, as well as the slag is removed and analysed to ensure that it has ideal characteristics in terms of fluidity and chemical composition, then the refining phases are carried out by adding ferroalloys.

After the refining process the ladle is placed in the VD Furnace, where the degassing cycle will proceed. The vacuum degassing process is achieved by vacuum pumps that remove gaseous elements such as nitrogen, hydrogen and oxygen, elements that are soluble in steel and that affect the mechanical characteristics of the steel (reduction of hardness, brittleness, formation of cracks).

Once the degassing process has been completed, the steel is overheated and brought to the casting temperature, which, considering all the thermal drops during the transport of the ladle to the casting, guarantees the correct fluidity during the entire casting process, both in the casting pits or in continuous casting.

An activity carried out in the plant connected with the cycle described above is the rebuilding of the ladle. The ladle is considered at the end of the campaign after reaching the maximum number of castings, for which the resistance of the refractory insulation is guaranteed, or in the presence of erosion of the same, such as broken or worn bricks.

Repairs and rebuilding of the refractory material of the ladles takes place in a special area after having been carefully cleaned of residues of casting and incrustations. The residue, once cooled, is evacuated classified and recycled.

After the restoration of the refractory and after being inspected, the ladle is then dried at a temperature of 1100 °C for approximately 20 hours.

2.3.4 The Rolling Mill Dept.

The rolling mill is the second step of steel manufacturing and is where the product begins to take the final shape. The rolling mill facility of NLMK is equipped with:

- A batch of 4 re-heating furnaces.
- 1 Walking Beam furnace.
- A 10.000 tons forging press.
- A 85 tons manipulator.
- A high power rolling stand 3.000 ton force.
- 5 rolls hot leveler.

The planning of the mill's processes and activities is the responsibility of the Planning Office, which provides the necessary inputs to coordinate and execute the required production.

The activities are mainly divided into two production lines.

2.3.4.1 Forging

The first line is the one dedicated to the forge. Once the casting has been carried out and the period of permanence in the mould has expired, the transfer of the ingots destined for heating is organised. These are divided into hot or cold ingots, depending on the temperature at which they are inserted into the furnace (Hot or Cold charge).

After having been identified and delivered to the department, the ingots to be reheated are loaded according to the production plan. In the department there are 4 wagon furnaces, which, before the ingots are loaded, are checked (sole and supports) and finally preheated to the specific temperature according to the heating cycles.

The permanence of the ingots in the furnace depends on the quality of the steel and the format.

Figure 9 Preheated Ingots Unloading

At the end of the heating cycle, the semi-products are taken out of the furnace and placed in a forge where an operator can start pressing the semi-product through the manipulator. The product being processed is monitored to prevent it from breaking down internally if it is too cold, in which case it is reheated and brought back to the processing temperature.

Once the forging process is finished, the product is evacuated into the rolling cage, where it will be processed with the normal rolling cycle, if required by the processing cycle, or otherwise directly into a cooling plate.

2.3.4.2 Rolling

The second line is dedicated to the production of sheets starting from:

- Continuous casting slabs
- Import slabs
- Rough-hewed ingots
- Import ingots

Unlike the forging cycle, the heating of the semi-finished products (slabs) intended for rolling is baked in the Walking Beam furnace (WB), with the exception of the hewed ingots which are transferred to the rolling cage still at a controlled temperature after the forging process.

Once unloaded at the processing temperature by means of a transferor, they are transferred to the roller conveyor and then sent to the rolling cage (duo cage).

The number of passes that must be made from the semi-product through the cage varies according to the desired final thickness, respecting the lamination specifications of the computer system and compatibly with the temperature of the work-piece.

During the process some cleaning operations are carried out by means of a descaler placed at the exit of the cage to remove residues that could compromise the surface quality of the semi product while rolling.

When the required thickness has been reached, the sheets are transported by means of rollers to the leveller, which has the task of making them flat within the tolerance range and finally to the in-line cut, where through oxycutting it is cut according to the measures of the order demanded by the programming.

Finally, after the marking process, they are transferred to the Heat Treatment & Finishing Department.

2.3.5 The Heat Treatment & Finishing Dept.

After the steel has undergone rolling, levelling, cutting and marking operations, the items that require further treatment from the product schedule must be conveyed to the BEFO (Building Extension and Finishing Operations) Dept. This department deals with heat treatments and further finishing treatments.

The BEFO is equipped with 24 furnaces for heat treatments, 2 quenching tanks, 4 cutting benches, an area for quality control and one for the storage of finished products. Possible heat treatments are:

- **Annealing**
  The purpose of annealing is to soften the steel to make it suitable for mechanical processing, eliminate residual stresses and eliminate the effects of plastic deformation.
- **Normalizing**
  The normalizing treatment allows the grain to be refined and uniformed in order to prepare the steel in the best possible way for the following heat treatments and must be carried out immediately after hardening to avoid the danger of cracks due to the high residual tension of the hardened products.
- **Quenching**
  The quenching treatment requires an austenization heating of the piece in a furnace, followed by a fast cooling, sufficiently to permit the transformation into martensite, structure of high hardness and fragility. The cooling fluid used is a synthetic fluid composed of water and polymer in percentage, able to treat a wider range of steels as well as being less polluting and expensive.

Figure 10 Quenching Treatment Operation

- **Tempering**
  After quenching, the steel has a high hardness and low toughness characteristics. It is therefore necessary to proceed with the tempering heat treatment, which can reduce the stresses and brittleness of the martensitic structure. This treatment must be carried out immediately after the quenching treatment in order to avoid cracks due to the high tension which hardened products present.
- **Anti-flakes**
  The anti-flake treatment is a special heat treatment whose purpose is to reduce the formation of cracks (called flakes) caused by the presence of hydrogen dissolved in the liquid steel, which during solidification can compromise the quality of the finished product.

Each furnace is used for one or more type of heat treatments and differs according to the size of the work-piece, the maximum operating temperature and the maximum heating temperature gradient.

3 MATERIAL HANDLING IN NLMK VERONA

3.1 Introduction

From the above-mentioned, it emerged the importance of movements within industrial plants. In fact, during the steel production cycle, from melting to the finished product, the material handling is performed, given the critical conditions in terms of loads and high temperatures, mainly through the use of bridge cranes. This importance is confirmed by the presence and use of 26 bridge cranes in the NLMK Verona plant, with a capacity range varying from 3.2 tons up to a maximum of 150 tons.

In this chapter, after having examined in sufficient detail the issue of material handling in the industrial-production field, I will go into specific detail for each single crane.

I will first describe the structure, classification and principles of operation, after that I will describe in more detail the technical characteristics, type, functions and layout within the production cycle of NLMK Verona S.p.A.

With regard to the last-mentioned, I will close the chapter by facing the relevant aspect of ordinary maintenance, which is part of the final objective of my work.

3.2 Material handling in industry

Material handling is the function of moving the right material to the right place, at the right time, in the right amount, in sequence, and in the right position or condition to minimize production costs.

Material handling can be also defined as all movement of materials in a manufacturing environment. The American Society of Mechanical Engineers (ASME) defines “material handling” as the art and science involving the moving, packaging, and storing of substances in any form. Material handling may be thought of as having five distinct dimensions: movement, quantity, time, space, and control. Movement involves the actual transportation or transfer of material from one point to the next. Efficiency of the move as well as the safety factor in this dimension are of prime concerns. The quantity per move dictates the type and nature of the material handling equipment and also the cost per unit for the conveyance of the goods The time dimension determines how quickly the material can move through the facility. The amount of the work in process, excessive inventories, repeated handling of the material, and order delivery lead times are affected by this aspect of the material handling systems. The space aspect of the material handling is concerned with the required space for the storage of the material handling equipment and its movement, as well as the queuing or staging space for the material itself. The tracking of the material, positive identification, and inventory management are some aspects of the control dimension.

Material handling is also an integral part of plant layout; they cannot be separated. A change in the material handling system will change the layout, and a layout change will change the material handling system.

One of the primary goal of material handling is to promote productivity through the following:

- Material should flow in a straight line, avoiding interruptions.
- Material should move as short a distance as possible.
- Mechanize material handling.
- Automate material handling.
- Maintain or improve material handling/production ratios.

Other fundamental goals are:

- Reduce cost of production.
- Maintain or improve product quality.
- Promote safety and improve working conditions.
- Promote increased use of facilities (as purchase versatile material and develop a maintenance program.
- Maintain, and replace as needed, all equipment and develop a preventive maintenance program.

3.3 Material handling equipment

There are literally thousands of pieces of material handling devices. Almost as varied and numerous are the classification strategies and methods of material handling equipment.

Material handling equipment has been grouped into four general categories:

- **Fixed-path or point-to-point**: This class of equipment serves the material handling need along a predetermined, or a fixed path. Conveyor systems, powered, gravity fed, or otherwise operated, fall into this classification. Fixed-path material handling systems are also referred to as continuous-flow systems.
- **Fixed-area material handling system**: This class can serve any point within a three-dimensional area or cube. Jib cranes or bridge cranes are examples of fixed-area systems. A bridge crane can move parts and other material from any point to any other point in the x, y, and z direction; however, this ability is limited within the confines of the equipment.
- **The variable-path variable-area**: The material handling equipment that can move to any area of the facility is referred to as variable-path variable-area equipment. All manual carts, motorized vehicles, and fork trucks can be pushed, dragged, or driven throughout the plant.
- **Auxiliary tools and equipment**: such as pallets, skids, automatic data collection systems, and containers.

In NLMK plant are present all these class of material handling equipment. In fact, depending on the movement, weight and production need of the material transported, as: Roller conveyors, transfer trolleys, carriages (for ladles, scraps and casting), jib and bridge cranes, multiple size and classes of motorized vehicles as fork lift, trucks and tractors.

In particular, in this thesis we will focus our attention on the bridge cranes as this handling equipment is the most commonly used in steel mill industry, due to the weight and bulky of the carried material and also due to the wide area of the plant that has to be reached.

As a matter of fact, in NLMK Verona are installed an amount of 26 bridge-cranes, that I'm going to introduce in the following paragraphs.

3.4 The Bridge-Crane

A bridge-crane is a machine intended for lifting and moving various types of materials, both in open areas than indoors.

Cranes are the best way of providing a heavy lifting facility covering virtually a part or in some case the whole area of a building. A bridge-crane is the most important material handling system for heavy goods due to its high load capacity. Indeed, they are commonly used in industrial environment such as steel mill plants, where at every step of the manufacturing process metal is handled by a bridge-crane and where efficiency or downtime are critical factors for production and quality.

Their design features vary widely according to their major operational specifications, such as: motion of the crane structure, weight and type of the load, locations of the crane, geometric features and environmental conditions.

3.4.1 Structure and working principle

A bridge crane consists of parallel runways with a traveling bridge (single or double) spanning the gap. A hoist, the lifting component of a crane, is mounted on a trolley, and travels attached to it along the bridge.

Thus is composed by 3 main parts: the bridge, the trolley and the hoisting mechanism (some bridges are equipped with a secondary hoisting mechanism).

The load is attached by a cable to the hoisting mechanism of the trolley, which can move in a horizontal plane at a certain height above the ground. The movement of the trolley takes place in the plane along two perpendicular axis, in fact it can travel along the straight track of the bridge and also can translate perpendicularly to its length. Furthermore, the hoisting mechanism moves up and down, allowing the load attached to cover a volumetric space, since can be moved in all three dimensions.

In Figure 11 it is presented the overall view of a bridge-crane (in particular an overhead type) with his main parts.

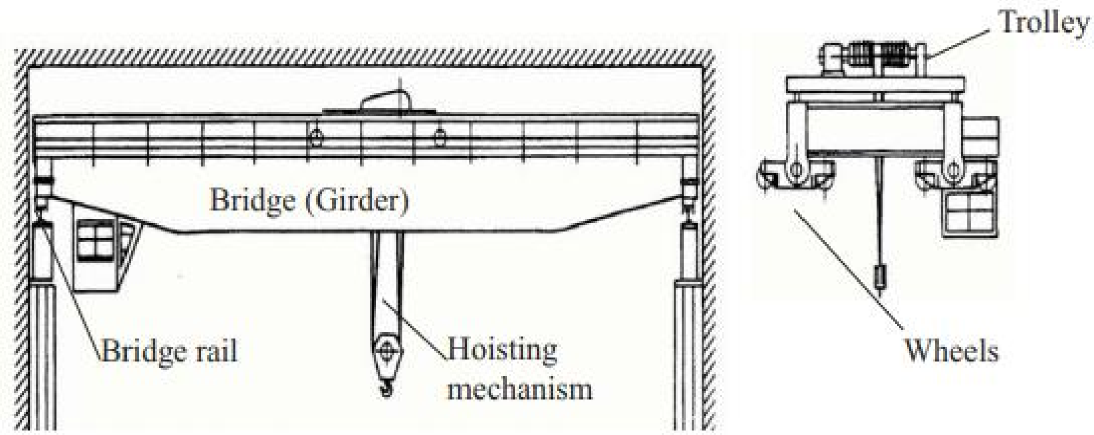


Figure 11 Bridge-crane Overall view

- **The bridge** (or girder): Is the main structure of the crane that serves as a platform for the movement of the trolley-hoist unit as well as support for the loads transmitted from them. It is provided with an electromechanical translation system that allows the translation.
- **The trolley** (or carriage): Is the structure that serves as support for the hoist. The movement of the trolley (as in the bridge) is allowed by an electromechanical system.
- **The hoist**: Thanks to the action of at least two pulley and steel cables, is the mechanism that allows the displacement of the load vertically. It is mounted on the trolley. Some bridges are equipped with a secondary hoisting mechanism.

Typical movements performed by the cranes are: the longitudinal movement of the bridge, the transverse movement of the trolley, the lifting and lowering of the load by means of the winch / hoist.

1. The lifting and lowering of the load by means of the winch / hoist.
2. The transverse movement of the trolley.
3. The longitudinal movement of the bridge (where the trolley is mounted) on his tracks.

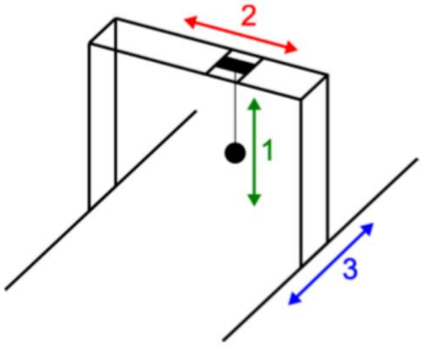


Figure 12 Crane's Manoeuvres

3.4.2 Bridge-cranes classification

In order to better characterize bridge-cranes is fundamental to say that according to the bridge structure they can be classified into different types.

In the plant are present three kinds of bridge-cranes, depending on operational condition and limited installation spaces, and they are:

1. **Overhead Crane**: This type crane operates on an elevated runways system along the length of the plant. The main structure is composed with a single or double beam bridge.

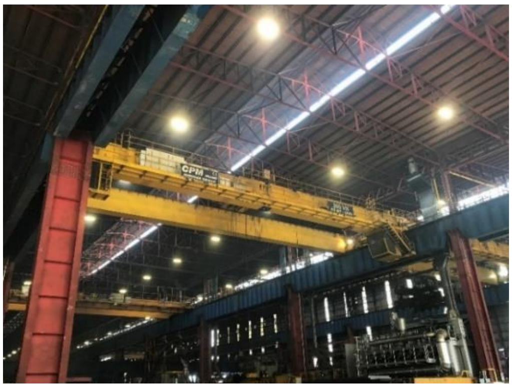


Figure 13 Overhead Crane F6

2. **Gantry Crane**: Unlike the overhead, the gantry crane is slightly different. In this case the bridge is supported by steel legs that rest on the floor and ride along a track installed on the floor.

Figure 14 Gantry Crane D7

3. **Lame-Gantry Crane**: The Lame-Gantry crane is a particular kind of gantry crane in which a side of the bridge structure slide along an elevated railway, while the other side on a track on the floor. This type of bridge-crane is not often used except on special occasion.

Figure 15 Lame-Gantry Crane P2

3.4.3 NLMK Verona cranes overview:

In the following paragraph the reader will be provided with information on the bridge-cranes present in the plant, including identification name and division into work areas. Subsequently, a brief description of the technical specifications will follow for each of them: class, load capacity, lifting equipment, function within the production cycle and location in the plant.

As mentioned above, there is a total of **26** bridge-cranes installed in NLMK Verona. So, for a quicker identification, an identification name has been assigned.

The name consists of a letter of the alphabet and a number, where the letter gives a general information of where the crane is located. Specifically:

- **L** for cranes installed on the 1°st span.
- **F** for cranes installed on the 2°nd span.
- **D** for cranes installed on the 3°rd span.
- **P** for cranes installed outside on quality control and shipping yard.
- **R** for cranes installed above the scrap yard.
- **C E M S** for cranes installed on particular positions (metallurgical furnaces, continuous casting, engine room and steel scale removing)

In the Table 1 it is presented the list of the 26 plant's bridge-cranes.

C1	**D3**	**D5**	**D6**	**D7**	**D8**	**D9**	**E1**	**F1**	**F4**	**F5**	**F6**	**F7**
L2	**L7**	**L9**	**L10**	**M1**	**P1 bis**	**P1**	**P2**	**P3**	**R3**	**R4**	**R5**	**S1**

Table 1 Cranes ID list

In order to make it easier to identify them, the bridge-cranes have been subdivided according to the departments in which they are installed. Then we can classify them in:

- **Steel Mill cranes**: That are in turn subdivided according to the working area into:
    - Melting zone
    - Casting pit zone
    - Continuous casting zone
- **Rolling Mill cranes**
- **Heat Treatment cranes**: That are in turn subdivided into:
    - BEFO zone
    - Shipment zone

The Table 2 shows the division of the cranes according to the departments and work areas previously mentioned:

STEEL MILL						**ROLLING MILL**		**HEAT TREATMENT**			
Melting Zone		**Casting pit zone**		**Continous Casting zone**				**Befo zone**		**Shipments zone**	
R3	C1	F1	D3	E1		L2	S1	D6	L10	P1	P3
R4	D5	F4	D9			L7	M1	D8	F6	P1 bis	
R5		F5				D7		L9	F7	P2	

Table 2 Cranes Department Division

I also would like to point out that some cranes, such as the D5 and F5, work between two different work areas. It was therefore necessary to subdivide them according to their respective workloads.

For instance, crane D5 is working for 75% in the melting zone while for the remaining 25% in casting pit, for this reason it was decided to insert it in the first zone, instead of the second one. For the same reason, the crane F5 was placed in the casting pit zone (60%) instead of in continuous casting (40%).

The following figure shows the layout of the plant complete with all the overhead travelling cranes (shown in yellow) so as to be able to visually show the reader their precise arrangement.

