POLITECNICO DI TORINO

MASTER'S DEGREE IN MECHANICAL ENGINEERING

Master's degree thesis

Implementation of Total Productive Maintenance in dairy industry: the case study at 3A Latte Arborea

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Summary

Abstract

Over the years, the concept of maintenance has changed considerably. Maintenance stopped being a mandatory activity following a failure but today it is a fundamental tool to work on to significantly increase the efficiency of a plant and therefore the performance of a company.

This thesis work began in March 2019 at the important dairy company *3A Latte Arborea* based in Arborea (OR), Italy. The increasingly global and rapidly expanding market demand for the last few years has meant that the Company revises its production processes with a particular focus on maintenance management. Through this work lasting about nine months all the fundamental steps for the implementation of the "Total Productive Maintenance" (TPM) methodology, first theorized in Japan in the early 1970s, were started. From a breakdown maintenance it has thus passed to a TPM maintenance with the aim of arriving within a few years at an ideal condition of Zero failures and Zero defects. There were many activities that were introduced in the company after an initial training period both for operators and top management: the production sheets were modified and improved, new control, cleaning and inspection sheets were created, the DCS (Daily Control System) in departments was introduced, the management of the tags for the anomalies was started, etcetera. This new efforts within the Company were done to make maintenance no longer a secondary activity and a simply production support, but a real fundamental cornerstone for the correct functioning of the company at the same level as the production itself.

Through all the new KPIs (Key Performance Indicators) introduced within this thesis work over the months, it is possible to develop an in-depth and real-time analysis of the production processes and of the main anomalies. Then, is now possible to carry out a serious monitoring of times and methods that must be standardized and always maintained at a very high level over the years in order to reach excellent results for the Company.

Abstract (Italian version)

Nel corso degli anni, il concetto di manutenzione è cambiato considerevolmente. La manutenzione ha smesso di essere un'attività obbligatoria a seguito di un guasto ma è oggi uno strumento di fondamentale importanza su cui puntare per poter aumentare significativamente l'efficienza di un impianto e quindi le performance di un'azienda.

Questo lavoro di tesi nasce a Marzo 2019 presso l'importante azienda nazionale lattiero-casearia 3A Latte Arborea con sede ad Arborea (OR), Italia. La domanda di un mercato sempre più globale e in continua crescita ha costretto l'Azienda, nel corso degl'ultimi anni, a ripianificare i suoi processi produttivi prestando particolare attenzione alla gestione della manutenzione. Attraverso questo lavoro durato all'incirca nove mesi sono stati messi in atto tutti i passi fondamentali per l'implementazione della metodologia "Total Productive Maintenance" (TPM), teorizzata per la prima volta in Giappone agli inizi degli anni '70. Da una manutenzione "a gusto" si è così passati a una manutenzione "TPM" con l'intento di avvicinarsi sempre di più nel corso degli anni alla condizione ideale di Zero Guasti e Zero Difetti. Molte sono state le novità introdotte in azienda dopo un periodo di formazione sia per gli operatori di linea che per il top management: i fogli di produzione sono stati modificati e migliorati, nuovi fogli di controllo, pulizia e ispezione sono stati creati, è stato introdotto il DCS (Daily Control System) all'interno dei reparti, è stata avviata la gestione dei cartellini per le anomalie, ecc. Tutti questi nuovi sforzi all'interno dell'Azienda sono stati fatti per rendere la manutenzione non più un'attività secondaria e un semplice strumento di supporto alla produzione ma un vero e proprio caposaldo fondamentale per il corretto funzionamento dell'azienda allo stesso livello della produzione stessa.

Attraverso tutti i nuovi KPIs (Key Performance Indicators) introdotti nel corso dei mesi durante questo lavoro di tesi, è possibile sviluppare un'analisi approfondita e in tempo reale dei processi produttivi e delle principali anomalie. Inoltre, è oggi possibile effettuare un serio monitoraggio dei tempi e metodi che devono essere standardizzati e mantenuti sempre ad un livello molto alto nel corso degli anni ai fini di ottenere risultati eccellenti per l'Azienda.

Introduction

Nowadays, companies are facing increasingly demanding and global markets. The national and international markets offer the possibility of sell the products all over the world in a very short time. In order to do this, companies focus their attention only on increasing production leaving out the efficiency of machinery and their productivity.

The maintenance management and the control of the production processes do not always find the right space within the company organization even though these are the key for a correct production process. Since the late 1970s in Japan, the focus has been on improving the production process in terms of machinery efficiency as a support tool for increasing production at a lower cost.

One way to monitor machine efficiency is the introduction and analysis of the so-called KPIs (Key Performance Indicators) within the company. Among the many types of KPIs present in literature, the most famous is certainly the OEE index, theorized for the first time in Japan in 1971 by Seiichi Nakajima. This index offers the possibility of simultaneously monitoring the three fundamental pillars for high machine efficiency: Availability, Performance and Quality.

Today not only all the world leaders, but also the small-medium companies of Asia, Europe and America, are introducing the calculation and analysis of the OEE index as a tool for evaluating the production process.

This is also the case with the *Cooperativa Assegnatari Associati Arborea*, better known as *3A Latte Arborea*, Italian leader in the dairy industry, based in Arborea (OR). Not only the national and European markets have pushed 3A Latte Arborea to increase its production, but also new intercontinental exports in countries such as the USA, China, Japan, Thailand, etc. have forced the company to make the most of its production facilities. From here, the need arises to introduce the TPM (Total Productive Maintenance) methodology within the company for maintenance management.

This thesis work started on March 2019, has been based on the implementation of this methodology at every stage: from its introduction to the analysis of the calculated indices, including data collection, OEE implementation, machine maintenance and cleaning standards, the daily control system for visual management of trends, management of anomalies tags, micro-downtime analysis, autonomous maintenance implementation and finally an economic evaluation of the investment to improve the layout of the department.

Further development of this work is for sure the Japanese "*Kaizen*" ("continuous improvement") in order to compete in the future for the Distinguished Plant Prize (the so called PM award) assigned by Japanese Institute of Plant Maintenance (JIPM) to those companies who successfully implemented TPM.

1 Total Productive Maintenance (TPM)

The Total Productive Maintenance is a set of methods and procedures adopted in a company as support of the production system in the logic of just-in-time and total quality control.

1.1 The evolution of the maintenance management

Until the '50s, the maintenance concept was to fix items when they are broken. During the years its perception is changed assuming maintenance as: "*all activities aimed at keeping an item in, or restoring it to, the physical state considered necessary for the fulfilment of its production function*" (Gits, 1992). Obviously this kind of definition includes also all the proactive tasks such as periodic inspections, daily monitoring, preventive replacement, etc.

Just in the second half of the 1900s, maintenance management assumed also a sort of economic role: it was still a tool of support of the production but it had to ensure some required quality and quantity levels in a safe and cost-effective manner.

Over the years, maintenance has gone through many phases:

- **Breakdown Maintenance (BM):** Maintenance is adopted only when it's strictly required after a component or machine failure/stoppage. This implies very long unplanned stoppages, high costs of repair, excessive damages to equipment, spare parts problems etc. This method was used prior to 1950.
- **Preventive Maintenance (PM)**: This method was introduced in 1951 and it comprises all the activities of physical check up of the equipment in order to prevent breakdowns. It's based on the concept that all the machines will undergo over breakdown in the future and so it includes all the activities to prevent it such as lubrications, cleaning, tightening, parts replacements. The production equipment may also be inspected during the preventive maintenance activities for sign of deterioration.
- **Corrective Maintenance (CM)**: Introduced in 1957, it is the utilizations of some physical equipment's improvements in order to totally prevent the machine failure (improving the reliability) and make the maintenance work easier (improving maintainability). The main difference with PM is that in corrective maintenance the

problem must exist before the corrective action is taken. The information coming from CM, are used as a starting point for the next corrective improvement of the machine and for preventive maintenance of the equipment.

- **Productive Maintenance (PrM):** The purpose of Productive Maintenance is to enhance the productivity of the equipment by reducing its total life cost over its entire life from design, fabrication, operation, maintenance and losses given by final degradation. It can be also seen as the sum of preventive and corrective maintenance operations. It's basically founded on the reliability and maintainability improvement concept as well as cost-effectiveness.
- **Computerized maintenance management system (CMMS):** CMMS is used as support in the maintenance activities through data collection, spare-parts inventories, repair schedules, failure histories. It can be seen as an automatization of PM. CMMS assists the maintenance management in the purchasing of material, reporting and data analysis.
- **Total Productive Maintenance (TPM):** Born in Japan in 1971, TPM is based in the Productive maintenance concept and Toyota Motor Company first introduced it. Total Productive Maintenance is an innovative approach of considering maintenance as a part of the production process and not only a support of it. It tends basically in avoid at all every kind of unexpected stoppage of equipment by introducing autonomous maintenance by operators and day-by-day activities including total workforce.

TPM is targeted to improve competiveness of companies and it is supported by a very strong mind-set of all employees' levels to make it effective. This methodology tunes up existing processes and equipment in order to prevent failure, accidents and guarantee a safe work environment.

1.2 The generic definition of TPM

Since the end of the Second World War, the Japanese companies tended to import the American innovation and techniques of the business-management and the maintenance management was one of these. Subsequently, in a short time, Japanese products were recognized for their superior quality and exported in the occidental industrialized countries.

For this reason, the occidental industries focused their attention on the new improved Japanese concept of business-management. Total Productive Maintenance, first theorized by Seiichi Nakajima in 1971, was the maintenance management technique of Toyota Motor Company imported in America at the end of the '70s and subsequently in all over the world.

TPM is usually defined as "the Productive Maintenance that implies total participating". In the most cases the companies that try to implement TPM in their departments end up failing because it is wrongly widespread the idea that maintenance is just a process workers' problem and not a top management's one. Therefore, the participation of all the hierarchic levels inside the business is strictly necessary so that TPM could be effective.