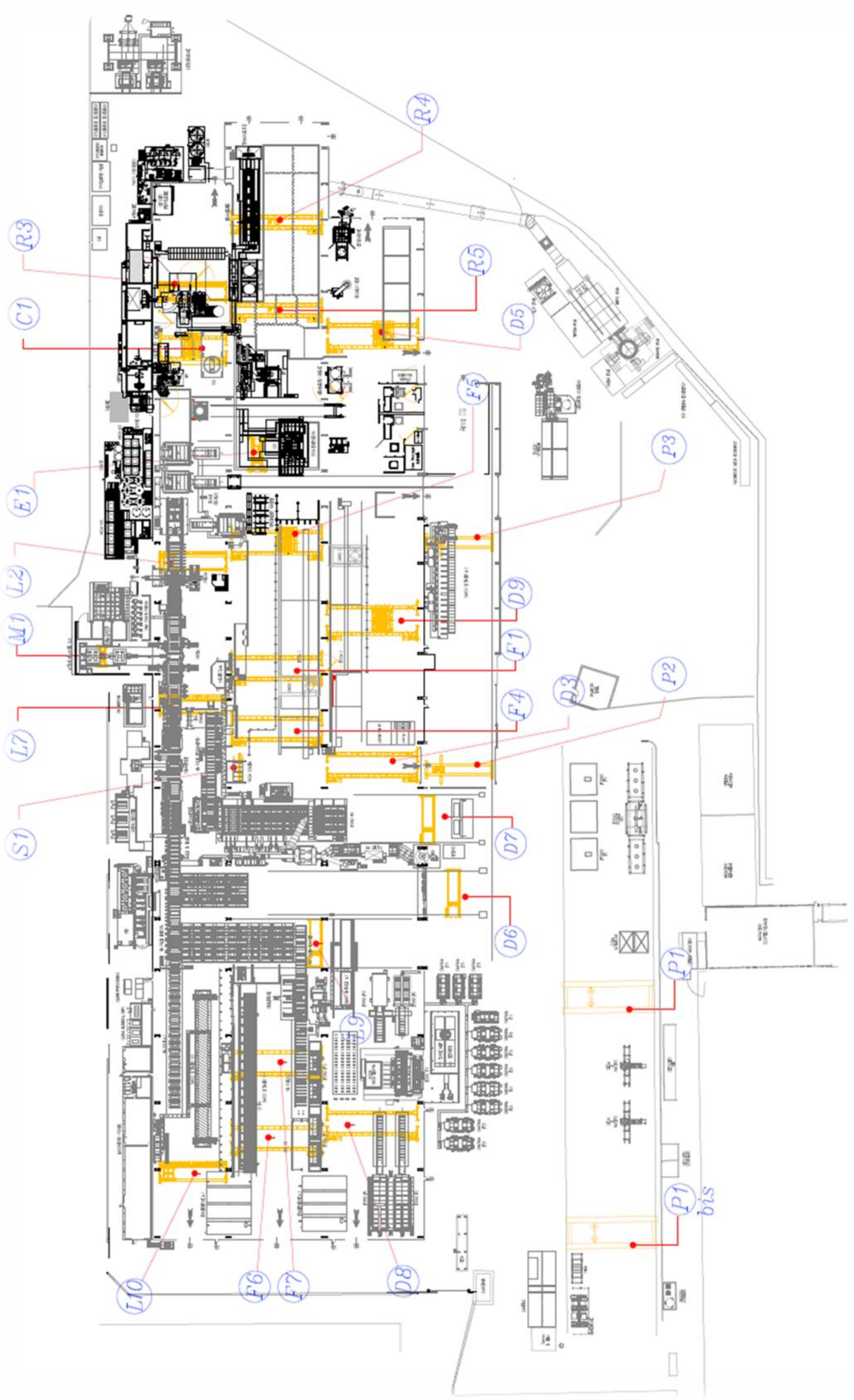


Figure 16 Overall Crane's Layout

3.4.4 Crane's characteristics:

Below is the technical list of overhead travelling cranes. For each one, a table has been drawn up specifying: type, load capacity, lifting equipment (if equipped also with an auxiliary lifting device), location and respective main functions.

- **C1**

Type: Overhead double bridge	**Capacity**: 150/30 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - LF1/ VD furnaces
Function: Steel mill services. Loading/unloading of the ladle into LF1 and VD furnaces. Loading/ unloading of the ladle carriage.	

- **R3**

Type: Overhead double bridge	**Capacity**: 90/30 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - EAF
Function: Scrap baskets handling and EAF loading.	

- **R4**

Type: Overhead double bridge	**Capacity**: 20 tons
Hoisting mechanism: Principal	**Location**: Steel mill - Scrap yard
Function: Scrap collection and baskets loading (coupled with R5).	

- **R5**

Type: Overhead double bridge	**Capacity**: 25 tons
Hoisting mechanism: Principal	**Location**: Steel mill - Scrap yard
Function: Scrap collection and baskets loading (coupled with R4).	

- **D5**

Type: Overhead double bridge	**Capacity**: 150/40 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - Ladle's parking
Function: Ladles maintenance services. Casting pit n°2 supplier.	

- **D3**

Type: Overhead double bridge	**Capacity**: 75/30 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - Casting pit n°2
Function: Casting pit n°2 services (coupled with D9).	

- **D9**

Type: Overhead double bridge	**Capacity**: 150/40 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - Casting pit n°2
Function: Casting pit n°2 services (coupled with D3).	

- **F5**

Type: Overhead double bridge	**Capacity**: 150/40 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - Casting pit n°1
Function: Casting pit n°1 supplier. Continuous casting services.	

- **F1**

Type: Overhead double bridge	**Capacity**: 100/40 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Steel mill - Casting pit n°1
Function: Casting pit n°1 services (coupled with F4).	

- **F4**

Type: Overhead double bridge	**Capacity**: 50 tons
Hoisting mechanism: Principal	**Location**: Steel mill - Casting pit n°1
Function: Casting pit n°1 services (coupled with F1).	

- **E1**

Type: Gantry double bridge	**Capacity**: 60 tons
Hoisting mechanism: Principal.	**Location**: Steel mill - Continuous casting.
Function: Continuous casting services, slabs lifting.	

- **L2**

Type: Overhead double bridge	**Capacity**: 95/25 tons
Hoisting mechanism: Principal + auxiliary	**Location**: Rolling mill - Forge
Function: Loading/unloading of ingots between forge and pre-heating furnaces.	

- **L7**

Type: Overhead double bridge	**Capacity**: 50 tons
Hoisting mechanism: Principal	**Location**: Rolling mill - Roller conveyor
Function: Rolling mill maintenance service.	

- **S1**

Type: Gantry double bridge	**Capacity**: 3.2 tons
Hoisting mechanism: Principal	**Location**: Rolling mill - Scale's tank
Function: Rolling mill scale-removal service.	

- **M1**

Type: Overhead double bridge	**Capacity**: 50 tons
Hoisting mechanism: Principal	**Location**: Rolling mill - Engine room
Function: Rolling mill servomotor maintenance.	

- **D6**

Type: Gantry double bridge	**Capacity**: 70 tons
Hoisting mechanism: Principal	**Location**: Heat treatments - Cooling Bed 2
Function: Cooling bed n°2 unloading.	

- **D7**

Type: Gantry double bridge	**Capacity**: 30 tons
Hoisting mechanism: Principal	**Location**: Rolling mill - WB furnace
Function: Walking Beam furnace loading for the rolling mill.	

- **D8**

Type: Overhead double bridge	**Capacity**: 65 tons
Hoisting mechanism: Principal	**Location**: Heat treatments - Furnaces
Function: Heat treatments services and heating-furnaces loading/unloading.	

- **L9**

Type: Gantry double bridge	**Capacity**: 24 tons
Hoisting mechanism: Principal	**Location**: Heat treatments - Cooling bed 1
Function: Cooling bed n°1 unloading. Cutting bench loading/unloading.	

- **L10**

Type: Overhead double bridge	**Capacity**: 35 tons
Hoisting mechanism: Principal	**Location**: Heat treatment - Cutting bench
Function: Cutting bench loading/unloading.	

- **F6**

Type: Overhead double bridge	**Capacity**: 30 tons
Hoisting mechanism: Principal	**Location**: Heat treatment - Cutting bench
Function: Cutting bench loading/unloading.	

- **F7**

Type: Overhead double bridge	**Capacity**: 20 tons
Hoisting mechanism: Only principal	**Location**: Heat treatment - Cutting bench
Function: Cutting bench loading/unloading.	

- **P1**

Type: Gantry double bridge	**Capacity**: 60 tons
Hoisting mechanism: Only principal	**Location**: Heat treatment - Shipments
Function: Finished plate loading for shipment.	

- **P1bis**

Type: Gantry double bridge	**Capacity**: 60 tons
Hoisting mechanism: Only principal	**Location**: Heat treatment - Shipments
Function: Finished plate loading for shipment.	

❖ **P2**

Type: Lame-gantry double bridge	**Capacity**: 40 tons
Hoisting mechanism: Principal	**Location**: Heat treatment - Quality control
Function: Cutting bench loading/unloading.	

❖ **P3**

Type: Lame-gantry double bridge	**Capacity**: 40 tons
Hoisting mechanism: Principal	**Location**: Heat treatment - Quality control
Function: Quality Control Service.	

3.5 Cranes maintenance at NLMK Verona

As mentioned previously, crane's downtime and inefficiency are critical factors for a manufacturing process, even more in a steelwork plant, where bridge-cranes are fundamental in material handling.

For this reason, a good maintenance program plays a crucial role in order to avoid unplanned failure and plant shutdown. Crane's maintenance is far from being easy, due to the machine complexity, working environment, high load and excessive wear that can lead to failure, potentially fatal to the safety of operators.

3.5.1 Ordinary maintenance planning

For all the above reasons, an ordinary maintenance programme for cranes is mandatory and is entrusted to an engineer, who is responsible for coordinating the maintenance teams.

The ordinary maintenance, is nothing more than the set of preventive maintenance actions that have as their only purpose to ensure the proper functioning of a machine (or system) and avoid the occurrence of failures, through a planned routine of specific actions. without modifying or improving the functions performed by the machine.

Ordinary maintenance activities are scheduled in complete accordance with production plans. In fact, each production line has certain planned downtimes to be respected, at the same time of which the maintenance operations of the cranes are planned, which would require a downtime of the line.

The Table 3 shows the weekly planning of the inspections on the respective bridge-cranes used during my internship period.

Notice that some cranes are checked twice a week whereas others as P1, P1bis, P2, M1 and S1 are not present into the weekly plan because the inspections are carried out by an outsider company.

NLMK Verona		WEEKLY INSPECTIONS CALENDAR			
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
R3	D5	D9	D8	R3	D5
R4	F5	D3	F6	R4	F5
R5	L2	F1	F7	R5	Jib crane
C1	L7	F4	L10	C1	Casting pit
D7	P3	L9	D6	E1	Grippers

Table 3 Crane's Inspection Calendar

The inspections, coordinated by the Maintenance Manager, are carried out with regular expiration by teams of skilled workers and qualified to work at height. Two teams composed of two people are therefore involved in each crane, the first being responsible for the mechanical inspection and the second for the electrical one.

The total duration of the inspection for a single crane is about 3 hours per team.

During both inspections bridge, trolley and hoisting mechanisms are checked. In Fig.17 and Fig.18 are shown the sheets used by the operators during the mechanical check with all the checklist of preventive actions.

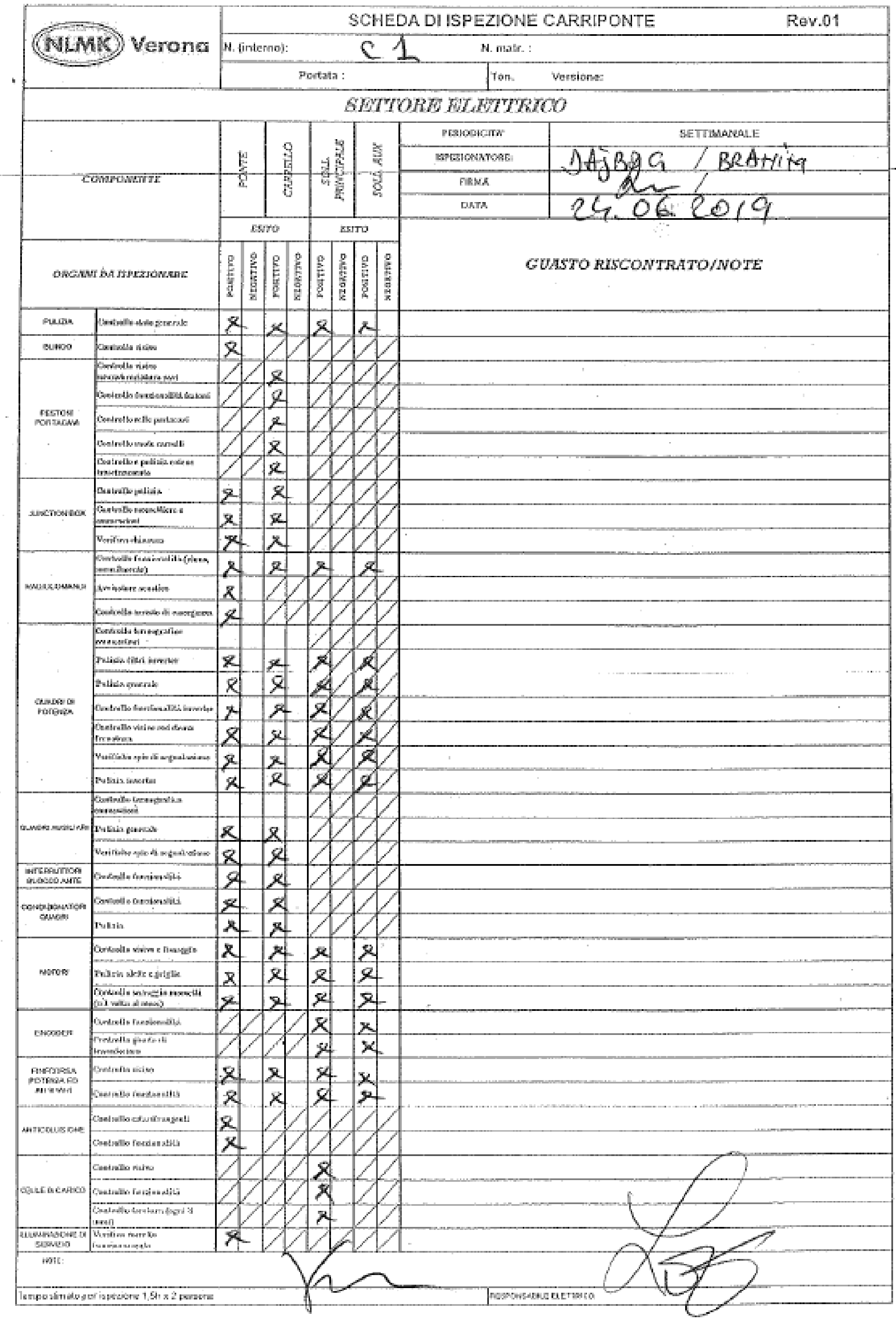
NLMK Verona	SCHEDA DI ISPEZIONE CARRIPONTE		Rev 01
	N. (interno): C - 1	N. matr. :	
	Portata :	ton.	Versione:

SETTORE MECCANICO

COMPONENTE			
PERIODICITA'	SETTIMANALE		
ISPEZIONATORE	VICTOR CORNEL		
DATA	24.06.19		

COMPONENTE	ORGANI DA ISPEZIONARE	PONTE POSITIVO	PONTE NEGATIVO	CARRELLO POSITIVO	CARRELLO NEGATIVO	SOLL. PRINCIPALE POSITIVO	SOLL. PRINCIPALE NEGATIVO	SOLL. AUX. POSITIVO	SOLL. AUX. NEGATIVO	GUASTO RISCONTRATO/NOTE
PULIZIA	Controllo stato generale	X		X						
FRENI	Controllo usura ganasce + pulizia piste freno	X		X		X		X		
	Controllo del tamburo					X		X		
	Controllo e ripristino gioco freni	X		X		X		X		
	Controllo servopompa e livello olio + pulizia	X		X		X		X		
	Controllo compressione molle (se completamente compresse pianificare sostituzione)	X		X		X		X		
GIUNTI	Controllo elementi elastici giunti trasmissione	X		X		X		X		
	Controllo rumorosità	X		X		X		X		
TAMBURO	Controllo rumorosità	/	/	/	/	X		X		
	Controllo supporti	/	/	/	/	X		X		
	Verifica usura gole	/	/	/	/	X		X		
	Controllo attacco funi sul tamburo (capofisso)	/	/	/	/	X		X		
BOZZELLO SOLL. PRINCIPALE	Controllo visivo + pulizia a.c.	/	/	/	/	X		/	/	
BOZZELLO SOLL. AUX	Controllo visivo + pulizia a.c.	/	/	/	/	/	/	X		
CARRUCOLE	Controllo visivo + pulizia a.c.	/	/	/	/	X		X		
RUOTE	Controllo usura ruote	X		X		/	/	/	/	
	Controllo giochi	X		X		/	/	/	/	
	Controllo lubrificazione	X		X		/	/	/	/	
BINARI	Controllo usura		X	X		/	/	/	/	DA SISTEMARE BINARIO PONTE.
	Controllo staffe di ancoraggio	X		X		/	/	/	/	
TELAIO	Controllo visivo	X		X		/	/	/	/	
ARRESTI FISSI	Controllo visivo	X		X		/	/	/	/	
RESPINGENTI	Controllo visivo	X		X		/	/	/	/	
CORRIMANO PROTEZIONI	Controllo visivo	X		X		/	/	/	/	
VIE DI CORSA	Controllo visivo	X		X		/	/	/	/	
	Pulizia	X		X		/	/	/	/	
CARTELLONISTICA DI LEGGE	Controllo visivo	X		X		/	/	/	/	
RIDUTTORI	Controllo livello olio	X		X		X		X		
	Verifica perdite	X		X		X		X		
	Controllo rumorosità		X	X		X		X		RUMOROSITÀ RIDUTTORI SOLL. PRINCIPALE
MOTORI	Controllo rumorosità/vibrazioni	X		X		X		X		
FUNE PRINCIPALE	Controllo visivo	/	/	/	/	X		/	/	
	Controllo lubrificazione					X		/	/	
FUNE AUSILIARIA	Controllo visivo	/	/	/	/	/	/	X		
	Controllo lubrificazione	/	/	/	/	/	/	X		
NOTE	lubrificazione completa del carroponte una volta al mese : ultima settimana del mese									
Tempo stimato per ispezione 1,5h x 2 persone										RESPONSABILE MECCANICO:

Figure 17 C1 Mechanical Inspection Sheet



NLMK Verona — SCHEDA DI ISPEZIONE CARRIPONTE — Rev.01

N. (interno): C 1 — N. matr.: — Portata: — Ton. — Versione:

SETTORE ELETTRICO

PERIODICITA': SETTIMANALE
ISPEZIONATORE: DAJBAG / BRAHIMA
FIRMA:
DATA: 24.06.2019

COMPONENTE / ORGANI DA ISPEZIONARE		PONTE POSITIVO	PONTE NEGATIVO	CARRELLO POSITIVO	CARRELLO NEGATIVO	SOLL. PRINCIPALE POSITIVO	SOLL. PRINCIPALE NEGATIVO	SOLL. AUX POSITIVO	SOLL. AUX NEGATIVO	GUASTO RISCONTRATO/NOTE
PULIZIA	Controllo stato generale	X		X		X		X		
BUNDO	Controllo visivo	X								
FESTONI PORTACAVI	Controllo visivo [illegible]			X						
	Controllo funzionalità festoni			X						
	Controllo delle portacavi			X						
	Controllo ruote carrelli			X						
	Controllo e pulizia rotaia trasversale			X						
JUNCTION BOX	Controllo pulizia	X		X						
	Controllo serraggio connessioni	X		X						
	Verifica chiusura	X		X						
RADIOCOMANDI	Controllo funzionalità (sirena, [illegible])	X		X		X		X		
	Avvisatore acustico	X								
	Controllo arresto di emergenza	X								
QUADRI DI POTENZA	Controllo termografico connessioni									
	Pulizia filtri inverter	X		X		X		X		
	Pulizia generale	X		X		X		X		
	Controllo funzionalità inverter	X		X		X		X		
	Controllo visivo [illegible]	X		X		X		X		
	Verifica spie di segnalazione	X		X		X		X		
	Pulizia inverter	X		X		X		X		
QUADRO AUSILIARIO	Controllo termografico connessioni									
	Pulizia generale	X		X						
	Verifica spie di segnalazione	X		X						
INTERRUTTORI BLOCCO ANTE	Controllo funzionalità	X		X						
CONDIZIONATORI QUADRI	Controllo funzionalità	X		X						
	Pulizia	X		X						
MOTORI	Controllo visivo e fissaggio	X		X		X		X		
	Pulizia alette e griglie	X		X		X		X		
	Controllo serraggio morsetti (1 volta al mese)	X		X		X		X		
ENCODER	Controllo funzionalità					X		X		
	Controllo giunto di trasmissione					X		X		
FINECORSA POTENZA ED AUSILIARI	Controllo visivo	X		X		X		X		
	Controllo funzionalità	X		X		X		X		
ANTICOLLISIONE	Controllo catarifrangenti	X								
	Controllo funzionalità	X								
CELLE DI CARICO	Controllo visivo					X				
	Controllo funzionalità					X				
	Controllo taratura (ogni 3 mesi)					X				
ILLUMINAZIONE DI SERVIZIO	Verifica corretto funzionamento	X								

NOTE:

Tempo stimato per ispezione 1,5h x 2 persone

RESPONSABILE ELETTRICO

Figure 18 C1 Electrical Inspection Sheet

If, during the checks, the operators find anything abnormal such as oil leaks, noise, vibrations or worn components, they are immediately notified to the maintenance responsible who, after evaluating the situation, will take charge of organizing future corrective maintenance interventions through a work order.

The work order (WO) is the document containing all the information relating to the maintenance operation and the links of reference to other documents necessary to perform the maintenance work.

The WO process flow is explained in Fig.19.

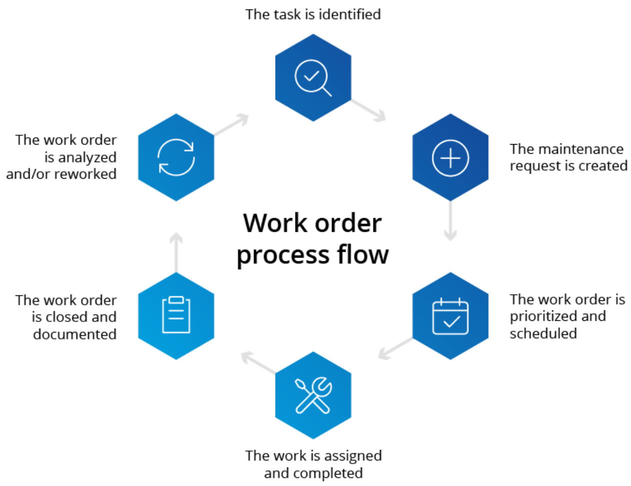


Figure 19 WO Process Flow

Each spare part of the machine is coded and stored in the warehouse. Warehouse management is supported by SAP MRP software. Through the use of this software, not only is it possible to keep track of the availability of each individual resource, but it is also possible to set fundamental parameters for each individual component, such as the reorder level and the maximum quantity that can be stored.

The definition of these parameters is the responsibility of the Maintenance Supervisor of the bridges and is very complicated. For this reason, the definition of these parameters is more correct where there is considerable experience in the field of overhead cranes.

Warehouse management through this software allows complete traceability for each purchase made and allows this procedure to be automated based on historical data and the supplier's lead time.

3.5.2 Quarterly cables and chain inspections

Cable degradation of lifting equipment is normally due to mechanical causes, due to the heavy static and dynamic loads applied and the bending forces and contact pressures resulting from bending around drums and pulleys. Another reason for cable deterioration, especially in the steel industry, is due to high operating temperatures and the presence of metal dust or dirtiness.

For this reason, it is necessary to carefully and methodically check the condition of the plant's bridge cranes ropes, as this is the element of the machine that can most easily be damaged as a result of incorrect use by the crane operator (such as oblique pulling) or under-maintenance.

The Italian Legislative Decree No. 81/08 imposes the mandatory quarterly checks of steel cables and chains.

In NLMK Verona S.p.A. the inspections of the cables are carried out on a regularly scheduled basis by competent personnel. For each cable of the lifting systems (main and auxiliary) an evaluation sheet is compiled regarding the respective status, as shown in Fig.20, with final result.

During the on-site inspection it is taken into account:

- ❖ Diameter reduction (reduction must be less than 10%).
- ❖ External wear
- ❖ Yield Presence
- ❖ Lubrication status
- ❖ Presence of broken wires (broken wires must be less than 2 in a 6d length)
- ❖ Condition of the Pulleys and barrel (grooves and coils wear less than 10%)

NLMK Verona	Scheda ispezione funi			
N° interno D5	Tipo fune 510		Data 16 03 19	
Tipo di Controllo	Esito P	Esito N	Note	Parametri
Diametro	X		34,2 ; 34,1	Max -10%
Usura esterna	X			Max condizione B
Snervamento	X			
Lubrificazione	X			
Fili rotti	X			Max 2fili rotti su 6d.
Capi fissi	X			
Carrucole	X			Max -10%
Spire Tamburo	X			Usura Max 10%
Schiacciamento	X			
Esito finale			Operatore	Firma
Buono Discreto ~~Sufficiente~~ Da sostituire			RISS	

Figure 20 D5 Principal lifting cables inspection sheet

If the inspection has negative results, the rope must be replaced.

As regards lifting equipment chains, they must also be checked on a quarterly basis; the inspection of the crane's chain harnesses, lifting equipment chains and shackles of the plant, is carried out by an external company.

Generally, it is necessary to replace the chains when:

- ❖ An elongation of more than 5% of the chain links is found.
- ❖ A reduction in diameter of more than 10% is detected or there are deformed/bent rings.

Once their condition had been verified, they were tagged, entered in the database and painted, so that they could be easily identified in anticipation of the next quarterly check.

4 BRIDGE-CRANES CRITICALITY ANALYSIS

4.1 Introduction

The aim of maintenance engineering is to maximise the overall performance of the production system and to seek a balance between maintenance costs and production losses by minimising machine downtime and maintenance times.

To do so, it is necessary to identify the most appropriate maintenance policy, which can be corrective for machines considered non-critical, preventive for those considered most important, up to the use of predictive tools, with inspections and scheduled replacements for machines considered strategic for production. Plant's machines can therefore be divided into critical and non-critical.

- **Non-critical machines** are those characterized by easiness of maintenance, lower probability of failure or marginal use in the production process. In this case, their eventual shutdown does not imply significant problems for the production.
- **Critical machines** on the other hand, are those on which it is recommended to pay particular attention to minimize failures or downtime not scheduled in the maintenance program, since they drastically affect the quantity and quality of the production process.

Therefore, since there are a total of **26** different cranes in the plant, it is fundamental to be able to identify the most critical cranes, where it will be necessary to concentrate efforts in order to improve their performance through an implementation of the maintenance program or to study corrective solutions to limit common problems.

In spite of everything, this does not mean excluding from my analysis the cranes evaluated as not-critical, because, although evaluated as less important, a failure could lead to significant problems for the company mainly in terms of safety and production losses.

Generally, the criticality of a plant is well known to maintenance technicians and managers, who know well the weak points and where they are and are able to identify them without difficulty, as the people in the production know where the bottlenecks of the process are.

Nevertheless, it is important to base the following analysis on objective criteria, that can give me a concrete value of the level of criticality of the crane in question, the **Risk Priority Number** (RPN).

Together with the crane's Maintenance Manager, and the Maintenance Engineer, I identified two different critical factors, each one divided into the following aspects

- Technical criticality [K_{tec}], which in turn consist of:
  - Usage coefficient [K_u]
  - Environmental coefficient [K_{env}]
- Operational criticality [K_{ope}], which in turn consist of:
  - Production coefficient [K_p]
  - Arrangement coefficient [K_a]
  - Temperature coefficient [K_t]

As shown in the Figure 21, for each of the above aspects a coefficient has been assigned according to the risk factors associated with the relevant condition.

We decided to assign the value of:

- 0.5 to the condition considered to be the most critical.
- 0.75 to the intermediate critical condition.
- 1 to the lowest critical condition.

K = 0.5	High Criticity
K = 0.75	Medium Criticity
K = 1	Low Criticity

Figure 21 Criticality's value assignation

The final value of the Risk Priority Number is then calculated by multiplying the coefficients deriving from the technical and operational criticalities (consisting in turn of 3 additional coefficients). The simplified scheme for calculating the RPN has been shown in Fig. 22.

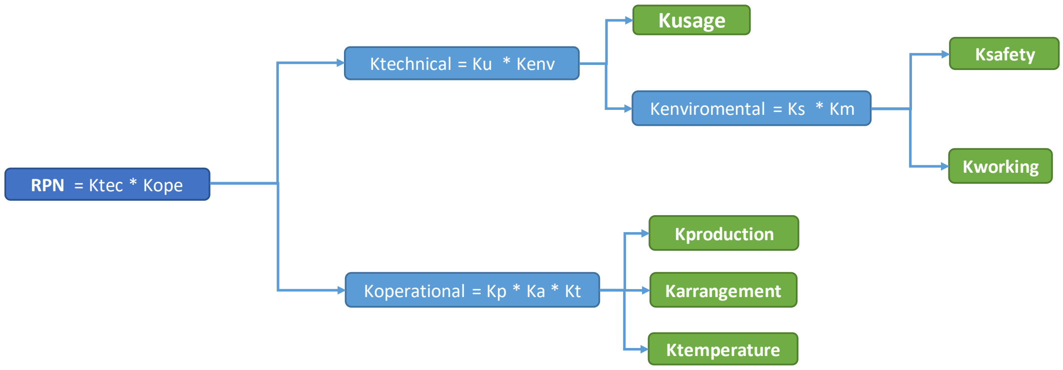


Figure 22RPN calculus scheme

In the following paragraph, all the respective coefficients will be analysed and calculated, both for technical and operational criticalities, which will then be inserted in a table for the final calculation of the RPN value.

4.2 Technical criticality [K_{tec}]

These are the critical issues concerning the working conditions and modalities of bridge cranes, which can often negatively influence the integrity of the machine and consequently its useful life. They vary depending on the crane, its usage and location in the plant. They are divided into two groups:

- The usage conditions are given by the coefficient [K_u].
- The environmental conditions [K_{env}], in turn divided into safety conditions and working conditions are given respectively by the coefficients [K_s] and [K_w].

Therefore, the value of the technical coefficient [K_{tec}] will be given by

$$K_{tec} = K_u * K_{env}$$

Where

$$K_{env} = K_s * K_w$$

4.2.1 Usage coefficient [K_u]

It should be noted that, because of the way in which the load is applied, attached to the trolley by means of ropes, the dissipative actions due to oscillating phenomena are relevant and, consequently, it is necessary to consider the different functions for which the cranes are used.

For this purpose, a usage coefficient has been assigned to each one, describing the different utilization methods and their consequences.

Three main operations have been identified:

- **Transport**: That is, transportation between substations of various materials such as ladles, plates and ingots. This type of operation is considered of low risk, as the various components are subjected to static loads and constant mechanical stresses.
  For this reason we have decided to assign a value of K_u = 1.
- **Pit-services**: Sub-services are basically defined as operations carried out into Pit 1 and 2, such as the placement of ingot moulds and plates and the stripping of ingots. These are very delicate operations as the crane is subjected to important dynamic loads that can lead to overloads, and oscillating phenomena.
  These can lead to damage the gearboxes and shafts of both the bridge and the trolley, as well as to the lifting system with damaging pulley ropes and bearings.
  It is important to note that most of these failures are due to incorrect manoeuvring by the crane's operator. In particular, during stripping, an oblique pull on the rope can lead to consequences such as rope slippage and consequent damage to the rope.
  Therefore, given the delicacy of the operations assigned to these cranes, we decided to assign a value of K_u = 0.5.
- **Scrapyard**: That is, the operations carried out in the scrap yard of loading scrap into the baskets, that will subsequently feed the EAF furnace, and are carried out by the overhead cranes R4 and R5. The components most stressed during this operation are the grapple, which is subjected to shocks, the electrical cables of the magnets, which are often ripped off due to a wrong manoeuvre, and ropes, which can be overlapped during the pickup.

Also in this case, considering the high solicitations, we have assigned to the usage coefficient a value of K_u = 0.5.

Table 4 shows the values of the usage coefficient K_u assigned to each crane according to its use.

	Transport	Pit-services	Scrap yard	Ku
C1	X			1
D3		X		0,5
D5	X			1
D6	X			1
D7	X			1
D8	X			1
D9		X		0,5
E1	X			1
F1		X		0,5
F4		X		0,5
F5	X			1
F6	X			1
F7	X			1
L2	X			1
L7	X			1
L9	X			1
L10	X			1
M1	X			1
P1 bis	X			1
P1	X			1
P2	X			1
P3	X			1
R3	X			1
R4			X	0,5
R5			X	0,5
S1	X			1

Table 4 Ku cranes values

4.2.2 Operating environment [K_{env}]

These are the environmental conditions in which cranes work, and how they influence both maintenance technician's safety during intervention in the case of failure (as well as the accessibility of the workplace to carry out maintenance) and the integrity of the machine.

For this reason, it will be composed of two distinct coefficients as represented by

$$Kenv = Ks * Kw$$

Where

- ❖ K_s gives the safety coefficient for operators;
- ❖ K_w gives instead the working coefficient of the machine’s environment;

4.2.2.1 Safety coefficient [K_S]

One of the main characteristics of an entity that influences maintainability (which in particular affects the Mean Time to Repair, MTTR) is its accessibility.

An entity is considered accessible if it is guaranteed easy and safe access to its parts subject to reparation, inspection and replacement.

This coefficient therefore takes into account those aspects that could affect the health of maintenance operators and therefore limit the accessibility of the crane in case of a repair during a machine failure.

It will not be considered dangerous those situations that can be avoided by the regular use of safety devices such as the presence of dust, loud noise or work at height.

The bridge cranes considered to be of major risk to the health of operators are mainly those that operate directly above heat sources, such as furnaces (EAF, LF and VD), ladles directed to casting or even forging ingots, where the temperature of the environment above during the operating condition can also exceed 80 °C, creating an off-limits environment for maintenance workers as well as significantly increase repair times.

Therefore, if the crane works in the presence of heat sources able to significantly heat the working area, I have assigned the value of K_S = 0.75 to the safety coefficient. While in the specific case of cranes R3 and C1, where, in addition to the high temperatures, there is also the presence of toxic gases produced by the steel melting, I assigned the value of K_S = 0.5.

The Table 5 shows the values of the Safety Coefficient assigned for the respective bridge cranes.

	Heat sources	Toxic gases	Ks
C1	X	X	0,5
D3			1
D5	X		0,75
D6			1
D7			1
D8	X		0,75
D9			1
E1	X		0,75
F1			1
F4			1
F5	X		0,75
F6			1
F7			1
L2	X		0,75
L7			1
L9			1
L10			1
M1			1
P1 bis			1
P1			1
P2			1
P3			1
R3	X	X	0,5
R4			1
R5			1
S1			1

Table 5 Ks cranes values

4.2.2.2 Working coefficient [K_w]

The working coefficient K_w instead considers the environmental operating conditions in which the crane works, and how these can affect the failure rate of the components of the crane and so its useful life.

Before going into detail, I think it is useful to briefly remember the trend of the failure rate $\lambda_{(t)}$ of a component in the time described by the model of the Bathtub Failure Rate (Weibull curve).

This curve represents the frequency at which the components of an entity fail and are measured in number of failures on operating time, is characterized by 3 distinct phases of life that characterize 3 different failure modes based on their distribution during the life of a family of components and are:

- **Early life failure:** These are the failures that occur during the initial life period, i.e. during the Wear-in period, the probability of these failures occurring gradually decreases with time until they stabilize at a constant value. They can be caused by defects in design, installation or of the component itself.

- ❖ **Random failure:** Are failures that occur during the useful life of the component and are random (for example, an accidental load on the rope during stripping operations). Failure rate keeps constant with time.
- ❖ **Wear-out failure:** These are the failures that occur in the last period of the useful life of the components (Wear-out) and are mainly due to effects of aging and deterioration. In this last case the probability of having a failure increases with time.

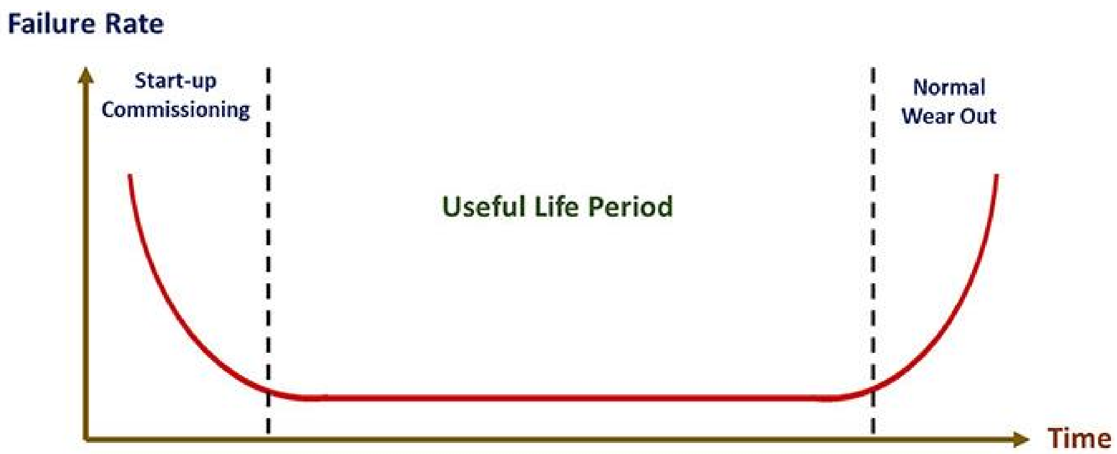


Figure 23 Bathtube Failure Rate curve

It is also important to note that the failure rate can only be calculated if the environmental conditions under which the components in question work are precisely defined. For this reason, it is necessary to indicate the environmental conditions and the place where the cranes work, as these can have a serious negative effect on the useful life of my components by increasing the probability of failures due to wear.

The main problems detected within the NLMK Verona plant are:

- ❖ **Heat sources:** The main sources of heat are located mainly in the steel and rolling mill Dept. and concern the overhead cranes located above the melting furnaces, those used for transporting ladles to casting and for loading pre heating furnaces.
  Those subject to the highest temperatures are the cranes used in the EAF, LF and VD furnaces where the temperatures of the melted steel reach 1600 °C, compared to 1200 °C of the forging ingots and about 800 °C of the quenching operation.

The temperatures reached can damage both mechanical components such as the oil seals of pumps and gearboxes, causing potentially dangerous oil leaks (it is highly recommended to use HFR lubricating oils) and electrical components.

- **Dust**: Another important problem in steel industries is the presence of metal powders, produced during steel making, such as calamine (also called lamination scale or black oxide), which in addition to being a problem for the health of operators, causes serious problems of wear to the moving parts of cranes as well as damages to electrical components.
  In particular, the components most affected by these residual dusts are the electromagnetic brakes, the festoon catenary, the bridge rails and wheels as well as pulleys and bearings, which wear out more quickly, reducing the useful life of the component. From an electrical point of view, since these metallic powders are conductors, they generate short circuits of electrical components and damage to the electronic components, such as inverters, contactors and relays.
- **Climate agents:** Such as rain and humidity, which affect the overhead cranes located in the outer yard, causing corrosion problems to the carpentry, electrical circuits and electronic components.

The following Table 6 shows the different coefficients assigned for each crane according to the respective working conditions. In case the crane works in the presence of a previously listed condition, I have assigned the value K_w = 0.75, in the presence of two K_w = 0.5, while in the case there is not even one K_w = 1.

	Heat sources	Dust	Climate agents	Kw
C1	X	X		0,5
D3		X		0,75
D5	X	X		0,5
D6				1
D7				1
D8	X			0,75
D9		X		0,75
E1	X			0,75
F1		X		0,75
F4		X		0,75
F5	X	X		0,5
F6				1
F7				1
L2	X	X		0,5
L7				1
L9				1
L10				1
M1				1
P1 bis			X	0,75
P1			X	0,75
P2			X	0,75
P3				1
R3	X	X		0,5
R4		X		0,75
R5		X		0,75
S1		X		0,75

Table 6 Kw cranes values

4.3 Operational criticality [K_{ope}]

Unlike the technical criticalities, which mainly judge the propensity to failure due to external conditions and uses, the operational ones are those criticalities of the facility that depend strictly on the layout of the cranes of the plant and that evaluate the impact of a downtime directly on the production.

Since their placement is difficult to modify, due to economic issues and available space, it is necessary to recognize which cranes are the most limiting in order to prevent their possible breakdown, as it could cause slowdowns or even production losses with significant economic consequences.

In the following paragraphs we will describe the 3 coefficients that constitute the value of the final operational criticality K_{ope}. These are:

- The production coefficient K_a
- The arrangement coefficient K_p
- The temperature coefficient K_t

Therefore, the value of the operational criticality will be given by:

$$K_{strat} = K_d * K_p * K_a$$

In order to evaluate the strategic nature of the cranes, it was necessary to study the steel flow from the scrap yard to the shipment of the finished product, focusing on the handling of the product between the various substations from upstream to downstream of production so as to highlight, graphically, the limits of the bridge-cranes.

4.3.1 Process Flowchart

The realization of the following Flowchart has been possible thanks to the experience in the field, personally following the steel production during its entire process, thanks to the help of the engineers of the Technical and Production Department and finally to the shift leaders of the Steel Mill, Rolling Mill and Heat Treatment Departments.

The study of product logistics has been rather complex because:

- ❖ Some cranes are used for multiple product displacements between different substations.
- ❖ In order to carry out a correct analysis, it was necessary to take into account the sub-services complementary to the production cycle, such as the recirculation of the post-casting ladles.
- ❖ Being a flexible production (due to the varied supply of types of steel and customer demand) the flow may undergo changes, especially downstream of the rolling mill department, depending on the characteristics required by the Programming Office.

The aim of this simplified flowchart is to highlights the principal limits of the production flow due to the crane's layout of the plant. In particular, it shows which crane is involved in the handling of the product between the principal sub-stations as also between the main spans.

By doing so it is possible to highlights the most evident overworked cranes, that represent a bottleneck in the production flow, and also identify which crane works coupled and which in line.

Thanks to this diagram it is easier to quantify graphically the consequences of a machine stop on the product handling between the stations and the impact that this has on the production.

For example, a hypothetical shutdown of the R3 crane, in charge of loading the EAF furnace with scraps, would put the entire Steel Mill out of service, as there would be no other way to load the furnace and continue with the melting process.

If, on the other hand, a failure of the F5 crane occurs, it would compromise production in Continuous Casting and in Casting Pit 1, but using the D5 it would still be possible to continue production in Casting Pit 2.

Furthermore, are represented also all the carriages used as auxiliary material handling and for cranes and allow the products to cross the spans. Cranes M1 S1 and P2 are not shown in the flowchart because are not directly involved in the material handling.

In the flowchart cranes are represented by a blue tag, substations with a yellow tag and the auxiliary material handling by a grey tag. For convenience, it has been divided into two parts:

- **Upstream Flowchart**
  The first part includes the Steel and Rolling Mill Department.
  The blue line represents the main flow of the process, it can be noticed that after the substation of the furnace VD is divided into 3 depending on the production line (Casting Pit 1, Casting Pit 2 or Continuous Casting).
  The red line, in the opposite direction to the main flow, represents the ladle service and allows the ladles used for casting to be put back into cycle. In the event of a breakdown of the D5 crane, in addition to shutting down the Casting Pit 2, it would block the possibility of supplying the EAF ladles ready for tapping, stopping the entire production in a short time. For this reason, the D5 is considered as a crucial crane.
- **Downstream Flowchart**
  The second part includes the Heat Treatment & Finishing department, up to the shipping.
  In this case there are three different flow lines that converge on the Heat Treatment Dept. This diversification is due to the limits imposed by the capacity of the cranes of each line. The orange line is used for semi-finished products weighing more than 35 tons, while the black and blue lines are the

orange line is used for semi-finished products weighing more than 35 tons, while the black and blue lines are used for those weighing less than 35 tons. All three lines converge on the heat treatment station, which is served exclusively by the D8 crane.

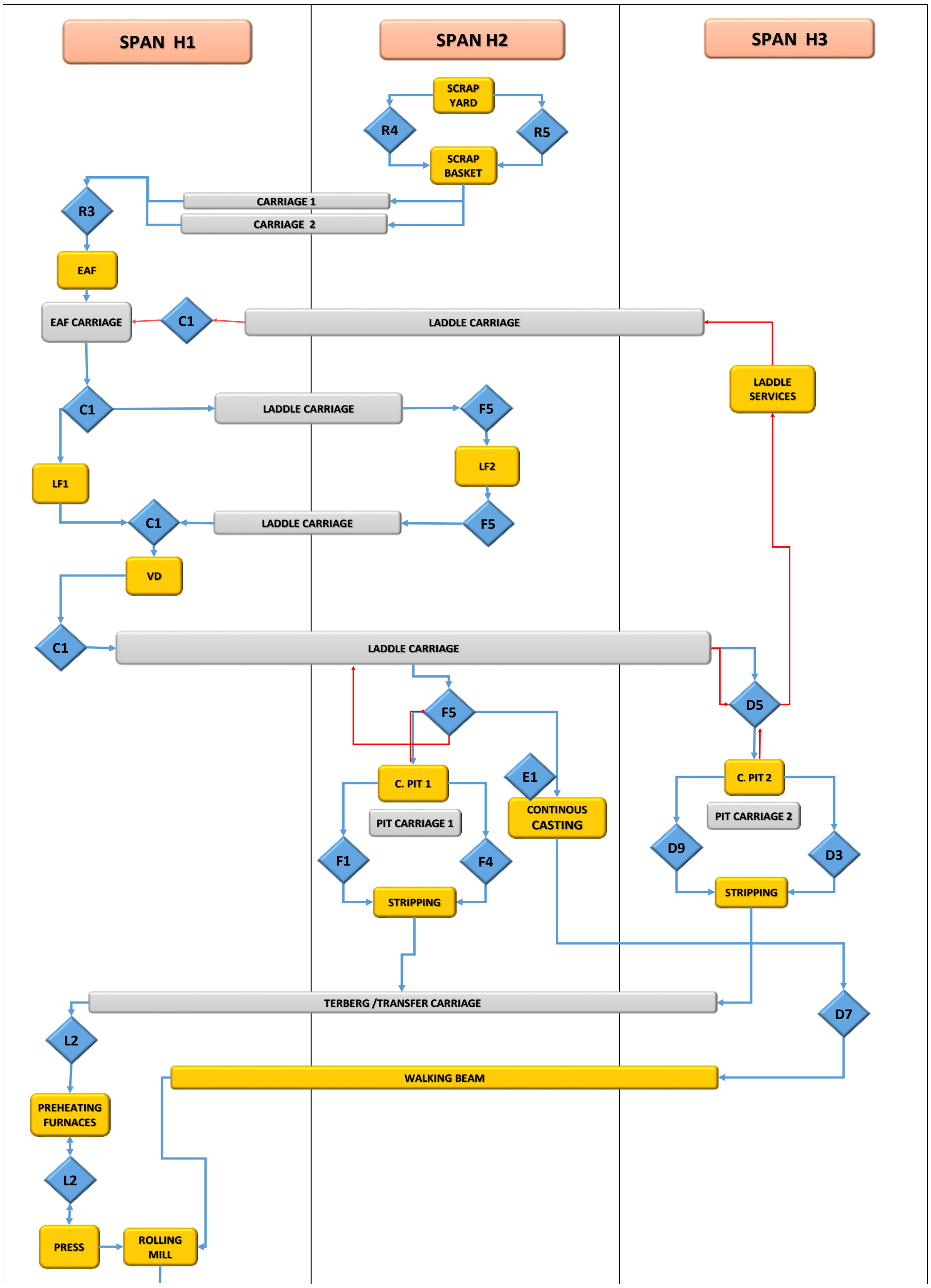


Figure 24 Upstream Flowchart

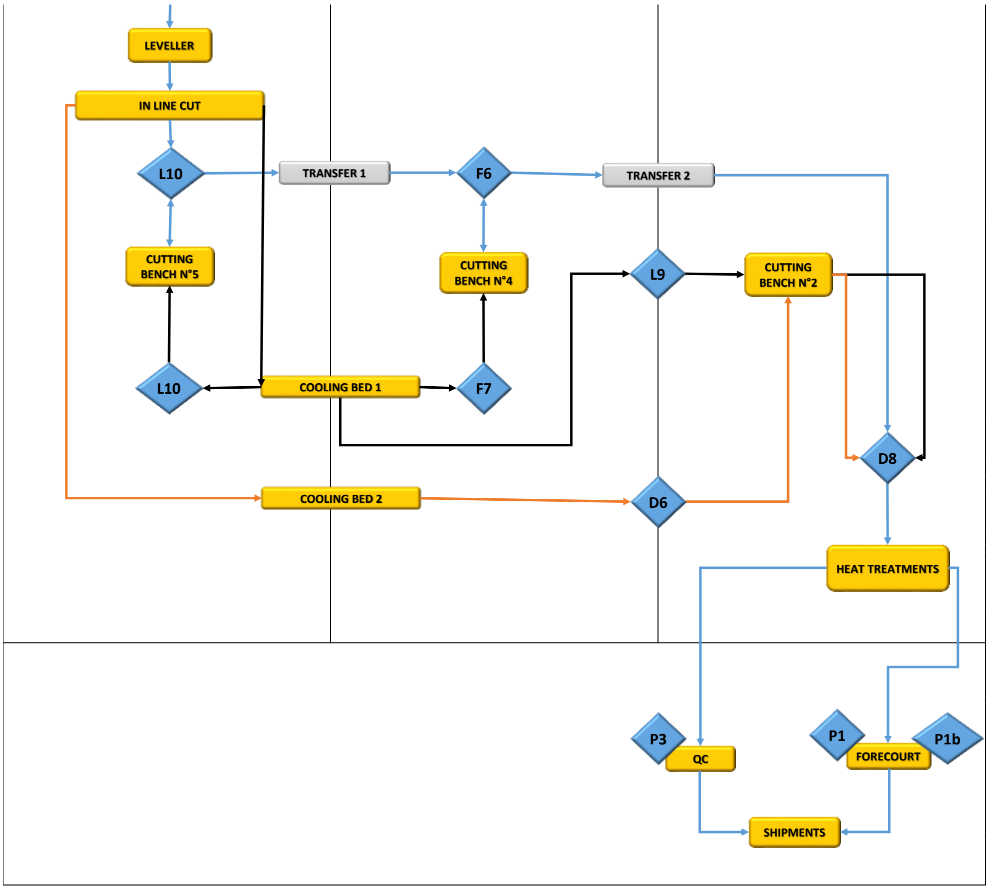


Figure 25 Downstream Flowchart

4.3.2 Production coefficient [K_p]

It is of fundamental, when analysing the criticality of a production system, to have a clear idea of the consequences that a machine shutdown can have on production.

Thanks to the Flowchart it is possible to visually identify the most strategic cranes and evaluate, using the production coefficient K_p, the impact of an unexpected crane stoppage on the output of my production line, pointing out which substations are indirectly disabled and which ones can still be in function.

It is possible to identify 3 different case, to which I have assigned a value of K_p according to the respective level of criticality:

- **Bottleneck** (K_p = 0,5)

  A bottleneck in production is "A resource that affects the performance of a system in the strongest manner, that is, the resource that, for a given differential increment of change, has the largest influence on system performance."

This is the most critical situation because a stop of the overhead crane, identified as bottleneck, leads to the shutdown of the entire production.
In the NLMK Verona plant there are 3 of them and they are detectable in the previous Flowchart. Two of them are located upstream of the production process and are crane R3 and C1, while the last, D8, is located downstream.
For instance, a hypothetical failure of R3 would shut down the entire steel plant, as there would be no other way to load the scrap into the EAF furnace and continue with the melting process. The same applies to the C1, which serves the melting furnaces.
The D8 is the only one to serve the entire BEFO Department, so a stoppage of the crane leads to a shutdown of the entire Heat Treatment Dept. for semi-finished products.
It was also decided to assign the most critical value to the D5 and L2 cranes, as they are also essential, the first one for the maintenance of the ladles and the second for the Rolling Mill Department, as it is the only one assigned to the loading of the pre-heating furnaces.

- **Production slowdown** (K_p = 0,75)

  In this case, a failure would not compromise the entire production as it is still possible to produce, even if with a reduced output and with consequent delay on the production schedule.
  This, for instance, is the case of the F5 crane. Assuming therefore a failure to F5 would be compromised production in both Continuous Casting and Pit 1 (in addition to the functionality of the furnace LF2), but using the D5 crane would still be possible to continue production in Pit 2.

- **Operative** (K_p= 1)

  These are cranes that have a minimal impact on the production output in the event of downtime, but can have negative consequences in the event of long-term breakdown.

	Bottleneck	Slowdown	Operative	[Kp]
C1	X			0,5
D3			X	1
D5	X			0,5
D6			X	1
D7		X		0,75
D8	X			0,5
D9		X		0,75
E1		X		0,75
F1		X		0,75
F4		X		0,75
F5		X		0,75
F6			X	1
F7			X	1
L2	X			0,5
L7			X	1
L9			X	1
L10		X		0,75
M1			X	1
P1 bis			X	1
P1			X	1
P2			X	1
P3			X	1
R3	X			0,5
R4		X		0,75
R5		X		0,75
S1			X	1

Table 7 Kp cranes values

4.3.3 Arrangement coefficient [K_a]

Another factor that should be taken into account is the arrangement of the cranes within the plant. In fact, as can be seen from the Flowchart, there are substations that can be served by two different cranes, while on the contrary there are others whose operation depends uniquely on a single crane.

The arrangement coefficient evaluates the position in which the machines are placed along the production line, i.e. whether they work individually or coupled.

We can therefore distinguish two distinct situations:

- **In line**: This is the most critical situation, since the functionality of a substation is strictly dependent on the functionality of the crane. In the event of a machine failure, there is no other way to guarantee the continuity of the process.
  An example is the D7 crane, which has the function of loading the slabs into the Walking Beam preheating furnace directed to the rolling mill to be processed, in case of failure of the above mentioned machine, since there is no other crane with the same function, it has the consequence of blocking an entire production line.

For this reason, in case of an in line arrangement, I assigned to the coefficient the value of K_a = 0,75.

- **Coupled**: That is, the situation in which there are two redundant machines working in couple. Unlike the in-line arrangement, therefore, one station can be served by two different cranes and consequently a failure of the first does not completely compromise the functionality of the station, since the same operations can be performed by the second.

  An example of redundancy is that of the scrap yard, where the two cranes, R4 and R5, are installed, both of which have the function of loading scrap into the baskets.

  In the case of two machines working in pairs I have assigned the value K_a = 1.

  Nevertheless, it is important to make a consideration, since in some cases there are limits to be taken into account that may affect their redundancy. These may be limits of:

  - **Capacity:** The two cranes can have different capacity limits.
  - **Lifting tool:** They can be equipped with two specific lifting grippers for the required purpose, which, although interchangeable, are limiting in terms of the time needed to change the tool.