The word "Total" in TPM assumes three different meanings: the first is "Total Efficiency" intended as economic efficiency and profitability; the second is "Total maintenance system" seen as the set of preventive maintenance (PM), corrective maintenance (CM) and productive maintenance (PrM); and finally "Total participation" including the autonomous maintenance carried on by small groups of workers. However, a definition of TPM can be summarized in five points:

1. Maximize plants' efficiency.
2. Establish an accurate maintenance plan for the entire life of the machine.
3. Empower all the factory departments.
4. Involve all the employees at any level.
5. Carry on the Productive Maintenance thanks to small groups of workers.

In the Japanese mentality, TPM cannot work if it's not associate with 5 key activities of *muda* (losses) elimination, the so called 5S: *Seiri* (Sort), *Seiton* (Set in order), *Seisio* (Shine), *Seiketsu* (Standardize), *Shitsuke* (Sustain).

Japanese nomenclature	English 5S	English 5C	Features
Seiri	Sort	Clear	Sort out unnecessary items from the workplace and discard them
Seiton	Set in order	Configure	Arrange necessary items in good order so that they can be easily picked up for use
Seisio	Shine	Clean and check	Clean the workplace completely to make it free from dust, dirt and clutter
Seiketsu	Standardize	Conformity	Maintain high standard of house keeping and workplace organization
Shitsuke	Sustain	Custom and practice	Train and motivate people to follow good housekeeping disciplines autonomously

Figure 1-Key activities for effective 5S implementation (Ahuja and Khamba, 2008)

In order to achieve its three main goals (Zero defects, Zero stops and Zero breakdowns), TPM is based in height fundamental pillars:

- Autonomous Maintenance
- Focused Maintenance
- Planned Maintenance
- Quality Maintenance
- Education and Training
- Safety, health and environment
- Office TPM
- Development management

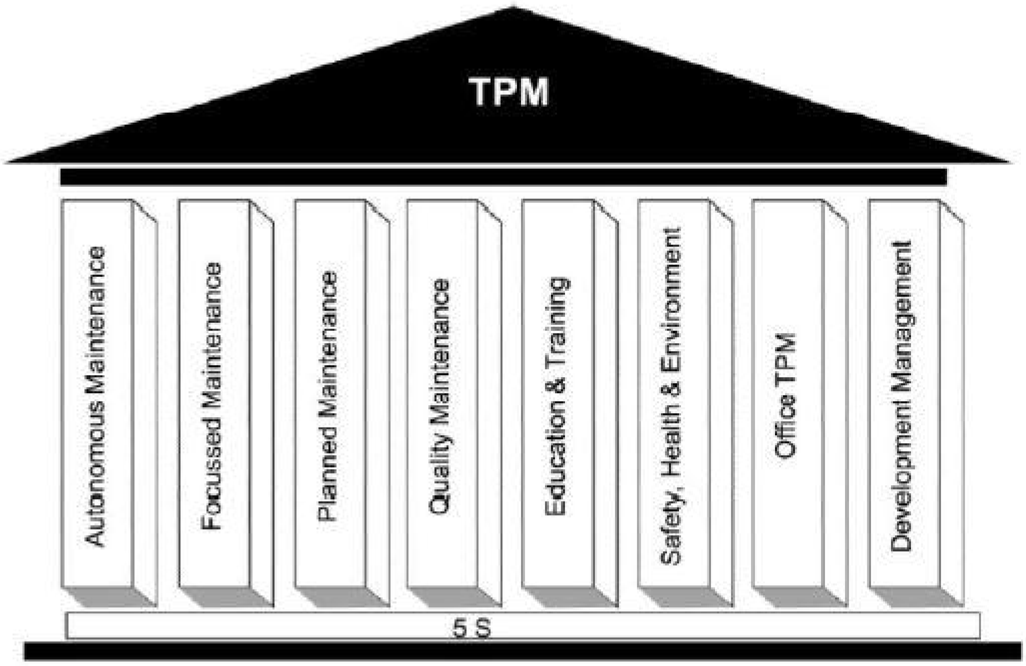


Figure 2- Eight Pillars of TPM (JIPM)

1.3 The contemporary companies' need of TPM

TPM results essential for a business in order to improve production equipment's availability, performance, quality, safety and reliability. Through a total participation of the employees, it is possible to aspire to the zero defects, stops and breakdown Japanese vision. The botton-line targets of a TPM strategic implementation are lower operating costs, longer equipment life and lower overall maintenance costs. In a more general view, the contemporary companies find in the TPM a necessary tool to satisfy some important requirement.

First of all, TPM is the best way of proceed in order to become world class and satisfy an increasing global market: it's not possible to remain competitive in the manufacturing scenario without implementing TPM and embrace this global change of conceive maintenance. Then, it is vitally important for a modern company to be flexible and adapt to the market demands. This is not possible nowadays if a business do not critically monitor its data and KPIs (Key performance indicators). A strategic TPM allows not only to improve productivity and quality but also to make the job simpler and safer. The job become smarter and not harder thanks to a standardized way of proceed.

All these factors give life to a significant cost reduction opportunity regarding maintenance related expenses and make possible to minimize investment in new useless technology and maximize return on investment ROI. Moreover, TPM implementation can also help to achieve the basilar business priorities and goal, more in detail:

- Productivity: reduced unplanned stops and breakdowns improving machine availability and productivity.
- Cost: lower life cycle cost, efficient maintenance procedure, reduced stoppage-related wastes.
- Quality: reduce quality related problems, improve production stability, reduce in component failure, provide customization with additional capacity, quicker change-over and design of products.
- Safety: Enhanced workplace environment, realizing zero accidents, elimination of dangerous situation.
- Morale: increase workers knowledge of the process and product, improved problem-solving skill, employees involvement and empowerment.

In addition, TPM gives to the workers the awareness of their transversal capability not only to produce a part but also to take care of their machines without being ordered to just because the TPM standardized procedure teach them how to do. Finally, the PM prize assigned by JIPM to those companies that successfully implemented TPM is a guarantee of intangible benefits in terms of improved image of the organization worldwide.

1.4 The twelve steps to develop TPM

Every year the JIPM assigns the PM award to those companies that successfully developed TPM. The implementation is a quite long process that required at least three year before the first results can be positively noticed. If a company tries to accelerate this process it's quite sure that it will be a failure because TPM requires small daily steps and a continuous improvement. In order to eliminate the 6 major losses it's fundamental to change first the attitude (*yaruki*) of all the employees that should strongly believe in TPM and then their professional skills (*yaruude*). Since all the workers with the aid of the management (for example assigning to each worker an objective to be achieved) share the fundamentals and the work environment (*yaruba*) is set to sustain the maintenance activities then the TPM implementation can take place through twelve main steps.

1. Communicate the decision to introduce TPM to all company levels;
2. Start an educational campaign to introduce TPM (seminars, PowerPoint presentations, etc.);
3. Create special committees to each levels to promote TPM;
4. Establish basic policies and targets;
5. Create the general plan to develop TPM;
6. Start TPM activities;
7. Improve efficiency of each machine's component;
8. Draw up a program of autonomous maintenance;
9. Develop a detailed program for periodic and predictive maintenance;
10. Organize courses to improve the TPM knowledge;
11. Create a startup process program of each machines;
12. Refine and continuous improvement;

The first 5 steps belong to the preparation phase: it requires at least six months to be completed. In the preparation phase the top management has the main role and it must promote the TPM activities organizing courses in order to let all the employees know this methodology. Typically in Japan during this phase the management put up posters in the plant or deliver leaflets with slogan that recall the TPM ideology.

Really important is also the organization in small groups with a team leader. Each group has its own objective to be achieved depending on the type of job it has in the company. The team leader therefore, participates as observer to the reunion of the upper level group being the connection between them.

The objectives of each group has been previously prepared by the top management so that the job is clear to everyone and well organized. Step number six represent the implementation phase: this is a fundamental step that might compromise the entire realization of the TPM. The activities must respect the plan provided in the preparation phase and each worker in the initial phase has to change its attitude to work otherwise the TPM activities will result useless and extra. From point seven onwards, realization phase takes place.

Engineers, maintainers, supervisors, and each group of workers work together in order to find the best solutions and solve problems related to production slowdown. Each breakdown of each machine is registered and analyzed so that it is possible to eliminate the chronicity of failures or at least reduce it as much as possible. Through a specified plan of daily maintenance (lubrication, cleaning, tightening, etc.) wrote for each machine it is easy to improve the performance and reduce the time losses due to micro breakdowns or failures because the machine results always at its top condition.

The last point is extremely important in the general overview because it means to calculate, monitor and analyze the principal Key Performance Indicators (KPIs) that allow to figure out how much the company can enhance and increase its production. The most relevant index in TPM is the OEE index, first theorized by Nakajima in 1971 and nowadays used all over the world.

1.5 Overall equipment effectiveness (OEE) index

In businesses, it is possible to find many indexes in order to monitor the production process and the state of health of the company. One of these allows to evaluate the rate of equipment effectiveness: the OEE index. Monitoring on a daily basis its trend makes possible to figure out how much the equipment is or could be leveraged.

An efficient TPM program can improve the OEE values and consequently the overall equipment performance. Despite its simplicity, this index contains a number of information regarding the production plant: the higher the index the higher the efficiency of the machinery of the plant and their logistic. With a deeper analysis of the OEE it’s easier to focus on the upsides and try to minimize weakness of the plant thanks to the structure of the index that is function of three fundamental factors: availability, performance rate and quality rate. By singularly analyzing one of this thee factors, it’s possible to understand where acting in order to improve the performance of the plant. In formula the OEE index is:

$$OEE = Availability * Performance\ rate * Quality\ rate$$

Excellent values of OEE to compete for the gold level in the PM award are at least 85%.

1.5.1 *Availability*

The first factor present in the OEE index is the availability. It allows to monitor how well the company is exploiting the available time of the total working day. The loading time is calculate by subtracting to the total working day the planned downtimes such as the daily reunion, the maintenance activities and so on, that have been previously arranged in the production plan. The operation time is then calculate by subtracting all the other unscheduled stoppages to the loading time and it represents the effective usage time of the machines. In formula:

$$Availability = \frac{Loading\ time - Down\ time}{Loading\ time} = \frac{Operation\ time}{Loading\ time}$$

The availability so, takes into account the time in which the system is not working due to breakdowns, setups, adjustments, etc. and it is probably the most discussed index in the TPM theory. In literature it’s possible to find some availability index in which the planned downtime are not considered outside the loading time but are included in it causing a big reduction of the final value being the downtime increased. It that particular case the loading time coincide with the total working day and the planned downtime are considered as simple stoppages of the plant reducing a lot the operation time and so the total availability.

This is the main difference between companies that are free to choose their way to calculate availability. Obviously, all the downtimes must be properly registered and meticulously calculated so that the availability can be reliable. The calculation and registration of the data can be done manually by the operators or with the assistance of machines’ internal software when available.

Summarizing:

<table>
<tr><td colspan="3">WORKING DAY</td></tr>
<tr><td colspan="2">LOADING TIME</td><td>PLANNED DOWNTIME</td></tr>
<tr><td>OPERATING TIME</td><td>DOWNTIME LOSSES</td><td></td></tr>
</table>

Table 1 - Availability

For Nakajima, the ideal value of the availability should be at least 90%.

1.5.2 Performance rate

The performance rate index allows to compare the actual operating speed and the ideal one provided by the machine. In order to figure out how much the production capability is exploited the performance rate takes into account the theoretical cycle time and the processed amount. The higher the difference between the theoretical and the real cycle time the lower the performance rate and the processed amount in the operating time. In formula:

$$Performance\ rate = \frac{Theoretical\ cycle\ time\ \left[\frac{sec}{unit}\right] * Processed\ amount[unit]}{Operating\ time\ [sec]}$$

Usually the reduction in the performance rate and so in the real cycle time is given by the idling operation or in the reduction in the operating speed due to wear in the components, inactivity times and micro-breakdowns. The latter are too often wrongly neglected in the companies that don't follows the TPM methodology. A micro-breakdown is a stoppage lower than 5 minutes that apparently is insignificant in the moment it appears because it's fast to recover but in the TPM analysis is really important not only because it is a time loss but because it is very frequent during the working day. If all the micro-breakdowns are added together it's possible to reach a consistent loss that otherwise would be overlooked.

The ideal value of the performance rate should be at least 95%.

1.5.3 Quality rate

The last parameter affecting OEE is the quality rate. It simply takes into account the quality of the process in terms of defectiveness or start up losses. It's simply calculated as the ratio between processed amount less the defects over the processed amount. In formula:

$$Quality\ rate = \frac{Processed\ amount\ -\ Defect\ amount}{Processed\ amount}$$

The ideal value of the quality rate should be at least 99%.

So the general scheme is:

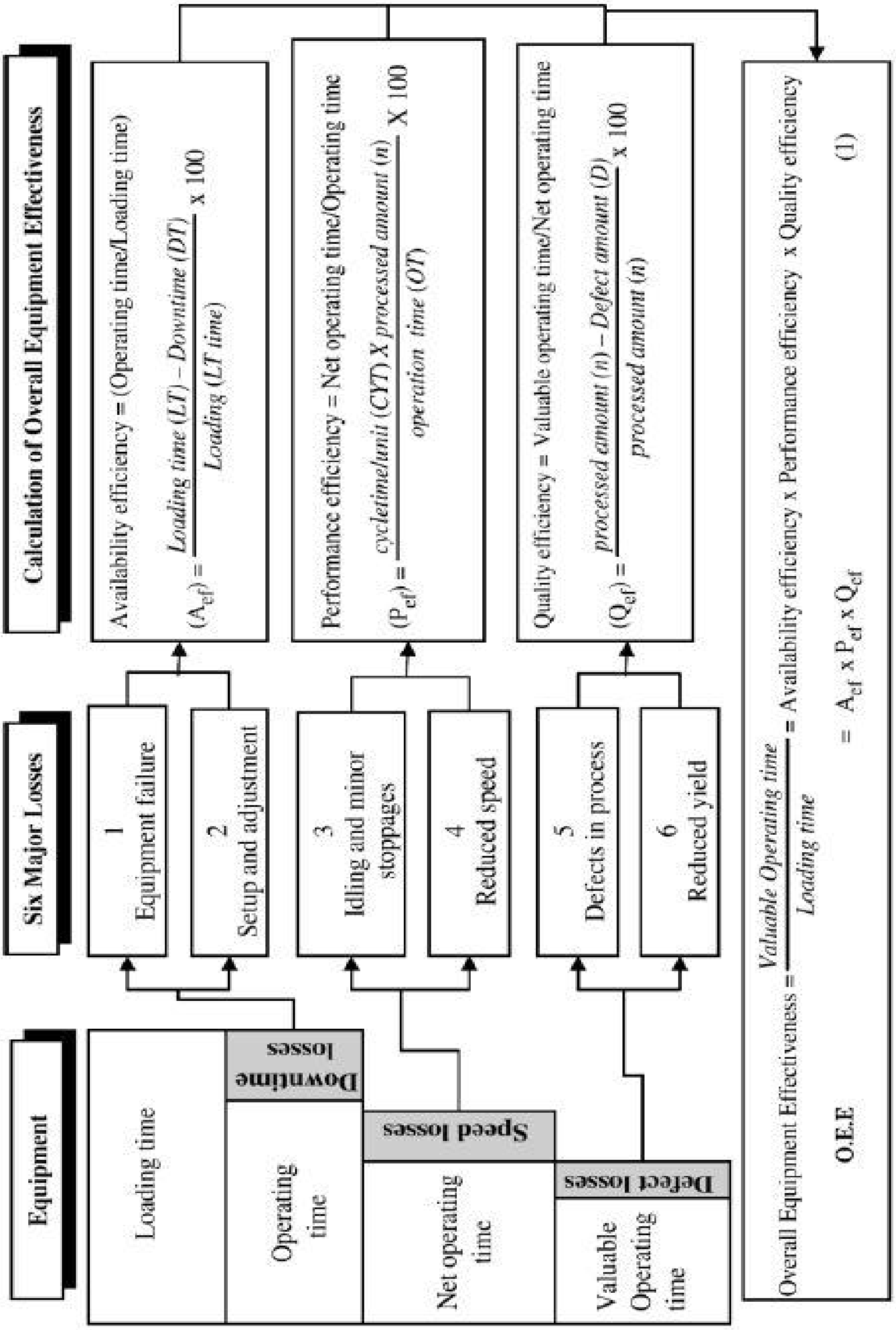


Figure 3 -OEE scheme (Nachiappan and Anantharaman, 2006)

1.6 Data collection and anaysis methods

Within a production plant it is possible to meet several problem that affect the OEE index and so the equipment's performance. The principal aim of the TPM activities is to identify trough the KPIs analysis and the physical inspection during the maintenance work of the machinery's state of health all the losses that impede OEE, loading time and the general equipment efficiency. Once identified all the losses that can occur in the production plant it is extremely important to register and successively analyze data in order to prevent the recurrence.

1.6.1 The sixteen major losses

The problems that factories have to face are generally the same independently on the type of product they produce. This highlight the independency between the type of product and the TPM methodology that can be followed in any case.

It's possible to recognize sixteen types of losses that occur in a plant grouped in four main set depending on the field influenced by.

- Impede OEE
  1. Breakdown losses: due to failure of a component.
  2. Set-up and adjustment losses: due to change in operating conditions.
  3. Reduced speed-losses: when actual operating speed is lower than theoretical one.
  4. Idling and minor stoppage losses: temporary stops or idle of work
  5. Defects and rework losses: Volume/Time losses due to defects or rework.
  6. Start-up losses: due to machine start-up, until production condition stabilize.
  7. Tool changeover losses: changing tool due to failure.
- Impede equipment loading time
  8. Planned shutdown loss: due to periodic or occasional inspections.
- Impede worker efficiency
  9. Logistic/Distribution losses: inability to automate, manual loading/unloading.
  10. Line organization losses: not optimal line.
  11. Measurement and adjustment losses: Frequent measure in order to prevent defects.

12. Management losses: waiting for material, tools, instructions, etc.

- Impede efficient use of production resources

13. Motion-related losses: due to violation of motion economy.
14. Yield losses: different weight in input and output.
15. Consumable losses: due to production or repair of dies, jigs, tools, etc. aging beyond service life.
16. Energy losses: ineffective utilization of input energy in processing.

During the maintenance activities or even during the operating time if the worker find one of these losses in the equipment has to register it in the database in order to provide to the TPM coordinator the useful instrument to analyze the production process and the state of health of the machines.

1.6.2 *Data collection*

There are three main ways to collect data in a factory and each one has its pros and cons. Data can be basically collected manually, automatically or semi-automatically.

	PROS	***CONS***
Manually	Low cost; A lot of solutions; Deeply detailed;	Time consuming; Possibility of error; Not-standard writing between operators; Difficulty to calculate time losses; Lack of motivation; Boring job;
Automatically	Continuous detection; Reliability; Standard writing; Excellent precision;	High cost; Difficulty to manage; Software knowledge required;
Semi-automatically	Flexibility, Simplicity.	Operator addiction; Difficulty to calculate time losses; High cost for sophisticate software.

Table 2 - Data collection

Obviously, the data collection method is a choice of the company in function of its financial resources, workers knowledge and required flexibility. It’s possible also to adapt one of these method to the own necessity and modify it over the years.

1.6.3 *Analysis methods*

Once the data are properly collected into a database it is for the TPM management to proceed with the analysis. Every single information coming from the data collection is used in the analysis in order to find immediately a solution to the problem and to provide a maintenance plan in order to prevent the recurrence. There are a lot of way to conduct an analysis and every method has its effectiveness in a specific field. In the TPM analysis the most used are the Pareto diagram and the Ishikawa (or fish bone) diagram.

- The Pareto Diagram is really effective when it's required to evaluate the importance of a stoppage and how much it influences the overall trend. This analysis is based on the 80-20% rule which states that the 80% of the effects are caused by the 20% of the causes. In other terms acting on the 20% of the causes of stoppage, it's possible to reduce until the 80% the effects in the overall trends. In a plant, this kind of diagram is obtain by summing up the same stoppages over a specified period of time (it could be a month or three or a year) and see how much each one influences the overall. The graph will be a histogram with a line (the cumulative percentage) in descending order in function of their importance.