	In line	Coupled	[Ka]
C1	X		0,75
D3		X	1
D5	X		0,75
D6	X		0,75
D7	X		0,75
D8	X		0,75
D9		X	1
E1	X		0,75
F1		X	1
F4		X	1
F5	X		0,75
F6		X	1
F7		X	1
L2	X		0,75
L7	X		0,75
L9	X		0,75
L10	X		0,75
M1	X		0,75
P1 bis		X	1
P1		X	1
P2		X	1
P3		X	1
R3	X		0,75
R4		X	1
R5		X	1
S1	X		0,75

Table 8 Ka cranes values

4.3.4 Temperature coefficient [K_t]

The following coefficient considers the temperature and physical status of the steel being processed.

During the process the steel can be found in liquid or solid state, the latter in turn is differentiated according to the temperature in:

- Hot worked (> 250 °C)
- Cold worked (< 250 °C)

When handling steel at high temperatures, it is important to reduce to a minimum the travel times between one station and another in order to avoid temperature drops that could compromise the quality of the finished product. A breakdown of the crane, even if it is only a few minutes long, can have great economic consequences, other than safety ones.

For this reason, it is advisable to insert a coefficient that describes the priority of the bridge cranes according to the status of the transported steel. We can distinguish 3 cases

- **Liquid Steel** (> 1550 °C): This is the most critical situation, in fact, if the machine stops during the transport of the tapped ladle, it would compromise the entire casting, with great economic losses. K_t = 0.5.
- **Hot-worked Steel** (250÷1200 °C): These are high-temperature operations such as Quenching, Forging, Rolling, Hot Cutting and Hot/Super-Hot Charges. Even if small, a delay in the handling of the piece creates inconveniences to the production in terms of energy costs and quality reduction. K_t = 0.75.
- **Cold-worked Steel** (< 250 °C): These are low-temperature operations such as cold cutting, cold loading, storage and quality control. This is the case of minor criticality. K_t = 1.

	Liquid Steel	Hot-worked	Cold-worked	[Kt]
C1	X			0,5
D3			X	1
D5	X			0,5
D6			X	1
D7		X		0,75
D8		X		0,75
D9			X	1
E1			X	1
F1			X	1
F4			X	1
F5	X			0,5
F6			X	1
F7			X	1
L2		X		0,75
L7			X	1
L9			X	1
L10		X		0,75
M1			X	1
P1 bis			X	1
P1			X	1
P2			X	1
P3			X	1
R3			X	1
R4			X	1
R5			X	1
S1			X	1

Table 9 Kt cranes values

4.4 Risk Priority Number

Once the 6 coefficients have been defined for each crane, the criticality value RPN has been calculated as described above. The results are presented in Table 10.

Risk Priority Number								
	Technical Criticity [Ktec]			Operational Criticity [Kope]			RPN	
Cranes	Ku	Kw	Ks	Kp	Ka	Kt		
C1	1	0,5	0,5	0,5	0,75	0,5	0,05	High
D5	1	0,5	0,75	0,5	0,75	0,5	0,07	
R3	1	0,5	0,5	0,5	0,75	1	0,09	
F5	1	0,5	0,75	0,75	0,75	0,5	0,11	
L2	1	0,5	0,75	0,5	0,75	0,75	0,11	
D8	1	0,75	0,75	0,5	0,75	0,75	0,2	
R4	0,5	0,75	1	0,75	1	1	0,28	Medium
R5	0,5	0,75	1	0,75	1	1	0,28	
D9	0,5	0,75	1	0,75	1	1	0,28	
F1	0,5	0,75	1	0,75	1	1	0,28	
D7	1	0,75	1	0,75	0,75	0,75	0,32	
D3	0,5	0,75	1	1	1	1	0,38	
F4	0,5	0,75	1	1	1	1	0,38	
E1	1	0,75	1	0,75	0,75	1	0,42	
L10	1	1	1	0,75	0,75	0,75	0,42	
D6	1	1	1	1	0,75	1	0,75	Low
L7	1	1	1	1	0,75	1	0,75	
L9	1	1	1	1	0,75	1	0,75	
M1	1	1	1	1	0,75	1	0,75	
P1 bis	1	0,75	1	1	1	1	0,75	
P1	1	0,75	1	1	1	1	0,75	
P2	1	0,75	1	1	1	1	0,75	
S1	1	0,75	1	1	1	1	0,75	
F6	1	1	1	1	1	1	1	
F7	1	1	1	1	1	1	1	
P3	1	1	1	1	1	1	1	

Table 10 RPN cranes values

In collaboration with the Maintenance Manager, it was decided to evaluate as highly critical the bridge cranes with an RPN value of less than 0.2, medium criticality those with a value between 0.2 and 0.5, and finally of low criticality those with a value higher than 0.5.

RPN	**< 0.2**	High Criticity
	0.2 ÷ 0.5	Medium Criticity
	> 0.5	Low Criticity

Figure 26 RPN Criticality classification

In conclusion, the previous analysis revealed 6 cranes, **C1-D5-R3-F5-L2-D8**, to be considered highly critical for production and on which in the next chapter, having the real downtime data, we will analyse in more detail, evaluating their efficiency.

5 CRANE’S DOWNTIME ANALYSIS

5.1 Introduction:

This chapter is dedicated to the analysis of company data relating to the downtime of bridge-cranes. After having introduced the database used to collect information, and some useful premises for a better understanding of the topics presented, such as the concepts of availability of the machine and the Performance Indicators adopted, the first step was to analyse the general performance of the plant's cranes. This allowed to compare the semester under analysis with the situation of the previous year, and to set targets for 2020.

Afterwards, using Pareto as an analysis tool, the actual Downtime Analysis was carried out, which was divided into two parts. While the first analysis focused only on downtime considered as critical, in order to identify the cranes and breakdowns that most affected production shutdowns, the second focused instead on all recorded downtime, thus making it possible to identify which components of the cranes, of the entire plant, have stored a greater number of minutes of downtime, and on which in the next chapter we will go into more detail.

5.2 Data gathering

In order to realize a Downtime Analysis that could further and more accurately describe the company actual situation of NLMK Verona S.p.A., the data relating to the first semester of 2019 (01/01/2019 to 30/06/2019) were analysed.

The data below concerning the 26 bridge-cranes of the company have been collected with the help of the Maintenance Manager, through the reports of the shift supervisors of the respective departments, who daily report any malfunctioning of the machine to the Maintenance & Technical Office by means of an official report. They were subsequently included in an Excel Database in order to obtain a continuous monitoring of the downtime trend.

In the Database, for each registered machine stop, is specified:

- ❖ The identification of the crane on which you have intervened.
- ❖ The date of intervention.

- ❖ The nature of the fault, whether of Mechanical or Electrical origin, and whether of Maintenance or Operational type.
- ❖ Description of the fault.
- ❖ Component of the fault involved.
- ❖ Duration of the machine stop expressed in minutes.
- ❖ Impact of the fault on production, i.e. whether the fault had repercussions on the plant causing a production stop or not.

An example of the Database is shown in Fig. 27

ID CP	Date	Failure description	Downtime [min]	Plant Shutdown	Component	Mec/Ele	Man/ODF
R5	07/04/2019	Cavo elettrico del magnete danneggiato; allungato cavo e sostituituzione della molla cavo.	180	NO	Magnet cable	Ele	Odf
R4	09/04/2019	Ragno con perno pistone rotto causa urto, eseguita sostituzione.	90	NO	Lifting claw	Mec	Odf
L10	14/04/2019	Argano noon va in discesa, riscontrato teleruttore con bobina bruciata, eseguita sostituzione.	60	SI	Contactor	Ele	Man
F1	15/04/2019	Registrazione del freno del sollevamento principale.	60	NO	Mechanical brake	Mec	Man

Figure 27 Database example

For each of the six months analysed, a summary table was created, as shown in Fig. 28, in which the total number of monthly minutes of downtime of the plant's cranes is indicated, specifying how many directly affected production, causing it to stop, and how many, despite the standstill, had no effect on the plant.

APRIL	From 01/04/19 To 30/04/19
Total monthly stop	1980
With production shutdown	180
Without production shutdown	1800

Figure 28 Monthly recap

Before proceeding with the following analysis, in order to clarify the situation of plant shutdown, it is necessary to make a couple of observations.

When studying handling equipment such as cranes, it is important to consider that, although they are not real production equipment, as they are limited to moving products between substations, a failure directly involves production. Especially in a steel plant because of the weights handled.

For this reason, the bridge crane is seen as an auxiliary production unit. The EAF furnace, for example, is closely dependent on the already mentioned R3, as it is responsible for loading scrap. Its operation, and consequently that of the Steel Mill Dept., depends on the availability of the crane to perform its task.

5.2.1 Availability

The UNI EN 13306 standard defines availability (A) as "the ability of an entity to be able to perform a required function, under certain conditions, at a particular time or interval of time".

It is calculated as the percentage ratio between the total time of availability and the total time of operation given by the periods of availability and unavailability.

It therefore expresses a percentage of the entity's actual operating time compared to a total requested service time.

In the specific case of cranes (or all handling equipment in general), as these are production support machines, their total time of availability must be the same as that of the department to which they belong. Therefore, in line with the previous example, the total availability of the R3 crane must be equal to the scheduled operating time of the Steel Mill Department, it is currently said that the crane is in an "operational status".

Nevertheless, an overhead crane, although available, can remain unused in a standstill state, ready to enter into operation in case of need, it is then said that the machine is in a "stand-by status".

If, on the other hand, its availability is not required, it is defined as "state of potential availability/unavailability".

The following scheme, represented in Fig. 29, summarizes what has just been said about the states of an entity of availability and unavailability with respect to the required time of operation.

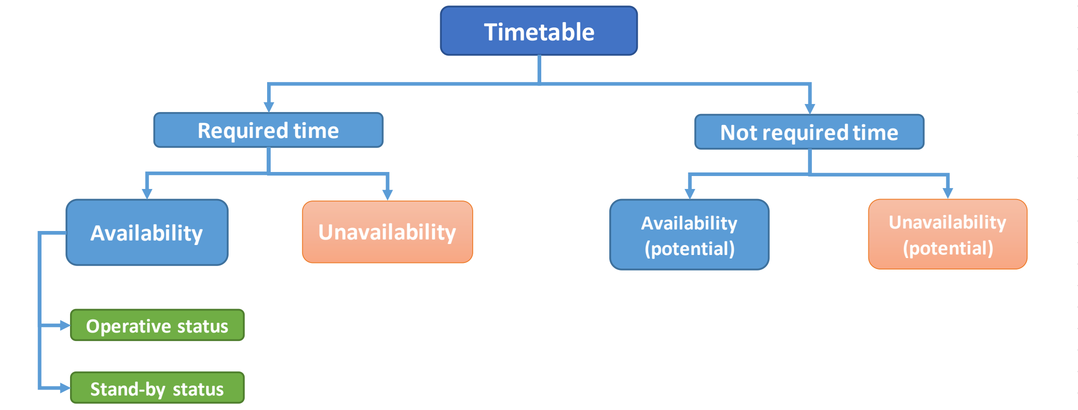


Figure 29 Availability/Unavailability scheme

The concept of availability becomes essential in order to understand when downtime due to a failure of the crane has a direct consequence on production.

In fact, if the fault occurs during the operating state of the overhead crane, its stoppage also involves the shutdown of the department concerned, while if it occurs during the stand-by state, the stoppage does not have immediate effects on production.

Ordinary maintenance operations are performed, after agreement with the Production Department, when the availability of the crane is not required.

5.2.2 Key Performance Index choice

Performance Indicators (PI) are used to measure the performance of any system or process. A PI is a product of several measures (metrics). When used to measure maintenance performance in an area or activity, it is called a Maintenance Performance Indicator (MPI).

PI's are used to find ways to reduce downtime, costs and waste, operate more efficiently, and increase the operation's capacity. A PI compares actual conditions with a specific set of reference conditions (requirements), measuring the distance between the current situation and the desired situation (target), the so-called 'distance to target' assessment.

Based on the literature, the commonly used Maintenance Performance Indicators fall into two major categories. The maintenance process indicators are defined as leading indicators and the maintenance results indicators as lagging indicators (as shown in Fig. 30).

Leading indicators monitor whether the tasks being performed will lead to the expected output (e.g. if the planning took place or if the scheduled work was completed on time). Under maintenance process indicators, there are three categories of indicators:

- ❖ Work Identification
- ❖ Work planning and scheduling
- ❖ Work execution indicators.

While **lagging indicators** monitor the results or outcomes that have been achieved (e.g. the number of equipment failures and downtimes). For maintenance results, there are three categories of indicators:

- ❖ Equipment performance
- ❖ Maintenance costs
- ❖ Safety and environment indicators.

Each category has its own performance indicators, as shown below.

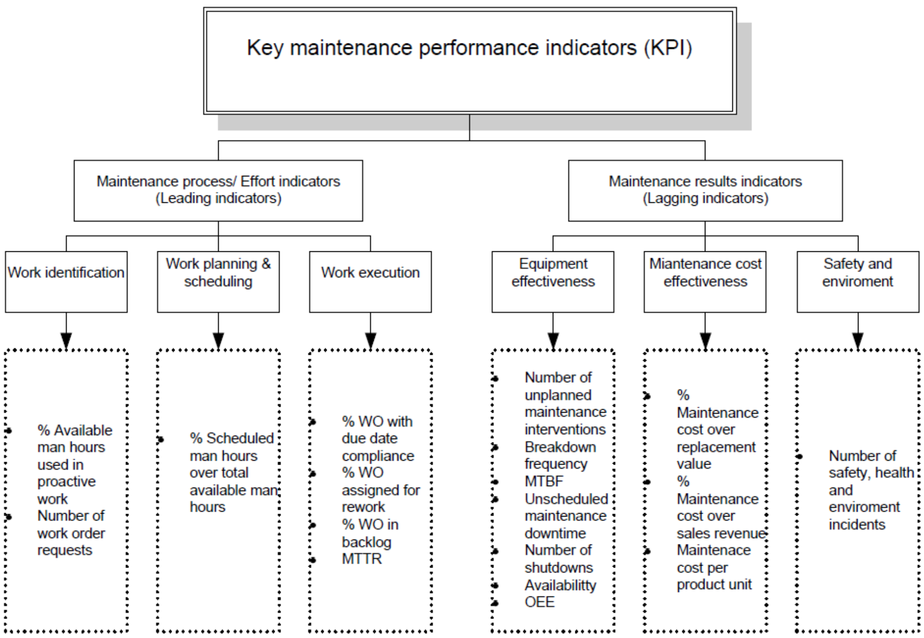


Figure 30 Key Maintenance Performance Indicators

In the analysis that follows in this chapter, it was decided to use the maintenance results indicators (Lagging) as the Performance Indexes of the plant's cranes. In particular, it was decided to use two PI inside the Equipment effectiveness category.

- **Unscheduled Maintenance Downtime**: Which is the length, in terms of minutes, of the unscheduled downtime of a bridge-crane, due to a breakdown, initially distinguishing when the breakdown stopped production and when it did not.
- **Unplanned Maintenance Intervention**: That is, how many times the Maintenance had to intervene to restore the operating state of a crane in failure due to the same type of malfunction.

While the first index gives an idea of the amount of downtime in terms of duration, the second gives information on its frequency, i.e. whether it is an isolated case or one repeated several times in a period of time.

5.3 Overall semester downtime trend

Once the data relating to the downtimes of the cranes had been collected, as a first step, the general situation of the machines in the months from January to June 2019 was examined, with the aim of assessing the overall trend of machinery stoppages during the first half of the 2019, comparing it with the situation related to the previous year 2018.

In the graph in Fig. 31, the grey line represents the trend of the total downtime minutes of the 26 company's cranes during the six months taken into examination. The dotted grey and red lines instead, represent the monthly average downtime of 2019 and 2018 respectively.

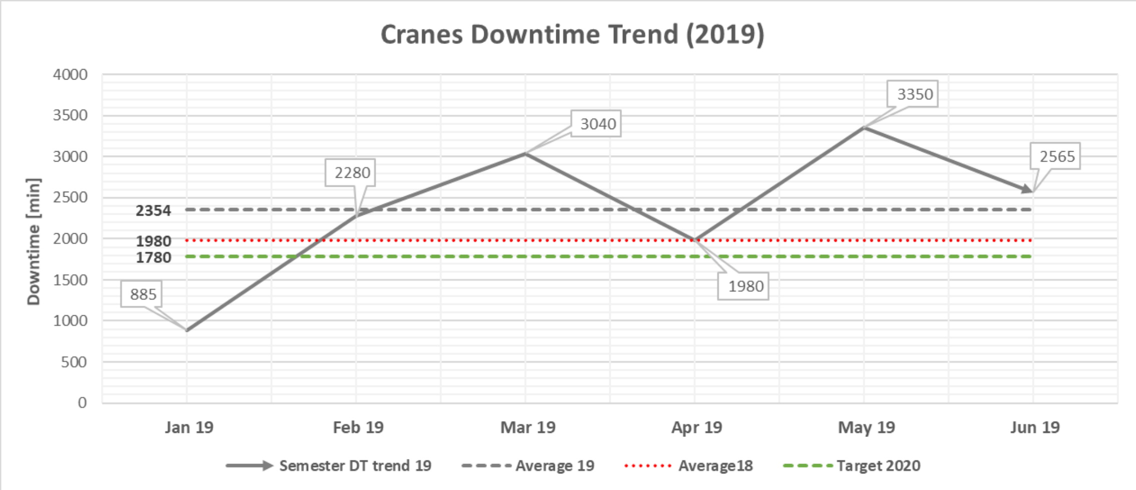


Figure 31 Semester Cranes Downtime Trend

During the first semester of the current year, a total of **14100 minutes** of downtime was recorded. The graph shows that the DTs have two peaks, the first in March (3040 min) and the second in May (3350 min).

In addition, the monthly DT average in the six-month period under analysis is about 16% higher than the average in 2018.

This data needs some clarifications, in fact, although the difference in the monthly averages between the current year and the previous one represents a warning sign, it should be pointed out that the average for the year 2018 has been calculated taking into account the months of August and December, months in which NLMK Verona shuts down the plant to carry out extraordinary maintenance activities. It is then presumable that the average for the year 2019 may be close to that of 2018 by the end of the year.

It was decided, in agreement with the Maintenance Manager and the Company Executive Board, to set a target for 2020 (represented by the green dotted line) of a monthly average downtime 10% lower than the 2018 average.

The previous graph shows the global minutes of machine downtime without, however, distinguishing between DT with production shutdown and DT without production shutdown.

In the histogram in Fig. 32, minutes of stoppage are therefore divided between those that caused the department stop (represented by the columns in red) and those that stopped the crane without having direct repercussions on the production (represented by the columns in blue).