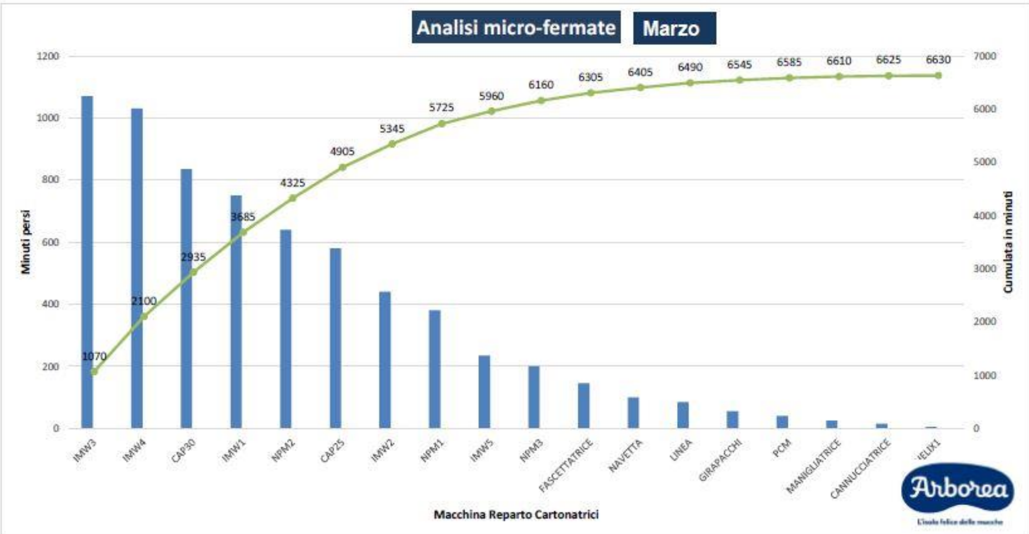


Figure 4- Pareto Diagram example

- The Fish bone diagram is a strategic tool to evaluate all the possible causes of a stoppage. There are 6 main categorize (material, man, methods, measures, machines, other) that allow to write down all the possible causes that are then further analyzed with the why to why analysis. In this type of analysis each possible cause of each categorize is analyzed and with a backward process (continuously asking "why?") it is possible to investigate the reason that triggered that problem and then the problem of the problem and so on.

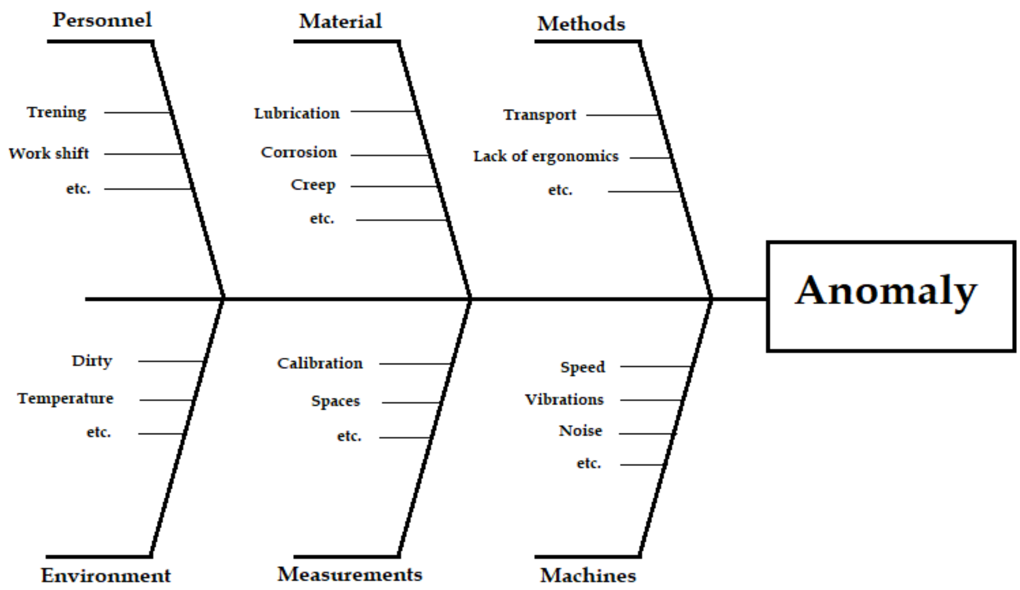


Figure 5- Ishikawa diagram example

1.7 Autonomous maintenance

The eighth step of the twelve fundamental ones is to draw up a program of autonomous maintenance. This step is a characteristic presence in the TPM methodology and it is probably the most important step because it regards the attitude to the work of the employees. Introducing TPM in a company is not an easy process since it involve all the levels that should cooperate and share the same goal: increase productivity and efficiency decreasing at the same time the total costs. TPM required in the initial phases a hard work and personal efforts by all employees. It is about change the mentality of workers, the idea "I produce and you fix" is not valid in TPM mentality in fact it is completely wrong. In the old business scheme workers spend all their working day producing the goods without caring about the machines that they are using. If a problem occurs, they don't care and immediately stop the production and call the maintenance department.

With TPM such mentality is deleted. All the workers are the first responsible of the machine they are using since they perfectly know how it works. In the first phases, the management has to organize meetings where the maintenance department teach to the other workers how to solve and fix the simpler problems that could occur during production. The worker as the first responsible of the machine is asked to keep the machine in the best condition as possible and if a stoppage occurs during production he has to fix by himself if it is possible in order to reduce the time losses and simply the entire process of maintenance.

For this reason, once passed the learning initial phase the TPM management with the help of maintainers has to provide for each machine a daily maintenance plan. This plan, attached in front of each machine, should provide the useful instructions about the daily maintenance (cleaning, lubricating, tightening, etc.) that the worker has to respect at the end or at the beginning of his shift. In order to check the carrying out of the activities the workers have to sign a paper declaring his activities have been done.

1.7.1 The 5 "S"

The 5 "S" are the main principles of TPM. *Seiri, Seiton, Seiso, Seiketsu,* and *Shitsuke* are the secrets of a Japanese company, but in the western industries these principles are too often overlooked. Most of the time businesses spend all their time focusing on the simply production and do not pay attention to the maintenance activities.

Maintenance does not mean only to fix a broken tool or to repair a damaged component but it includes all those logic activities to preserve in a good state the plant. Mopping the floor, whitewashing the walls, painting the machines is not sufficient and not so useful to keep the plant neat and clean: it's about remove the dirty sources.

A puddle suggests a leakage that should be removed, encrustations suggest a difficult access for cleaning activities, machines' noise suggest a poor lubrication and so on. The aim of autonomous maintenance is to remove this sources in order to keep the plan day by day in the best conditions as possible.

To make it possible TPM recalls the 5 "S":

- **Seiri (Sort):** sort out all the items that are not used in the workplace

- **Seiton (Set in order):** Put in order all the tools that are necessary for the production in order to make simpler and faster picked up them.
- **Seiso (Shine):** Clean the workplace and remove all the dirty sources.
- **Seiketsu (Standardize):** Standardize the best condition as possible in order to follow it.
- **Shitsuke (Sustain):** Maintain the standards and motivate people to do their best to keep the workplace in that state.

1.7.2 *Tags in cleaning activity*

The cleaning activities include not only removing the dirty in the plant but also inspecting all the hidden parts which are hard to reach. A cleaning that doesn't include an inspection activity can not be considered a real TPM cleaning.

The inspection includes touching, listening and looking at the machine at every point to try to find all the possible points of intervention. If the cleaning activity has been carried out correctly, considerable points will be discovered where apply new maintenance and improvement activities. For this purpose, a tag will be posted on the point of interest during the cleaning activity if that particular anomaly can not be resolved immediately. This tag contains the anomaly signal and proposes the corrective activity to be applied.

Sometimes, depending on the type of intervention, different colors can be used (red for safety, white for cleaning etc.). The tag will be successively registered in the database and the department in charge will resolve the problem. If it is necessary the maintenance group once fixed the anomaly and removed the tag from the machine will provide a new autonomous maintenance plan in order to avoid repetition.

Figure 6- Tags (JIPM, Manutenzione autonoma con il TPM)

2 3A Latte Arborea

3A Latte Arborea is the fourth dairy industry in Italy - in terms of turnover – that is experiencing a strong growth in the national and international market with particular attention, in recent years, to Asian Countries that increasingly appreciate the company's products.

2.1 The company profile

3A Latte Arborea, i.e. *Assegnatari Associati Arborea*, is the leader cooperative of the Sardinian dairy industry today. More than 250 members (producers and farm owners) deliver an average of 550.000 liters of milk every day, which are checked and worked in a few hours to become the famous "Arborea" products guaranteeing very high quality-levels.

Figure 7- Arborea Plant

Arborea is a municipality in the province of Oristano. At the beginning of the '20s this region was totally impracticable: swamps and impenetrable terrain. Following a land reclamation, many families settled there from north-eastern Italy in order to farm cattle and work the land. So the milk production rapidly increased: the government agency for Sardinian land and farming transformation (ETFAS) was established in the '50s. In 1956, the co-operative took over the Aziende Alimentari Associate plant giving life to the fourth Italian dairy industry.

Many factors contributed in the 3A expansion: the products' genuineness, the partnership with TetraPak in 1970 and the short chain that guarantee the milk collection, the delivery and working phase to be completed in not more than a morning ensuring excellent standard quality that rarely can be found anywhere else.

Nowadays the headquarter occupies 61.000 m^2 of which 24.000 are built over with more than 400+ employees.

The increasing in the volume of milk to process and in the market demand pushed 3A Latte Arborea to acquire other three brands becoming a multisite group: the local Fattorie Girau (15.400 m^2, specialized in sheep and goat products), the Tuscan Coplac (with the San Ginese brand) and Trentinalatte (21.000 m^2, specialized exclusively in the production of yoghurt).

Figure 8-Group's brands

2.2 Products

A wide variety of products makes up the production of 3A Latte Arborea. The plant in Arborea (OR) is divided into two main sections: the dairy and the cheese factory. This is where the main "Arborea" brand products, which are exported all over the world, are born.

The dairy produces:

- Whole fresh milk
- Low-fat milk
- Lactose-free milk
- ESL milk
- UHT milk
- Flavoured milk
- Cream

The cheese factory, instead, produces:

- Mozzarella
- Ricotta cheese
- Spreadable cheese
- Soft cheese
- Cured cheese
- Butter
- Slices

Yoghurt, sheep and goat aged or semi-aged cheeses are product in the other plants, respectively Roveré della Luna (TN) and San Gavino (CA).

2.3 Dairy chain

The milk collected every morning along the farms of the cooperative members owes its high quality level to the respect and attention of the hygiene and cattle welfare standards. Ensuring a high quality of life for the cows can increase their production capacity. The feed given to the animals comes directly from the surrounding fields and is nutritionally balanced in order to guarantee a good product of superior quality. The short chain ensures an incomparable level of authenticity and quality to all the products of the group: all processes from milking to shipping fresh milk or cheese to various supermarkets take place in a single morning. This is the real strength of the company that makes quality its main objective.

Milking operations are carried out in compliance with standard hygiene procedures and respect for the animal and the environment. The highest level of cleanliness and hygiene of the stables and of the equipment used, the preparation of the cows, the discarding of the first milk jets, ensure an excellent product that must be subsequently analyzed and transformed.

Freshly milked milk is immediately cooled and stored at +4 °C to preserve freshness and organoleptic properties. With refrigerated tankers, this is delivered in a very short time (less than half an hour) to the cooperative thanks to the central strategic position of the plant with respect to the surrounding farms.

The company's chemical laboratories constantly carry out analytical and microbiological check. If the milk in the tankers does not have the minimum quality level required by the company, this is not discharged so as not to damage the milk already present in the tanks.

The milk being processed and the final products are then constantly analyzed in order to maintain the high quality standards throughout the entire production cycle and to ensure the customer the excellent products it requires.

Finally, the milk collected in the tank is immediately subjected to a pasteurization process and on the basis of the daily production programs is sorted and destined for the production of fresh and UHT drinking milk, cream, butter, yoghurt, cheese, mozzarella, etc.

2.3.1 *The dairy: fresh and UHT milk bottling process*

The packaging plant for fresh and UHT milk is the first department where TPM was developed during this thesis work.

Obviously, due to hygienic constraints, the milk never comes into contact with the operators but runs through the pipes from the tanks to the aseptic chambers of the TetraPak packaging machines. The UHT packaging department has 14 different lines that can work simultaneously up to a maximum of 6 at a time. The fresh milk line is single. There are two other lines for ESL (Extended Shelf Life) milk which is a mix between fresh and UHT with a duration of about a week before the deadline.

At the end of May and during the month of June, the UHT plant underwent a modification of the lines due to the replacement of a machine. The lines have therefore passed from 11 to 16 with modifications on the routes and connections between the various machines. The fresh and ESL lines have remained unchanged. The following pages show the general layout of the fresh, UHT and ESL lines before and after the changes of the month of June. The symbolic representation of machinery respects the ASME (American Society of Mechanical Engineers) regulations for production flows (ASME, 1947).

Symbol	*Category*	*Description*
○	Operation	Material transformation, working phase, assembly, actions that produce something (not necessarily product parts but documents, for example)
⇨	Transport	Moving, material or document transport
□	Control	Inspection or quality review
D	Waiting	Temporary suspension of activities
▽	Stocking	Material or product stocking
⧇	Inter-connected activities	Composed phase

Figure 9- ASME symbols ("An FMECA-based approach to process analysis"

2.3.2 *The fresh milk line*

The fresh line is a single line and is managed independently by only one operator during the winter season where demand is low and at most two operators during the summer season where demand becomes almost triple. Obviously, all the production of fresh milk is programmed in the first work shift to preserve the freshness and quality of the product. Due to the simplicity in the management of the line and the high experience of the operator in charge, this line shows the highest KPIs in the entire packaging department.

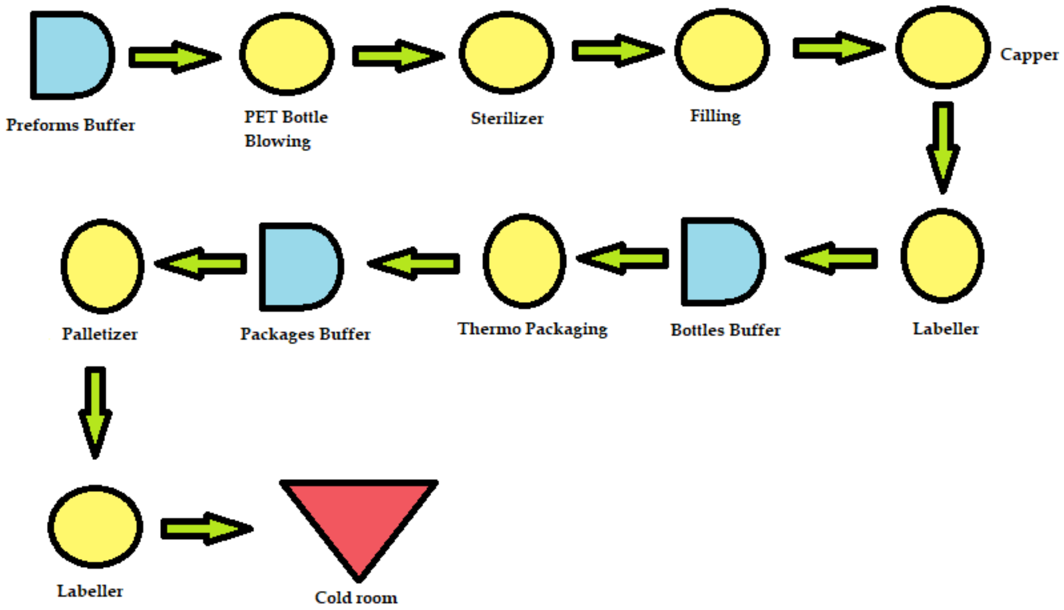


Figure 10- Fresh line representation according to ASME standards

2.3.3 *The ESL (Extended shelf life) milk line*

This product is made up of two different references as it presents the 500 ml and 1000 ml formats that run on two different lines. It has the advantage of a high temperature pasteurization which guarantees the maintenance of quality for several days unlike fresh milk. The lines have basically the same layout.

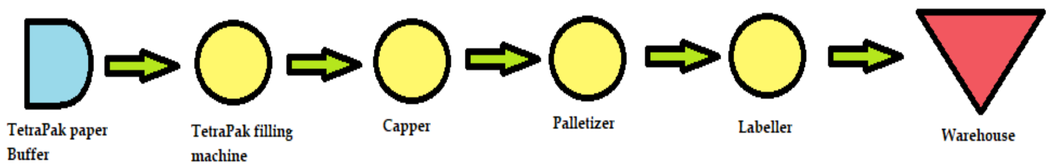


Figure 11-ESL line representation according to ASME standards

2.3.4 *The UHT milk line*

The UHT lines are the most numerous in the packaging department due to the large production volumes and the high demand of national and international markets. These lines have undergone a change during the month of June due to the replacement of one of the TetraPak filling machines, specifically that indicated with the number 3 in data collection and analysis. This change, in addition to signifying a new layout of the lines, highlights a change in the structure of the data collection sheets and their results. These sheets as well as the layout will therefore be different in the period between March (beginning of TPM implementation and this thesis work) and June compared to the period from June onwards.

2.3.4.1 *UHT lines before June*

Below the packaging lines are illustrated according to the ASME standard before the June change. This will be useful later in the data analysis to understand the layout of the department and the meaning of the changes present.

The following table shows the connections between filling machines and case packers in a schematic and summary way. Please, note date the word "IMW" stands for "case packer machine". It is hereby made known that TetraPak provides the filling machines and the number in brackets refer to an internal faster way to refer to the machines.

FILLING MACHINE	IMW 1	IMW 2	IMW 3	IMW 4	IMW 5	BAG CASE PACKER
A3 FLEX COMPACT 200/250 (1)					X	
A3 FLEX BASE 500/1000 (2)		X	X	X		
A3 SPEED SQUARE 1000 (3)	X					
A3 FLEX EDGE 500/1000 (4)			X			
A3 FLEX EDGE 500/1000 (5)				X		X
TBA8 BASE 1000 (6)		X	X	X		

Table 3 - UHT lines before June

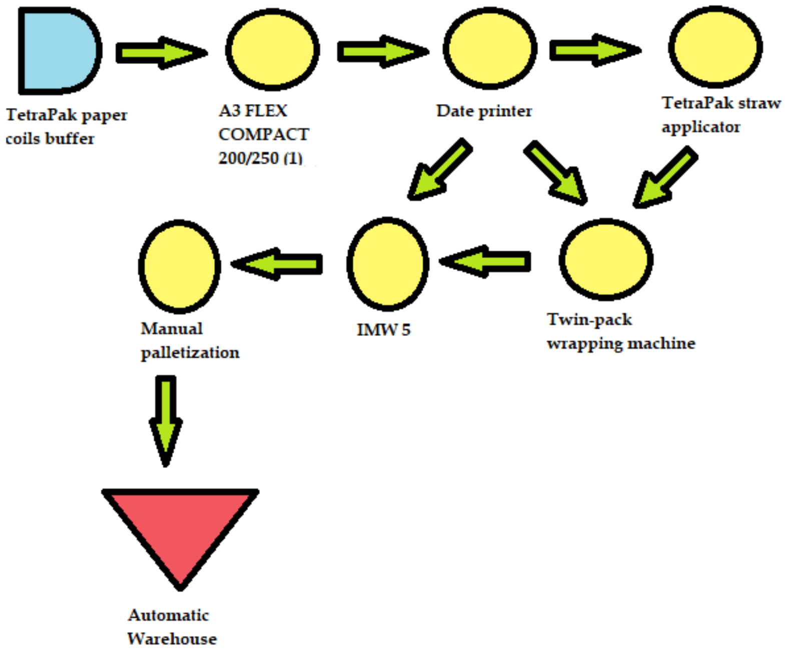


Figure 12- Line (1)
A3 Flex Compact 200/250 +Date printer + (eventual) Straw applicator + (eventual) Twin-pack wrapping machine + IMW 5 + Manual palletization