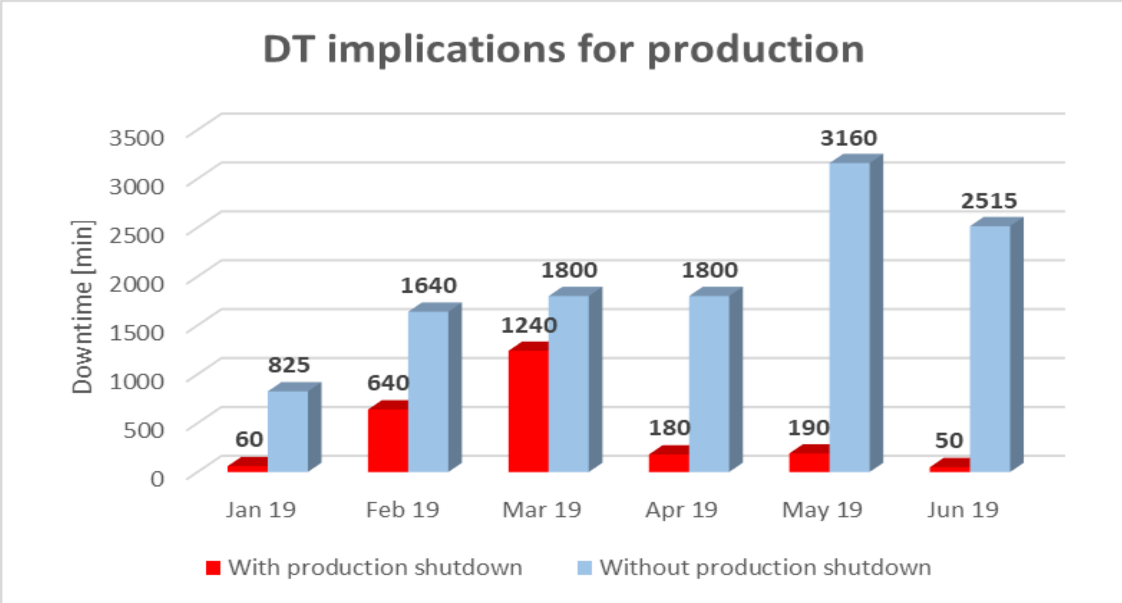


Figure 32 Downtimes impact on production

Between January and June 2019, the minutes of breakdown of the bridge-cranes that led to production stoppages amounted to a total of 2360 (out of a total of 14100 minutes), with a significant increase between February and March.

In particular, the maximum peak was reported in March, where there were 1240 downtime minutes, mainly due to a fault that affected the C1 crane and that will be detailed in the analysis below. In the remaining months, the minutes of plant downtime were contained between 50 and 190 minutes.

The above graphs represent the general trend of the downtime minutes of the cranes, without assessing which departments have been most affected by them. The histogram in Fig. 33 has to show which, of the three departments, is the one that has accumulated the greatest number of minutes of downtime of the lifting equipment.

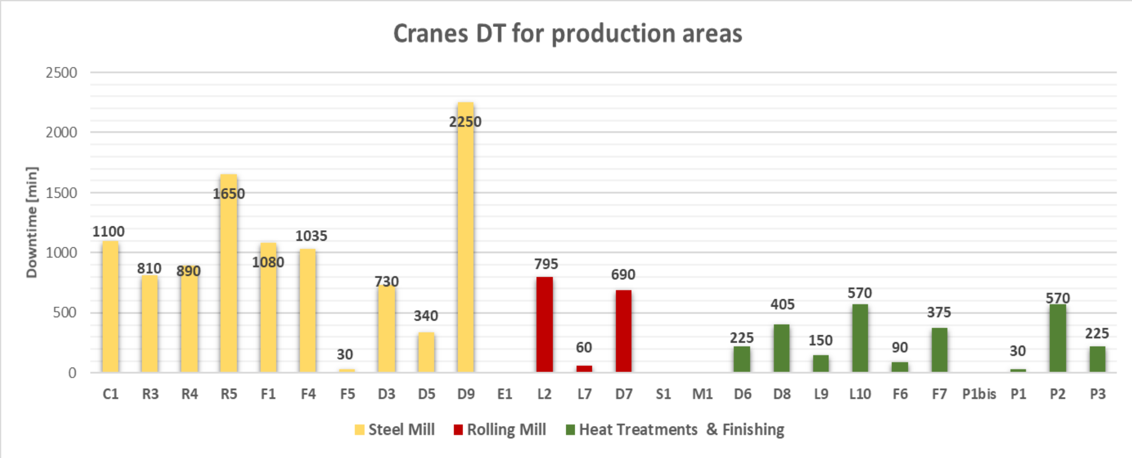


Figure 33 Downtimes distribution between departments

In the graph above, the cranes have been subdivided by department: The Steel Mill cranes are coloured in yellow, the Rolling Mill cranes in red and the Heat Treatments & Finishing in green. In this way it is possible to notice, in addition to the most severe department, which are the bridge-cranes with the highest amount of total DT minutes.

It is clear that the cranes in the Steel Mill are those with the maximum minutes of stops. It should also be added that this is also the department with the largest number of cranes.

The pie chart in Fig.34 therefore shows the number of DT minutes per department, divided by the respective number of cranes (11 for the Steel Mill, 5 for the Rolling Mill and 10 for Heat Treatments).

As a result, the steelmaking department accounted in percentage up to 63% of total downtime, compared to 15% for Heat Treatments and 22% for the Rolling Mill.

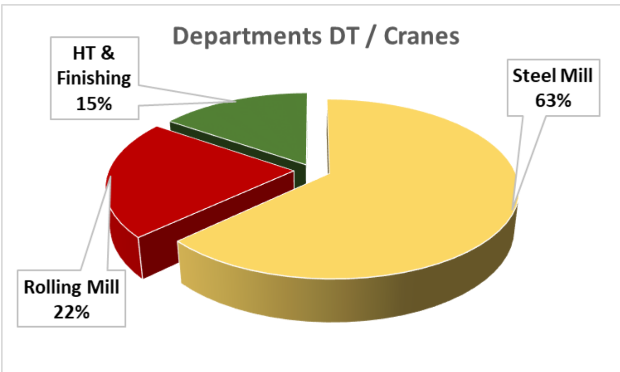


Figure 34 DT percentage per department

These results are attributable to the fact that the operating conditions of the overhead cranes belonging to the steelworks department are the most severe, as discussed in the previous chapter.

In fact, it can be seen from the graph in Fig.37 that among the cranes with the highest number of DT, can be found:

- The pit cranes (D3 D9 F1 and F4) and those of the scrap yard (R4 and R5) which present a very high level of criticality mainly due to their usage coefficient (K_u = 0,5).
- The R3 and C1 cranes, which work under the worst operating environment of the entire plant (K_w = 0,5).

5.4 Failure analysis

As the bridge-crane is a complex system, a failure can affect a large number of components between the bridge, the trolley and the hoisting mechanisms. Moreover, the breakdowns of the overhead crane, especially in the steel industry due to the operating conditions, are mainly of random nature and therefore difficult to predict deterministically.

During the months under analysis, a total of 151 malfunctions were found, each affecting a component of the machine.

Therefore, before analysing in more detail the mechanisms and causes of the failure, it was necessary to identify and standardise all the elements considered critical for the machine, which during the six months of analysis were subject to a malfunction. This standardisation has made it possible to identify, during downtime analysis, which types of components have had the greatest impact on the downtime of cranes with the associated failure modes, the analysis of which, in terms of frequency and causes of failure, will concern the next chapter.

Among the 151 data collected, 21 critical components were identified as responsible for the malfunctions, which are listed below.

1. **Anti-collision Lasers** sensors of the bridge translation.
2. **Busbars** house protection for electric distribution.
3. **Lifting Cables** of hoisting mechanisms.
4. The **Lifting Claw** tool of the scrap yard crane.

5. **Contactor** switches for electrical power circuits.
6. Positioning **Electro Limit Switches** for translation mechanisms.
7. **Electromagnetic Brakes** of bridge and trolley translation motors.
8. **Electric Motors**
9. Translation **Gearboxes**
10. **Hydraulic Control Unit** for principal lifting emergency brakes
11. **Inverters** electronic devices
12. Hoisting **Load Cells** devices
13. **Mechanical Brakes** of hoisting mechanism
14. Lifting **Magnets tool**
15. Hoist **Over-travelling Limiters**
16. **Pulleys**
17. **Remote Controllers**
18. **Relays** switches
19. **Transmission joints** of bridge translation
20. **Electric Failures**
21. **Mechanical Failures**

Mechanical and electrical failures consist of a category of generic failures of mechanical or electrical nature relating to parts that are difficult to associate with a specific component, such as, for example, the failure of a tensioning spring or the short-circuit of a battery during a start-up of the machine.

5.4.1 Failure classification

Faults can be considered in different ways and classified accordingly. Among the various modes of classification, it was decided to evaluate them:

- ❖ Depending on the nature of the fault, i.e. whether it is related to a problem that required mechanical or electrical maintenance. It was found that 66% of the total failures are related to an electrical problem, while the remaining 34% are due to a mechanical problem.
- ❖ Depending on the frequency of occurrence of faults, given by the number of Unplanned Maintenance Interventions, they can be classified as occasional or recurring faults.
- ❖ Lastly, if the cause of the failure is due to an incorrect use of the equipment by the crane operator, commonly known as the operative failure, or maintenance, if due to other factors such as under-maintenance, normal

decay of the component in question or other external causes. A clear example of an operational failure is the damage to the lifting cable caused by the slippage during an incorrect manoeuvre (oblique pull), on the contrary a leak of oil in the gearbox is classified as a maintenance failure.

From a first analysis, the inefficiency of the cranes due to operational failures is considerably high, as can be seen from the graph shown in Fig.35.

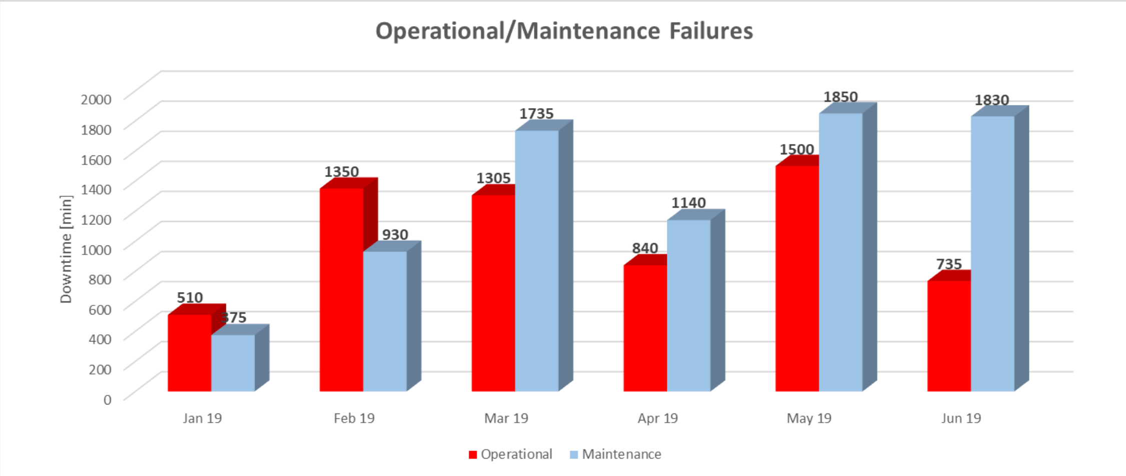


Figure 35 Operative-Maintenance failures histogram

5.5 Downtime Analysis

In the following paragraph the data collected during the analysis will be interpreted, with the aim of classifying in order of importance which are the cranes and their components that have mostly influenced the availability and efficiency of the NLMK Verona plant.

In order to do this, one of the most widely used technique in the classification will be adopted, i.e. the Pareto Analysis, which allows me to visualize:

- The incidence by category
- The cumulative percentage growth curve.

This analysis tool makes is a useful tool and consists of a histogram of the percentage distribution of a phenomenon, ordered in descending order, coupled with the graph of cumulative percentages.

It is thus possible to identify the main causes that need to be addressed in order to solve most of the problems and thus improve the planning of both the interventions to be carried out and the human and technical resources to be employed. In practice, these techniques make it possible to identify on which areas to focus the interventions in order to obtain the maximum in terms of benefits achieved. It is common, in fact, to refer to Pareto as a rule of 80/20, in the assumption that, in all situations, 20% of the causes determine 80% of the problems.

Two separate Pareto analyses were then carried out:

1. **Critical Downtime Analysis**
   In the first analysis were taken into account the data relating to the Downtime considered most critical, as they led to the shutdown of production, with its already mentioned implications. The Pareto analysis will then first identify the bridge cranes most involved and then the main components responsible for the downtimes.
2. **Overall Downtime Analysis**
   In the second analysis, instead, all the collected data will be analysed, with and without production stops, in order to have an overview of the major problems of all the 26 cranes of NLMK Verona. Once the main critical causes of DT have been identified, will concentrate more on the search for practical solutions.

5.5.1 Critical Downtime Analysis

During the months from January to June 2019, due to the breakdowns of the lifting equipment, a production shutdown was detected with a total duration of **2360 minutes**, spread between the 3 departments of the plant in the following measure:

- **1410** minutes in the Steel Mill Department, distributed among 5 different bridge cranes (R3, R5, C1, D5 and D9)
- **660** minutes in the Rolling Mill Department, distributed between two bridge cranes (L2 and D7).
- **290** minutes in the Heat Treatments and Finishing Department, also distributed between 2 bridge cranes (L10 and D8).

The production stoppage was therefore caused by a failure of the above cranes during the scheduled operation time of the EAF furnace for the steelmaking department, the press and rolling mill for the rolling department, and the heating furnaces for the heat treatment department.

In the first part of the analysis, it is thus possible to identify the cranes that during the semester have accumulated a greater number of minutes of delay in the manufacturing facilities.

The collected data are initially displayed in the spreadsheet below, with the respective cumulated percentage of each crane, and then graphically in Fig. 36.

Critical Downtime Analysis - Cranes				
CRANE	**DT[min]**	**Dept.**	**%**	**CUMULATIVE**
C1	830	Steelmill	35,2%	35,2%
L2	360	Rollingmill	15,3%	50,4%
D7	300	Rollingmill	12,7%	63,1%
R3	270	Steelmill	11,4%	74,6%
D5	250	Steelmill	10,6%	85,2%
D8	180	Heat Treat.	7,6%	92,8%
L10	110	Heat Treat.	4,7%	97,5%
D9	30	Steelmill	1,3%	98,7%
R5	30	Steelmill	1,3%	100,0%

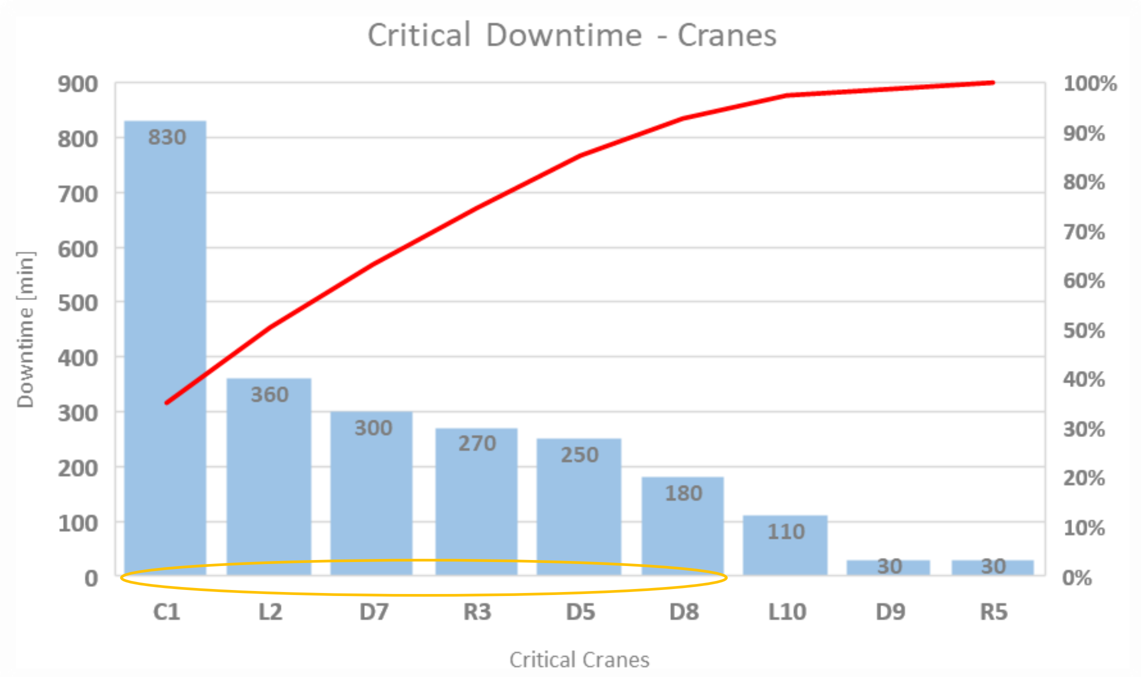


Figure 36 Pareto Critical Downtime Analysis-(Cranes)

This first analysis shows that the first group (circled in yellow) consisting of 6 bridge cranes is responsible for more than 90% of total production downtime, while the other 3 for the remaining 10%.

Among the cranes of the first group 5 out of 6, i.e. C1 L2 R3 D5 and D8, are exactly those classified as highly critical in the plant's criticality analysis of the previous chapter, while the remaining cranes, i.e. D7 L10 D9 and R5, were assigned a medium criticality value.

This graph therefore confirms that the cranes considered as critical are, to all intents and purposes, the most responsible for the inefficiency of the departments and that with the same number of downtime of low criticality cranes, the probability of stopping production directly is greater. Moreover, there is no crane considered to be of negligible criticality in the above mentioned graph.

The second part of the analysis will instead focus on the failures of these overhead cranes to assess their impact on machine downtime, so as to identify the components whose repair has had the longest duration.

As before, the data relating to the causes of failure are initially displayed in a spreadsheet, in which cranes that have suffered a certain failure are also specified, and then graphically in Fig. 37.