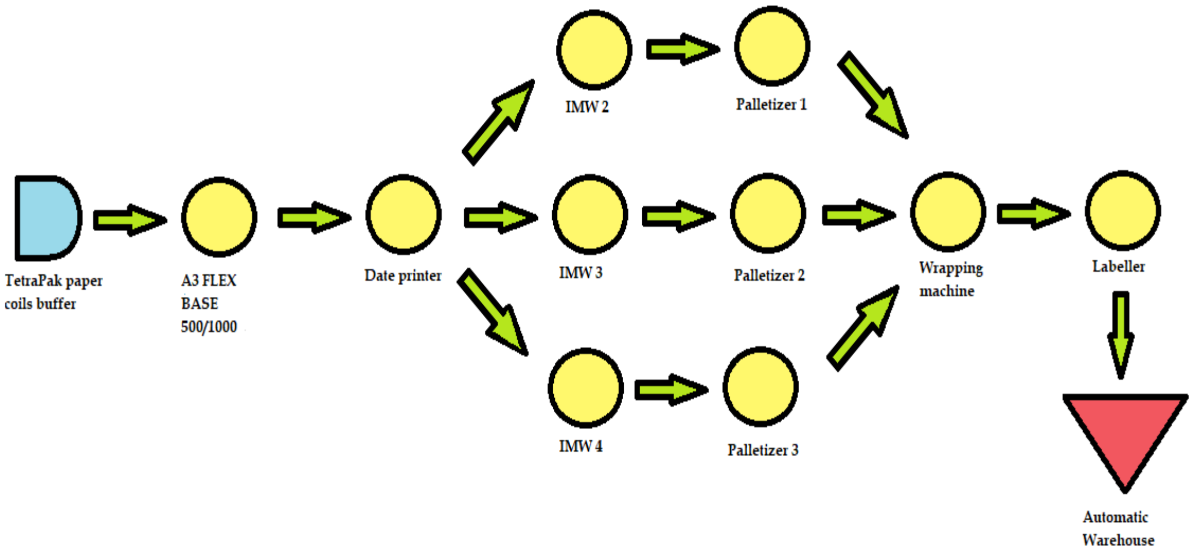


Figure 13-Line (2)
A3 Flex Base 500/1000 (2) +Date printer +IMW 2 or IMW 3 or IMW 4 + Palletizer + Wrapping machine + Labeller

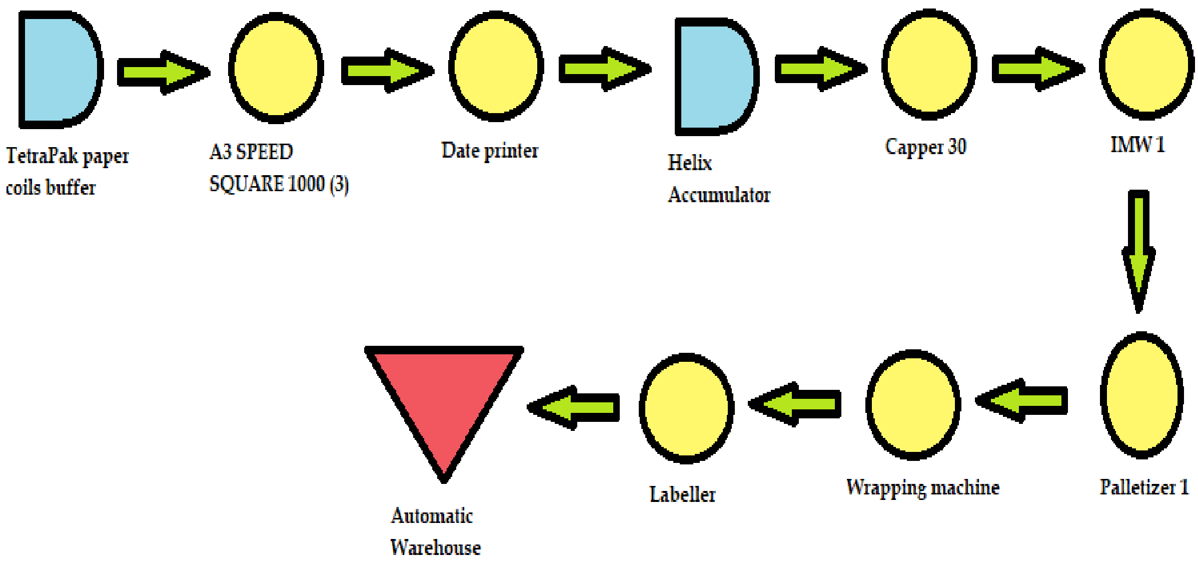


Figure 14- Line (3)
A3 Speed Square 1000 (3) +Date printer + Capper 30 + IMW 1 + Palletizer + Wrapping machine + Labeller

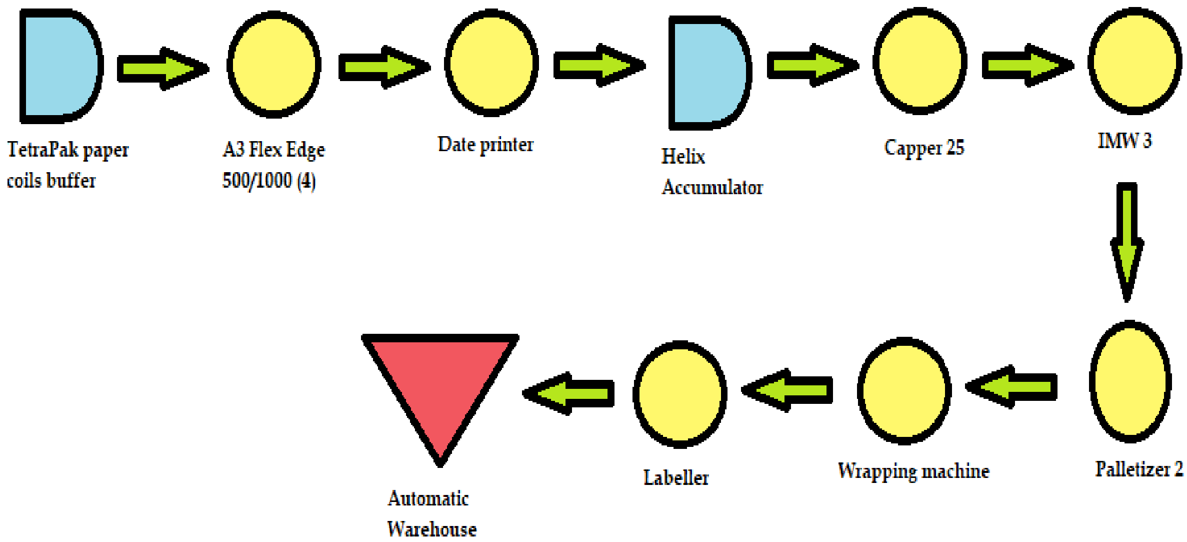


Figure 15- Line (4)
A3 Flex Edge 500/1000 (4) +Date printer + Helix accumulator + IMW 3 + Palletizer + Wrapping machine + Labeller

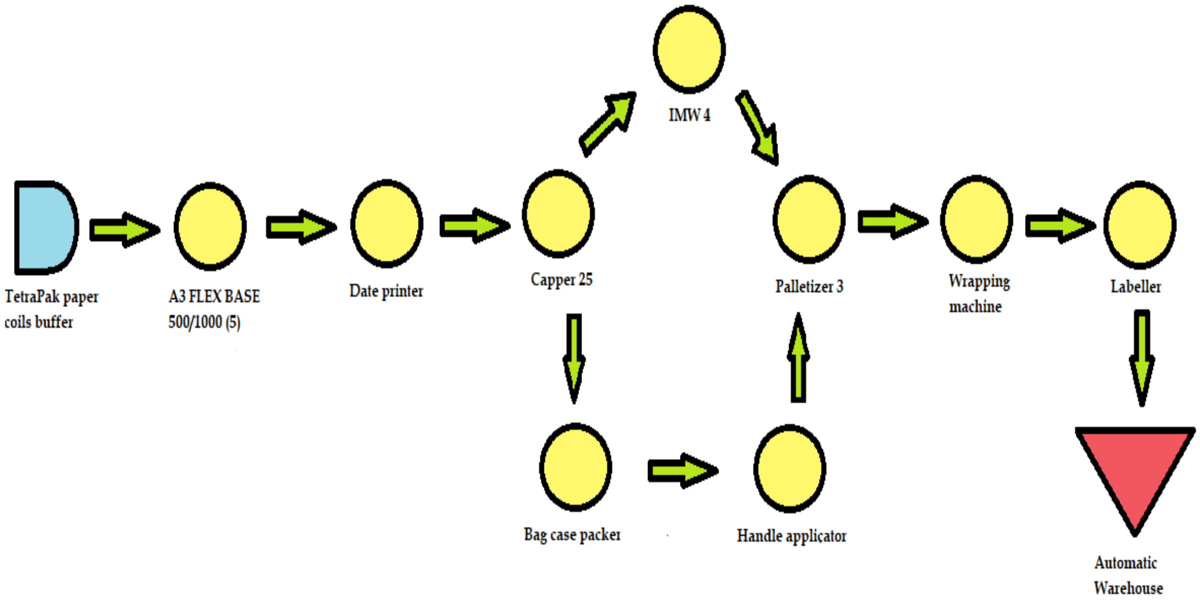


Figure 16- Line (5)

A3 Flex Edge 500/1000 (5) +Date printer + IMW 4 or Bag case packer and handle applicator+ Palletizer + Wrapping machine + Labeller

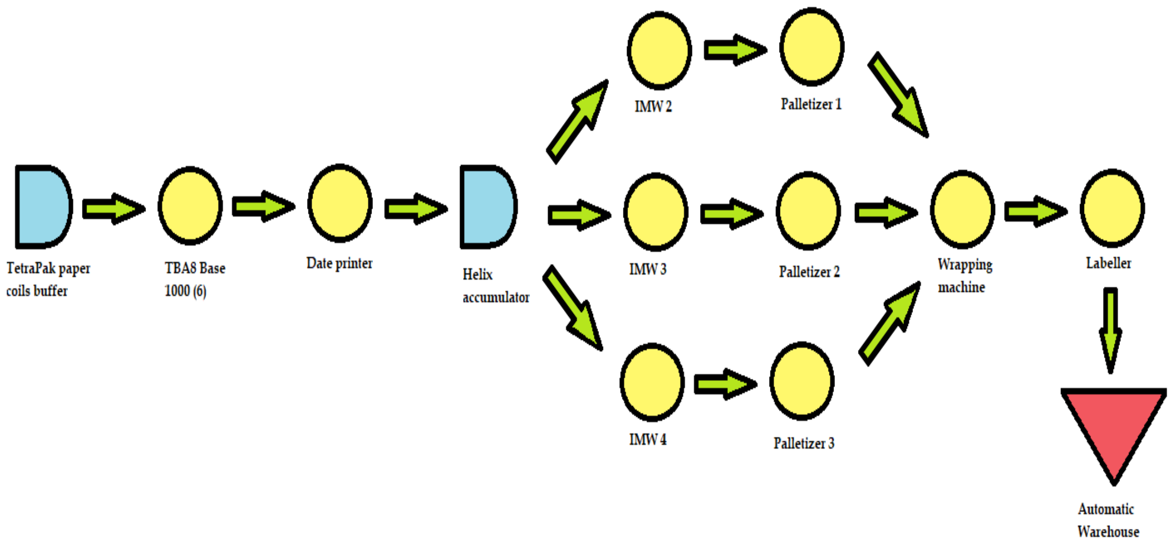


Figure 17 -Line (6)

TBA8 Base 1000 (6) +Date printer +Helix accumulator + IMW 2 or IMW 3 or IMW 4+ Palletizer + Wrapping machine + Labeller

2.3.4.2 *UHT lines after June*

As already mentioned, in June the company underwent a change in the layout following a replacement of a machine that allows new formats. The filler machine number (2) now is a A3 SPEED SQUARE and the number (3) is now a A3 FLEX BASE. Furthermore the manual palletization has been replaced by a robotic arm for the line number (1) in October. Due to this change, the new lines are illustrated below using a scheme in accordance with ASME regulations and a summary table similar to the previous one.

FILLING MACHINE	IMW 1	IMW 2	IMW 3	IMW 4	IMW 5	BAG CASE PACKER
A3 FLEX COMPACT 200/250 (1)					X	
A3 SPEED SQUARE 1000 (2)	X					
A3 FLEX EDGE 500/1000 (3)	X		X			
A3 FLEX EDGE 500/1000 (4)	X		X	X	X	
A3 FLEX EDGE 500/1000 (5)				X		X
TBA8 BASE 1000 (6)	X	X	X	X		

Table 4 - UHT lines after June

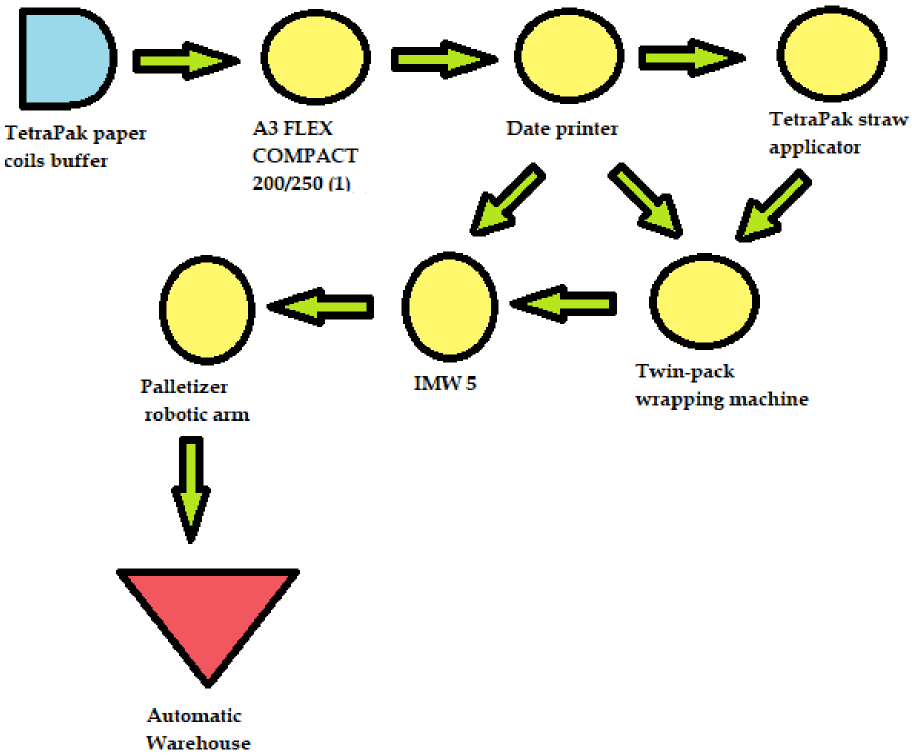


Figure 18- New line (1)

A3 Flex Compact 200/250 +Date printer + (eventual) Straw applicator + (eventual) Twin-pack wrapping machine + IMW 5 + Manual palletization

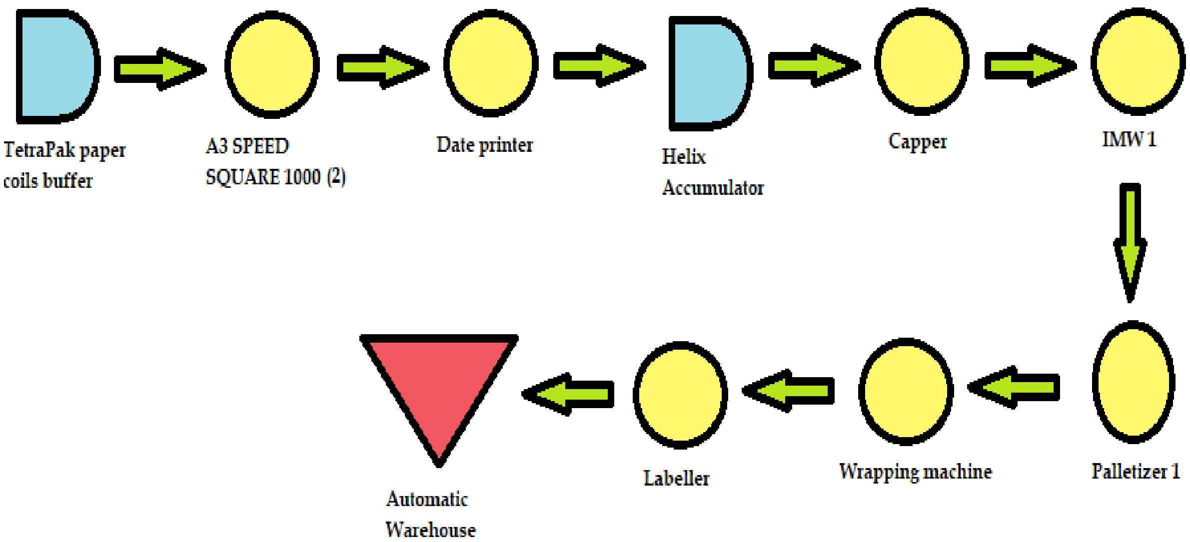


Figure 19- New line (2)

A3 Speed Square 1000 + Date printer +Helix + Capper + IMW 2 + Palletizer + Wrapping machine + Labeller

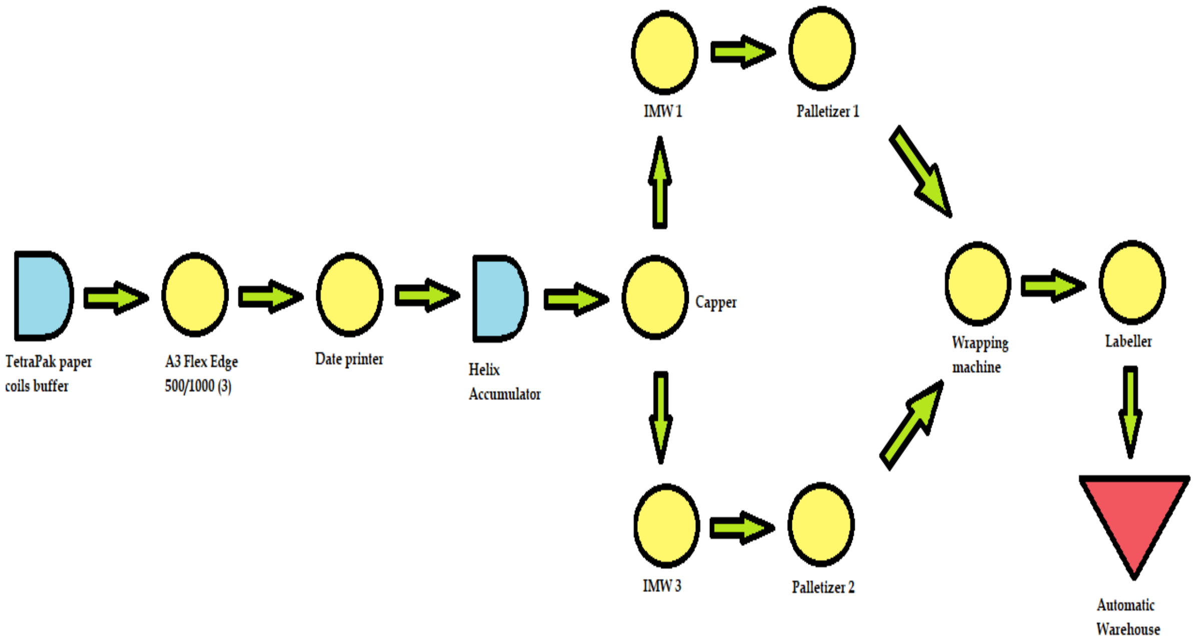


Figure 20- New line (3)
A3 Flex Edge 500/1000 + Date printer +Helix + Capper + IMW 1 or IMW 3 + Palletizer + Wrapping machine + Labeller