Critical Downtime Analysis - Failures				
Failure	**DT[min]**	**Crane involved**	**%**	**CUMULATIVE**
Hydraulic Control Unit	800	C1	33,9%	33,9%
Lifting Cables	540	L2-D7	22,9%	56,8%
Electro Limit Switch	180	R3	7,6%	64,4%
Mechanical Failure	180	D8	7,6%	72,0%
Relay	160	D5	6,8%	78,8%
Anti-collision Laser	120	D7	5,1%	83,9%
Electrical Failure	90	R3	3,8%	87,7%
Pulley	90	D5	3,8%	91,5%
Inverter	80	C1-L10	3,4%	94,9%
Contactor	60	L10	2,5%	97,5%
Magnet Cable	30	R5	1,3%	98,7%
Transmission Joint	30	D9	1,3%	100,0%

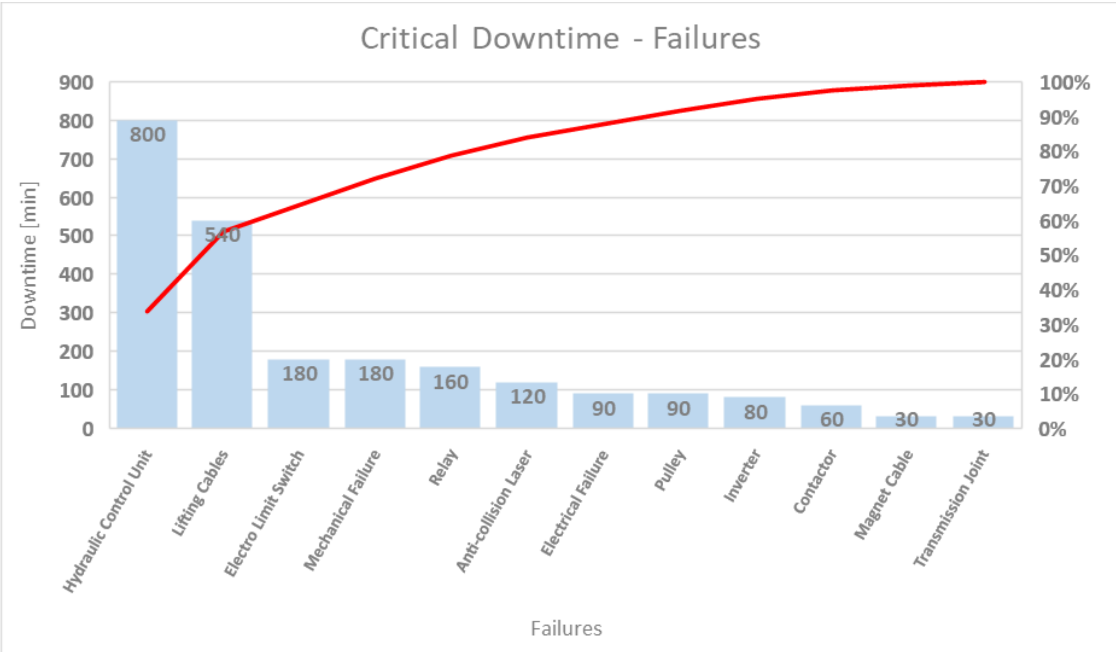


Figure 37 Pareto Critical Downtime Analysis-(Failures)

According to Pareto analysis the DT causes have been divided in two different groups of components:

- **Group 1**, composed of the first 5 components, responsible for 80% of the total downtime, on which a more in-depth analysis and a greater concentration of efforts aimed at the solution will be necessary.
- **Group 2,** composed of the remaining 7 components, to which 20% of the DT is attributed.

5.5.2 Overall Downtime Analysis

While in the previous analysis the data related to the most critical case were analysed, in the following analysis all the data collected will be taken into account in order to have an overview of the situation of all the cranes of the plant.

In fact, it would not be convenient to exclude from our analysis and research of corrective solutions those cranes considered to be of low or even medium criticality, since even a failure of them, as well as representing a danger in terms of safety, if extended can lead to numerous inconveniences for production. Moreover, it would be limiting, in view of the final objective of my Thesis, which is to reduce the overall downtime of the cranes of the whole NLMK Verona plant.

As a result, the critical components identified in the previous failure analysis were analysed to determine which caused the highest number of DTs among all the 26 bridge cranes. The following table shows the spreadsheets relating to the data developed for the current analyses, while Fig. 38 shows the Pareto graph.

Critical Downtime Analysis - Failures			
Failure	DT[min]	%	CUMULATIVE
Magnet	1755	12,4%	12,4%
Transmission joint	1635	11,6%	24,0%
Lifting Cables	1560	11,0%	35,0%
Inverter	1510	10,7%	45,7%
Hydraulic Control Unit	950	6,7%	52,5%
Electro Limit Switch	945	6,7%	59,2%
Electromagnetic Brake	660	4,7%	63,8%
Mechanical Brake	630	4,5%	68,3%
Over-travelling Limiter	570	4,0%	72,3%
Remote Control	495	3,5%	75,8%
Gearbox	495	3,5%	79,3%
Electrical Failure	450	3,2%	82,5%
Mechanical Failure	420	3,0%	85,5%
Load Cell	390	2,8%	88,2%
Electric Motor	330	2,3%	90,6%
Pulley	300	2,1%	92,7%
Anti-collision Laser	240	1,7%	94,4%
Relay	265	1,9%	96,3%
Lifting Claw	225	1,6%	97,9%
Contactor	180	1,3%	99,2%
Bus-bar	120	0,8%	100,0%

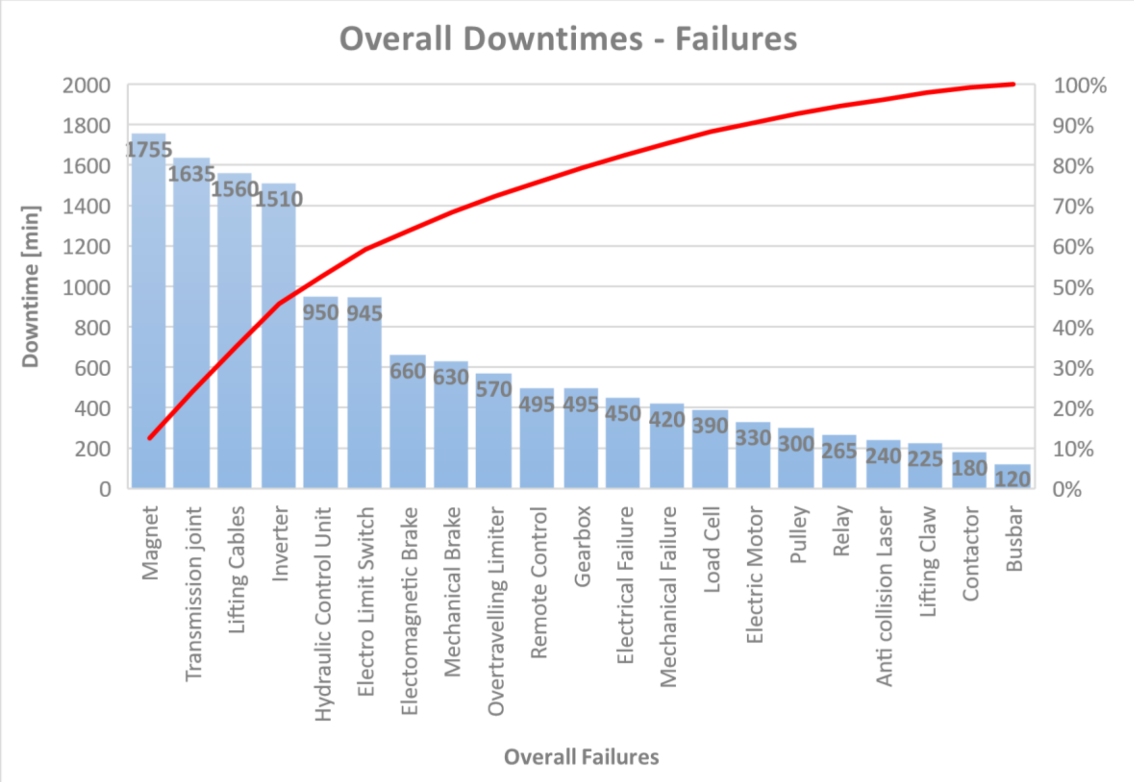


Figure 38 Pareto Overall Downtime Analysis

In conclusion, the analysis revealed 11 critical components responsible for more than 80% of the registered DT, divided between almost all the bridge-cranes of the plant. Among these, 3 components had already been determined as being at the top of the failures of critical cranes in the previous analysis (cumulative percentage of 64%). These are: The hydraulic control unit of the emergency brakes, the lifting cables and the positioning electric limit switches.

In the next chapter these components will be examined individually, analysing the failures in detail and identifying possible corrective solutions.

6 MAINTENANCE IMPLEMENTATION

6.1 Introduction

In the following final chapter, the 11 components highlighted as critical by the previous analysis will be examined in detail. These in fact are directly responsible for 80% of the downtime minutes of the 26 cranes, amounting to a total of 11205 minutes. Each component will then be studied individually in order of relevance, identifying the main mechanisms and failure modes, their frequency and duration, and finally which cranes they have affected.

The main purpose is to identify, if available, possible corrective solutions, both technical and organizational, useful to prevent and limit the occurrence of malfunctions that have most impacted on the cranes functionality.

Before moving on to the conclusions of the work, it should be made clear that the suggestions aimed at improving the activity of cranes that I have reached are not exclusively the result of my direct experience as an intern. The problems encountered and the solutions proposed are in fact the synthesis of a daily commitment made at the side of the engineers and maintainers of the plant, finally verified through a series of meetings with my Company Supervisor and the Maintenance Manager.

In order to facilitate the following search for solutions, to identify which factors have contributed most to the malfunctioning of the above mentioned components, the Ishikawa cause-and-effect diagram, shown in Fig. 39, has been used as a tool.

The causes or factors that can influence a production process and, in our case, cause the failure of a crane, are often organized into five macro groups (defined as the 5M model), which are:

- Man (Lack of training, Carelessness and Negligence)
- Machine (Old equipment, Design)
- Material (Out of standards, Material defects)
- Method (Process, Inventory, lack of cleanings/inspections)
- Environment (Dust, Temperatures and climate agents)

For each component, therefore, we evaluated which of the above macro-groups was the main cause of the malfunction, so as to identify the most appropriate corrective action.

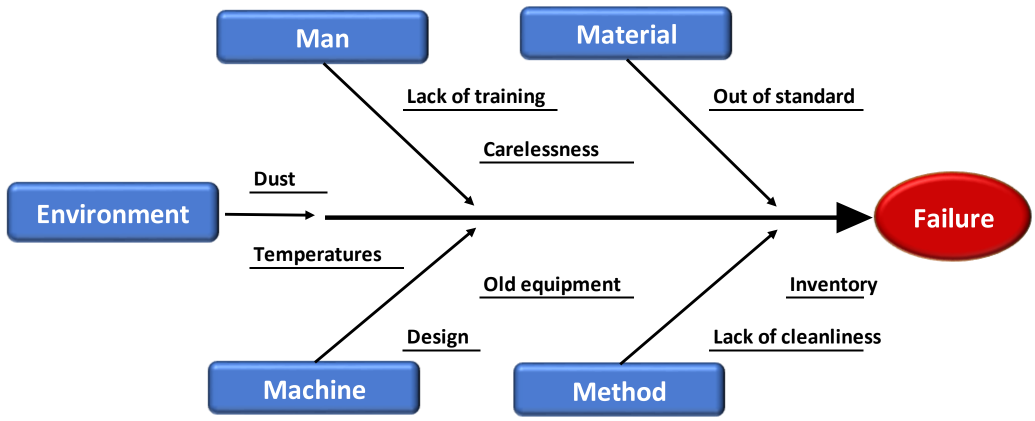


Figure 39 Ishikawa diagram

6.2 Corrective actions

The above components, presented in descending order of importance, are the following:

Lifting Magnets		
Collected DT: 1755 minutes	**N° of interventions:** 19	**Cranes involved:** D7, R4, R5, L9, L10

Magnets are among the most common lifting tool devices between the cranes of the plant, and are mainly used for loading scrap or handling hot and cold plates.

These being a ferrous core fitted with pole shoes at its extremity and an electro conductor winding (typically made of aluminium or copper) surrounding part of the core. The passage of direct current through the winding results in the magnet being energized.

In total, the magnets accumulated 1755 minutes of delay and the problems encountered were mainly two:

- **Overheating of the lifting magnets**
  Collected Downtime: 210 minutes

N° od failures: 5
Cranes involved: D7
Description: Loss of magneto-motive force caused by a critical overheating of the magnets in the D7 gantry crane. Reset and cooling down of the magnets is necessary.
Proposed solutions: The malfunction is due to the overheating of the magnets during the hot loading of the slabs, coming from the continuous casting, into the Walking Beam pre heating furnace, in which the slabs reach up to 400 °C. The problem may therefore be due to an incorrect charging sequence. The possible corrective actions identified are:

- Temperature monitoring with thermal camera in order to identify an optimal hot charge sequence for a batch of slabs and alternate hot charges with cold charges, in order to keep the temperature under control.
- Introduction of operational practice for cooling the magnets (30 minutes of stopping every 4 hours of use at high temperatures).
- Alternate the use of the operating magnet with the backup magnet when a prolonged hot charge is required.

❖ **Damaged magnet power supply cable**
Collected Downtime: 1545 minutes
N° of failures: 14
Cranes involved: R5 R4 L9 L10
Description: Damage or rupture of the power cable of the magnets. Repairs or replacements required. The damaged element is shown in Fig. 40

Figure 40 R5 Magnet power supply cable

This fault mainly affected the magnet of the R5 crane (11 out of 14 total cases), and is caused by an incorrect manoeuver by the operator during the loading operation of the scrap, where the cable is sheared by the scrap during the upward movement of the hoist.

Proposed solutions: This fault is only of an operational nature, although precautions such as tensioning springs and metal protection have already been taken. It is therefore recommended training courses for the crane operator or assistance with more experienced operator.

Transmission Joints		
Collected DT: **1635 minutes**	**N° of interventions:** 8	**Cranes involved:** D9

Description: This failure was an isolated case of the D9 crane, and affected the 4 transmission joints of the bridge translation gearboxes, which suffered 8 failures over the six months taken into account, for a total of more than 27 hours of downtime. Since the bridge crane is used for stripping operations, the joints of the translation mechanism are heavily stressed by dynamic loads.

Proposed solution: Given the unusual frequency of failures, an inspection was organised with the manufacturer's specialised technicians, who assessed the joints as undersized with respect to the loads handled, given the introduction of the 120-tons pit casting. The new joints were then ordered and replaced in August during the extraordinary maintenance.

Lifting Cables		
Collected DT: **1560 minutes**	**N° of interventions:** **8**	**Cranes involved:** General

Description: Damage to the cables of the lifting mechanisms is the third factor responsible for the majority of machine downtime. The main cause of the damage is due to the carelessness of the operators during the operations of ascending and descending the hoist during the handling of the weight, such as:

- **Extra-rotation pulling**, with consequent overlapping of the cables and intervention of the emergency limit switch. This limit switch has been adopted to avoid damage during lifting with overlapping ropes.
  Three cases were recorded for a total of 390 minutes of stoppage on the R4 crane, in which no one caused significant damage to the cables.
- **Oblique pulling**, which consists in lifting the load without keeping the rope plumb-lined with its pulley, as shown in Fig 41, if the angle of incidence is too high it can cause the rope to run off the pulley with consequent breakage of the stranded wires, signs of pinching and plastic deformation (if tethered).

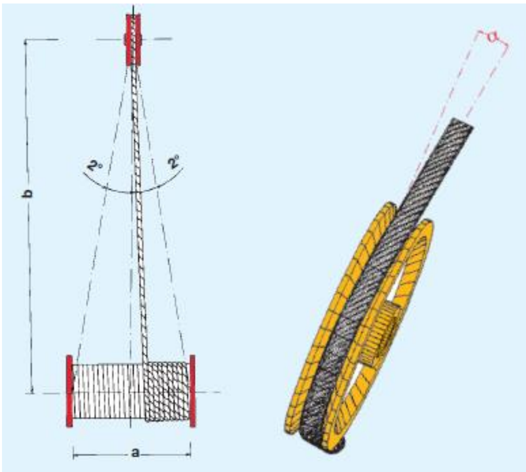


Figure 41Oblique pulling

Despite the anti-derailment systems, consisting of a metal plate placed above the pulleys of the block, there have been 5 cases of derailment by oblique pull, of which 4 have required the replacement of the cable because it had a considerable number of torn wires and signs of compression. The replacement interventions required a total stop of 1200 minutes of the cranes.

Proposed solutions: As in the previous case of the magnets, the causes are operative in nature, certainly aggravated by the temperatures and dusty environments in which the cranes work.

Inverters		
Collected DT: **1510 minutes**	**N° of interventions:** 14	**Cranes involved:** General

The inverters are electronic frequency converters whose function is to control the electric motors regulating the restarts and braking of the systems of translation of the bridge, trolley and lifting systems of the crane. The application of the electronic inverter guarantees a substantial lengthening of the life of the mechanical parts of the machine, a lower oscillation of the load and a lowering of the noise level of the machine.

These devices are installed in special electrical panels located on the bridge. Although it is recommended to apply the inverter outside the panel for better heat dissipation, this becomes impossible due to extreme operating conditions. For this reason, the electric cabinets are equipped with internal cooling systems, which is essential to reduce the operating temperatures.

Description: During the months under analysis, in the 14 recorded cases of malfunction, 6 inverter faults were found for a total of 1210 minutes of delay, 4 of which required the replacement of the entire electronic device.

The possible causes of the faults can be assumed to be deterioration due to excessive heat and dust deposits, which prevents the correct operation of the inverters.

These in turn can be attributed to a malfunction of the cooling unit of the air conditioner (poor cleaning of the filters, engine fan, lack of cooling gas), or a loosening of the clamps and contacts.

In addition, extreme temperatures in the long term result in a deterioration of the insulation characteristics of the electrical cables caused by continuous expansion and / or contraction that compromise the insulation.

Proposed solutions: Among the corrective solutions to be adopted have been identified:

- ❖ Implement general cleanliness. During the weekly inspections, insert the blowing operation of the dust accumulated with compressed air from the electrical panels (with disassembly of the front panel).

- ❖ Monthly check of the insulation status of the electrical cables using a megaohmmeter to reduce possible residual currents.
- ❖ Periodic check of cooling systems (air conditioners).
- ❖ Installation of temperature alarm into the electrical panels in the critical cranes as R3 C1 D5 and F5.
- ❖ Monitor the operating temperatures of the R3 overhead travelling crane by means of a thermal camera or thermos-sensitive tags, as it is frequently hit by flames and hot fumes during scrap loading.

The remaining 8 recorded interventions are due to the reset of the inverter alarms of the lifting devices, caused by a cable run-off due to an inaccurate adjustment of the mechanical brakes. The device, reading a delay in the braking signal, goes into alarm and requires a manual reset. However, the generated delay of 300 minutes is negligible.

Hydraulic Control Unit		
Collected DT: **950 minutes**	**N° of interventions:** 5	**Cranes involved:** C1

The failure of the hydraulic control unit, as well as the transmission joint of the D9 crane, was an isolated case that affected only the C1. Nevertheless, this failure is the one that has had the greatest impact on production, causing it to stop for 800 minutes out of a total downtime of 950.

Description: Five malfunctions were found within 20 days. These involved the hydraulic control unit for the emergency brake operation of the principal crane lifting mechanism. In particular, the main hoist did not perform the ascent because the control unit did not provide sufficient pressure to open the brake shoes of 110 bar. Non-return valve leakage and overheated oil were found. The first step was then to replace the valves and the oil. When the fault occurred again, the new hydraulic control unit was ordered and installed.

Proposed solutions: It should be noted that about 50% of the total downtime is due to the research for material, as there was no spare hydraulic control unit in the warehouse. The order of the spare part was then proceeded (as it was fundamental for the functioning of the machine).

Afterwards, two control units were installed in parallel, one operational and the other as spare, selectable by means of a key switch located in the electrical panel. Fire-resistant HFR oil has been adopted.

It is also advisable to check the operating temperatures of the C1 crane after the introduction of the 120-ton casting, since the workload induces a consequent increase in the local temperature of the components on the bridge of the C1 crane.

Electro Limit Switches		
Collected DT: **945 minutes**	**N° of interventions:** 12	**Cranes involved:** General

These are position limit switches for translation installed on the cranes which intervene directly on the electric motors of the machine through a PLC interface when the crane moves beyond the running limit. These are 4-position cross type, with deceleration and stop both forwards and backwards.

During the translation, when the bars of the limit switch on the bridge come into contact with the appropriate stopper installed on the stroke ways, they rotate switching the normally open contact of the limit switch and stopping the movement of the machine.

Many malfunctions in the limit switches were recorded, the main ones are described below:

- ❖ **R3**: Because of the limit switch, the R3 crane underwent 240 minutes of downtime, 180 of which caused the shutdown of the Steel Mill Department. In between January and April 5 malfunctions were recorded due to the fact that the cross of the trolley limit switch was blocked by the dust deposited on the railway, causing the machine to stop and making it necessary for maintainers to intervene in order to restore and adjust the limit switch.
  Proposed solutions: It should be noted that, since the R3 crane is continuously exposed to the fumes generated by the EAF furnace, it is difficult to completely eliminate the metallic dust deposited on the structure. However, it was considered appropriate to implement the total cleaning rounds of the overhead crane, bringing them to a bimonthly frequency (instead of quarterly) during which the entire structure is aspirated.

- **L2**: The L2 overhead crane was delayed for 435 minutes due to the operational failure of the anti-rotation limit switch on the block (due to a collision with the furnace door during ingot loading operations) and the trolley translation limit switch.
  Proposed solutions: A mechanical protection to be installed on the block is necessary to protect against impacts against the furnace's door. This protection must also act as a shield for the heat during the opening of the furnace, which reaches up to 1200°C.
- **D3 and F4**: Pit cranes stoppages are caused by the emergency limit switch stuck between the cables due to an incorrect manoeuvre of the operators (extra-rotation pulling).

Electromagnetic Brakes		
Collected DT: 660 minutes	**N° of interventions**: 10	**Cranes involved**: General

The electric motors of the cranes are equipped with electromagnetic brakes to ensure precise braking and minimum stopping times. These act in the absence of power, through the pressure applied by springs inside the system, activated magnetically.

In the absence of tension to the magnet, in fact, the effect of the magnetic field is null and a spring pushes against a pressure disk, crushing the brake disk between the pressure disk and the external fixed plate. This frictional clamping force is transferred to the hub, which is mounted on a shaft. In this way, the load can be braked and held in place safely even in the event of a loss of power.

Conversely, when the magnet coil is supplied with DC current, a magnetic field is then generated. The magnetic force, which overcomes the force of the preloaded spring, attracts the friction disk through the air gap towards the electromagnet, thus making the rotation of the shaft available. Fig. 42 shows a cross-section of the electromagnetic brake.

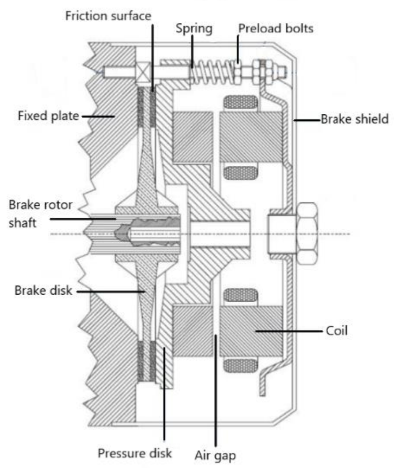


Figure 42 Electromagnetic brake cross-section

The electromagnetic brakes are equipped with a thermal protection of the windings and consists of a bi-metal thermal contact, normally closed. If an overload causes the coil windings to overheat, the thermal contact opens at a certain temperature (standard 130°C) and interrupts the current.

Description: The recorded malfunctions to the electromagnetic brakes are attributable to the extreme temperature conditions in which they work, which cause them to overheat. In the months under analysis, 10 thermal protection interventions were recorded, 5 of which required the replacement of the brake, as they showed damage to the coils, for a total of 510 minutes of downtime.

The possible cause of the coil damages, in addition to the wear of the electrical components caused by dust, is attributed to mechanical interference during normal brake operation between the coil windings and the ferrule of the pressure disk. In the Fig. 43 you can see the winding wires damaged by the contact.

Figure 43 Damaged coil windings

Proposed solutions: This problem is due to oversized winding made during the external overhaul of the brakes, which reduces the backlash on the cone of the pressure disk that leads to contact and consequently to failure (red arrow). This is also amplified by the high operating temperatures, as the thermal expansion of the internal components further reduces the aforementioned backlash and by the accumulation of dust inside.

Some precautions have therefore been identified to extend the useful life of the electro-brakes. These include:

- ❖ Before replacing the brake, check the winding tolerances and air gap adjustment to 0.8 mm. The adjustment can be done by acting on the spring preload or on the air gap by means of a thickness gauging device. Check that the tolerances are maintained during each inspection.
- ❖ Check brakes during inspections with cleaning and blowing operations of the same every fourth week of the month. In addition, cleaning with disassembly of the brake kit components during scheduled extraordinary maintenance activities.
- ❖ Check the absorption of the windings with recording of the value on the inspection board each time the electromagnetic brake is replaced, 0.8-1.1A to specification.

Mechanical Brakes (Brake blocks)		
Collected DT: **630 minutes**	**N° of interventions:** 12	**Cranes involved:** General

The braking of the lifting mechanism is guaranteed by means of an electro-hydraulic brake blocks in which the blocks act directly on the brake drum attached to the axis of the lifting gearbox. These brakes are equipped with a backlash recovery system, i.e. it provides for each operation to decrease the backlash between the brake blocks and the surface of the brake drum, thus compensating for the reduction in friction pad thickness.

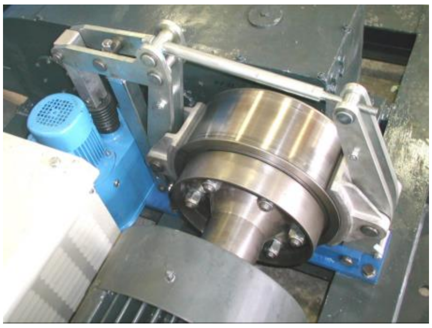


Figure 44 Electro-hydraulic lifting brakes

Description: The 12 recorded stops, totalling 630 minutes, were due to interventions to adjust the backlash of the brake blocks, caused by the regular consumption of the pads. Although the brakes are equipped with automatic backlash recovery, when they reach a threshold value they require either manual adjustment or replacement of the brake blocks. Excessive consumption or incorrect adjustment of the brakes of lifting systems can cause a slight delay in braking, this delay when read by the inverters can cause them to block, by sending them into alarm.

Proposed solution: The problem described above is attributed to the regular consumption of the brakes and as such does not present solutions.

Over-travelling Limiter + Remote Control		
Collected DT: **1065 minutes**	**N° of interventions**: 23	**Cranes involved:** General

It has been decided for convenience to deal with the over-travelling limiter and the remote control together as the nature of the fault is the same. The first is a mechanical limit switch installed on the lifting systems that intervenes in the event of a limit ascent of the hoist, while the second is the electronic device used by operators to manoeuvre the bridge-crane.

The 23 total faults are classified as operational and can be attributed to the carelessness of the operators in manoeuvring the cranes, either by causing the over-travelling limiter to intervene, with the consequent reparation, or by damaging the remote control. The sum of the downtime caused by these two problems amounts to 1065 minutes (570 by the over-travelling limiter and 496 by the remote control).

Gearboxes		
Collected DT: **495 minutes**	**N° of interventions:** 4	**Cranes involved:** D9, F4

Among the cranes that have had problems with the gearboxes are the D9 and F4 pit cranes, which, as seen previously, are among the most dynamically stressed. 495 minutes of downtime are considered an excellent result considering the severe conditions in which they operate.

In the D9, was replaced a translation gearbox of the trolley damaged during the 120-ton casting due to a slippage during stripping. In addition, some oil leaks of the bridge and hoist gearboxes were identified. In F4 instead a bridge translation gearbox was replaced.

In order to prevent oil leakages, it was decided to mount Viton double lip oil seals, these are made of fluorocarbon rubber and resist to temperatures up to 200°C.

6.3 Conclusion

In conclusion, it can be stated that the main factors that causes the failures of the components listed above, which are also responsible for about 80% of the downtime of the 26 bridge-cranes in the plant, are mainly:

- **Environmental**
  The severe conditions in which the cranes work, i.e. high process temperatures and metal powders, are the cause of a large part of the mechanical and electrical failures, in particular of the cranes identified as critical. For this reason, it becomes advisable:
    - To increase the level of general cleanliness, with particular attention to the Steel Mill Department, implementing the frequency of cleaning shifts in line with an appropriate economic balance.
    - To monitor the operating temperatures on the bridge of the cranes mostly exposed to heat sources, such as R3 C1 D5 F5 L2 D8, especially during the casting of the 120-ton format.

- **<u>Warehouse</u>**

  Taking into consideration the case of the failure of the hydraulic control unit of the C1 crane, which is responsible for the 34% of the minutes of production downtime, it emerged that most of the repair time was spent on the research of the spare material not in the warehouse.
  It becomes necessary to review and analyse the minimum stocks of spare parts classified as essential for the functioning of the machine.

- **<u>Operational Failures</u>**

  A worrying fact that emerged from this analysis is the percentage of operational failures due to improper use of equipment by the crane operators or incorrect manoeuvring during the handling of loads.
  In fact, as can be seen from the pie chart in Fig. 45, of these 11205 minutes of total delay caused by the 11 components highlighted, almost half (5280 minutes) were attributed to carelessness on the part of the operators, and concerned principally the magnets, lifting cables, limit switches, over-travelling limiters, remote controls.

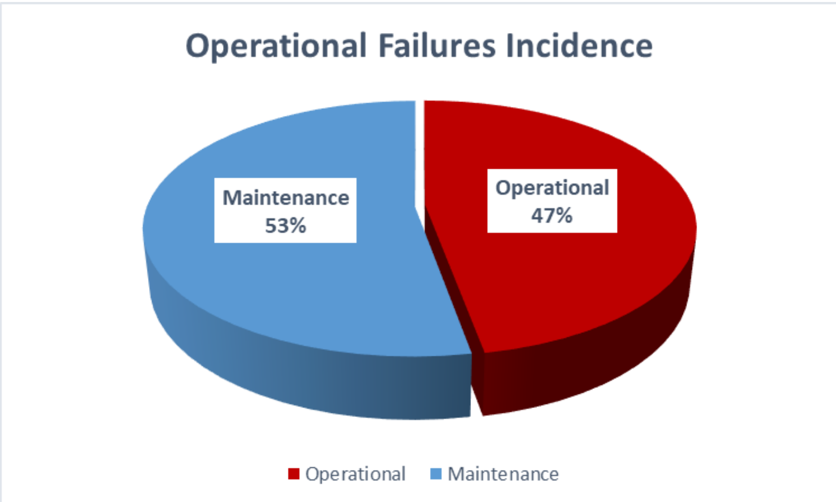


Figure 45 Operational & Maintenance failures averages

In addition, it has been observed that most of the operational failures occur at certain time slots, i.e. during shift changes, and in particular at the night shift at 6:00 am, where negligence is higher and the attention of operators due to tiredness is reduced.
First of all, it is necessary to clarify whether the breakdowns can be attributed specifically to a single operator, in which case the hypothesis of

a training course or coaching with a more experienced crane's operator, that assists the new operators during the learning process, should be considered.

- **Lack of information**

  During the present analysis some problems concerning the lack of useful information have been noticed. The duration of recorded downtime, for instance, only describes the time elapsed between reporting the fault and returning the crane to service, but does not specify information useful to identify more accurately the severity of the fault and its response times, such as:

    - Intervention time (or management delay)
    - Fault diagnosis time
    - Logistic delay time
    - Maintenance net time

  It is considered appropriate then to integrate a first analysis module for faults that directly affect the production, useful to better describe the nature, understand the causes and evaluate any applicable technical improvements. A draft of the above front and back module in Italian language is presented in the appendix.

In conclusion, it must be pointed out, that the solutions presented are to be understood as suggestions and therefore do not have the certainty of constituting definitive remedies, since there has been no way of applying them within the Company and consequently of predicting their levels of concrete effectiveness. Nevertheless, it is believed that they have a good level of validity and that if applied they could significantly reduce the downtime of the cranes analysed, as well as reducing the risk of a production stop with its respective economic consequences.

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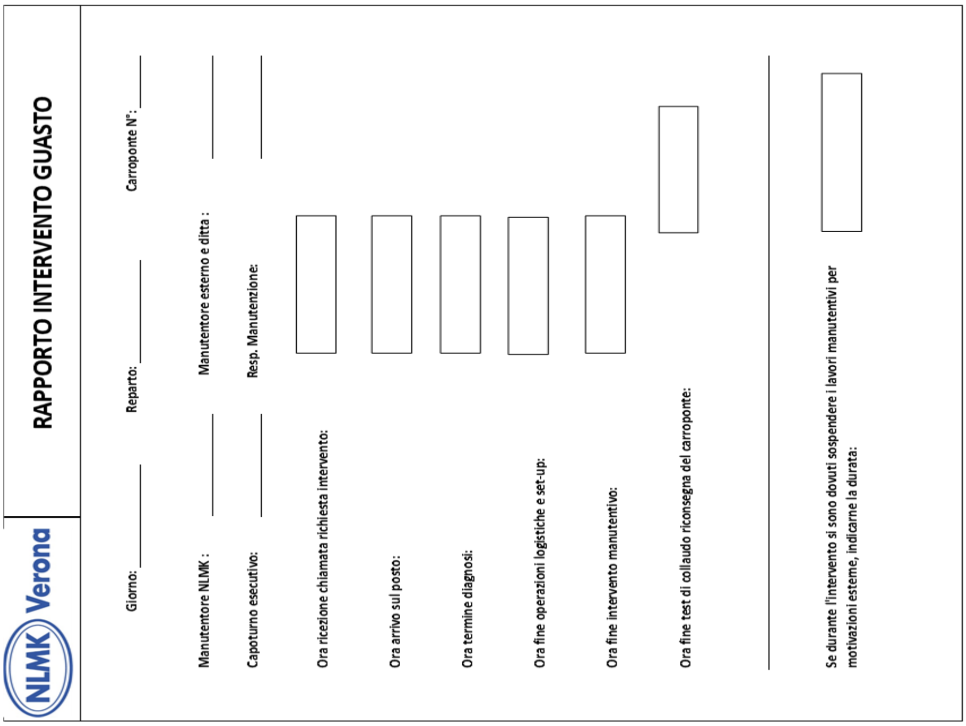
APPENDICES


RAPPORTO INTERVENTO GUASTO

Giorno: ______ Reparto: ______ Carroponte N°: ______

Manutentore NLMK : ______ Manutentore esterno e ditta : ______

Capoturno esecutivo: ______ Resp. Manutenzione: ______

Ora ricezione chiamata richiesta intervento:

Ora arrivo sul posto:

Ora termine diagnosi:

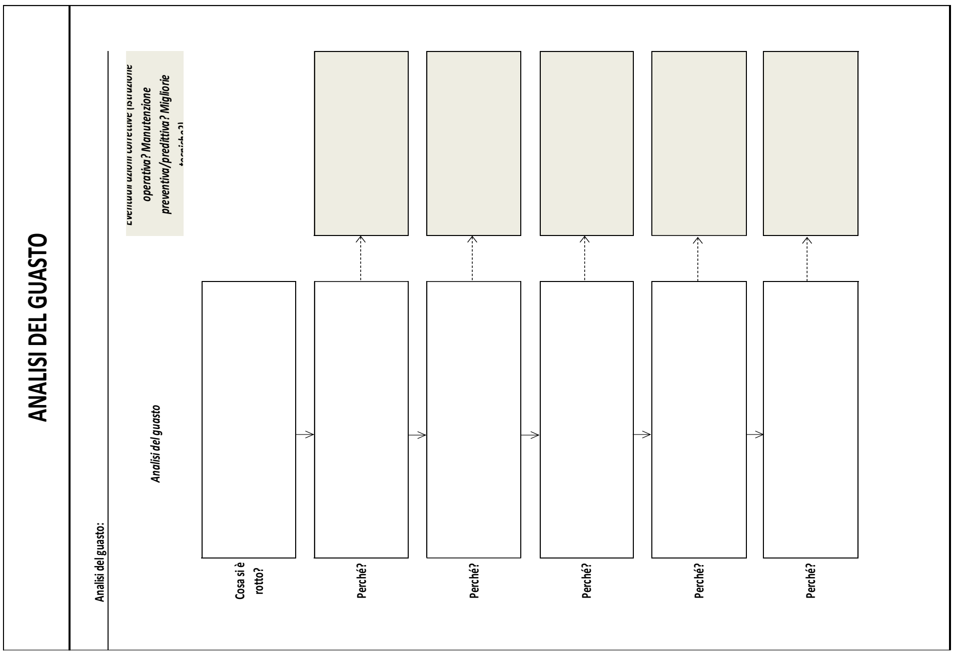
Ora fine operazioni logistiche e set-up:

Ora fine intervento manutentivo:

Ora fine test di collaudo riconsegna del carroponte:

Se durante l'intervento si sono dovuti sospendere i lavori manutentivi per motivazioni esterne, indicarne la durata:

Figure 46 First analysis sheet - page 1/2


ANALISI DEL GUASTO

Analisi del guasto:

Analisi del guasto

operativa? Manutenzione preventiva/predittiva? Migliorie

Cosa si è rotto?

Perché?

Perché?

Perché?

Perché?

Perché?

Figure 397 First analysis sheet – page 2/2