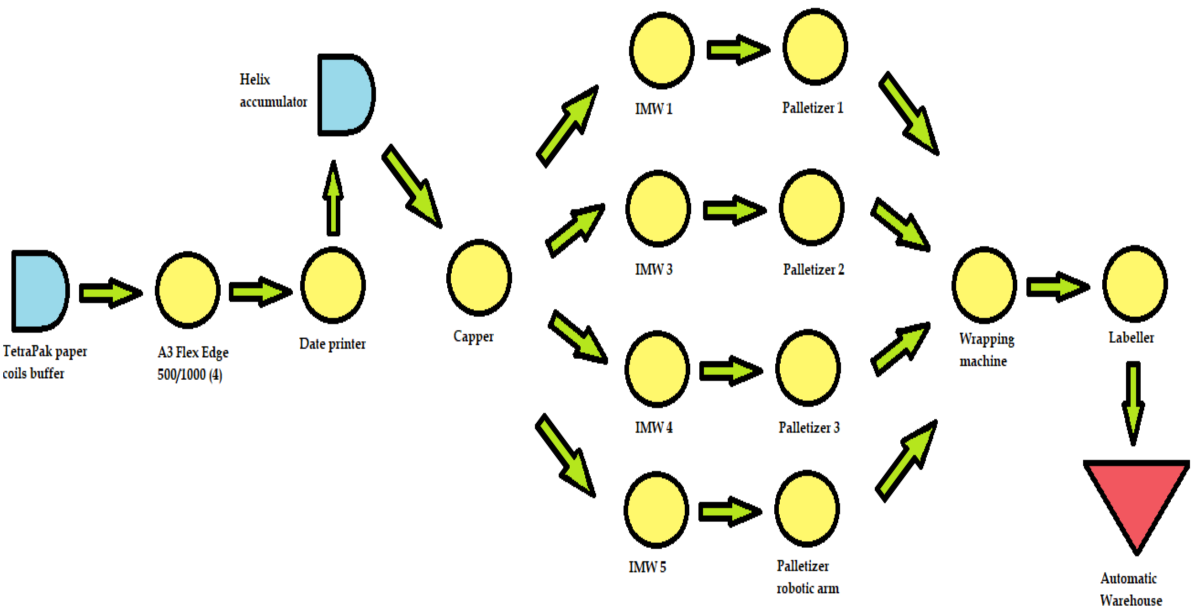


Figure 21- New line (4)
A3 Flex Edge 500/1000 + Date printer +Helix + Capper + IMW 1 or IMW 3 or IMW 4 or IMW 5 + Palletizer + Wrapping machine + Labeller

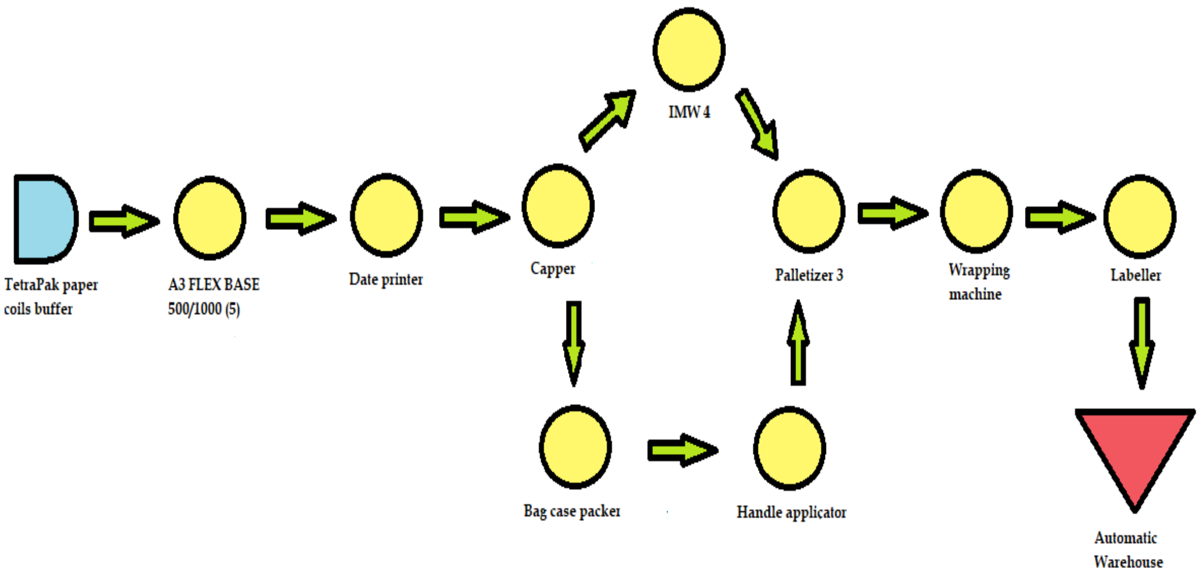


Figure 22- New line (5)
A3 Flex Edge 500/1000 +Date printer + Capper + IMW 4 or Bag case packer and handle applicator+ Palletizer + Wrapping machine + Labeller

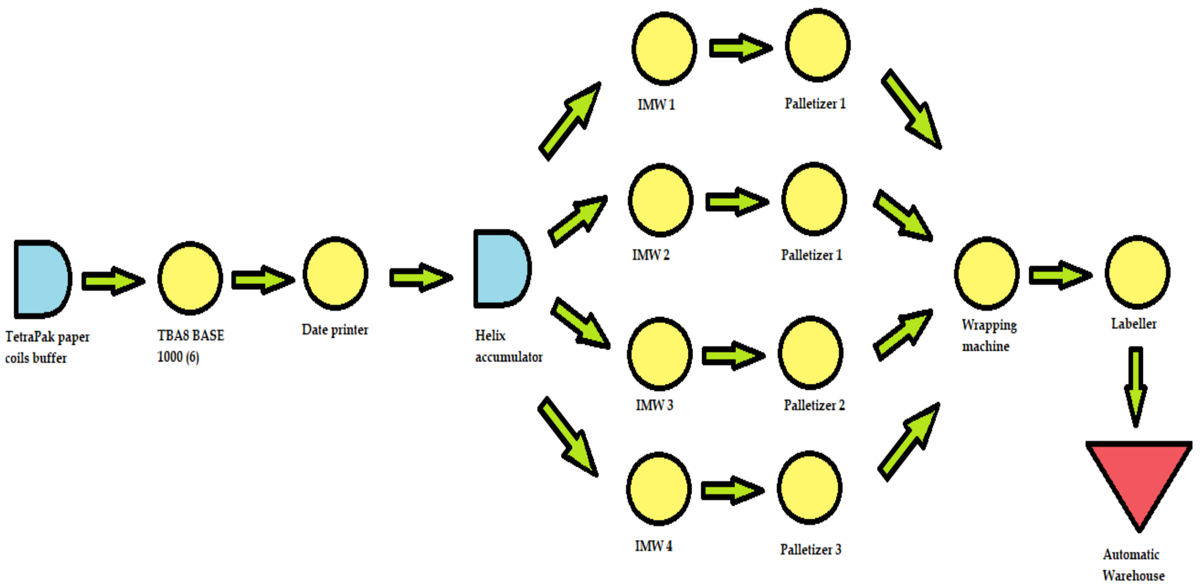


Figure 23-New line (6)
TBA8 Base 1000 + Date printer +Helix + IMW 1 or IMW 2 or IMW 3 or IMW 4 + Palletizer + Wrapping machine + Labeller

3 TPM implementation at 3A Latte Arborea

This thesis work was born thanks to the collaboration of the *3A Latte Arborea* Company that offered its complete availability to the implementation of the TPM in it.

3.1 The starting point in March 2019

At the beginning of 2019, *3A Latte Arborea* started to implement TPM in its departments. The first one was the milk-packaging department where this thesis work is inserted. The choice of activating TPM started with the top management, which during the months of January and February provided for the training of the employees. At the beginning, this type of maintenance management was almost unknown to the majority of the operators who for the first time found themselves facing these issues. Employee training began during seminars and courses held outside working hours. In order to undertake the training phase the Company has relied on an external consultant that could guarantee an excellent level of preparation for employees. The main problem of this phase was to inculcate to the operators the idea that TPM was not an additional job to what they were used to do during the working day but it was precisely the modification of their way of working in order to make more engaging and less tiring their day. Obviously, this was certainly not easy at the beginning: the idea of having to devote to cleaning and maintenance of machinery was not welcomed by the operators who had until then delegated these tasks to the maintenance and cleaning departments.

The main problem for them was the lack of time and help: they were unable to support the pressing production with TPM maintenance activities. They used to complain about the lack of time and the fact that they were never enough in one shift to be able to follow at the same time the machinery in production and the maintenance activities on the stationary machines and on the working environment. Despite all the problems that it would have involved, however, the idea of implementing the TPM was immediately accepted.

The employees immediately understood the purpose of the TPM and the target that the company wanted to meet. They recognized the activities of the TPM as useful and indispensable to achieve those standards set in terms of lean production. The training period turned out to be very useful from the point of view of the new knowledge inculcated to the workers and very useful for the top management to understand which one were the main problems of the employees who complained about too heavy work shifts and too little time available for activities other than production. Thanks to this mutual exchange of ideas and requests, the management engaged in the reorganization of work shifts: a new operator was added to the shift in order to support colleagues in the maintenance activities. At the same time, the workers devoted themselves more carefully to those activities of cleaning and maintenance of machinery that until then were largely neglected up.

One of the main points in order to start with the activities of the TPM is the monitoring of the various KPIs. Before March 2019, the Company did not in any way keep track of the machine stops, the problems that arose during work shifts, the improvements to be made, etc. The only spreadsheet that the operators filled out during the shift was the "daily production file" that kept the account of the various references produced and the lines used. These files were very useful for programming and monitoring production but were in no way used as a critical tool for analyzing performance and anomalies that were not registered anywhere.

The first step of this work still in progress, was to modify and often create new files to start taking note of any type of anomaly and different trend that occurred during the working day. Machine start-up and production start-up times, stops and their reasons, washings at the end of the shift, all started to be registered in the appropriate spreadsheets.

Before it was decided to activate the TPM in the departments, the micro-stops were always underestimated. All the stops less than five minutes that do not produce a line's stop but only a temporary impediment of easy and fast resolution such as a dropped packaging in the line, a cardboard stuck in the case-packer machine, a problem with the palletizer photocell which causes its stop, were not registered. In addition to confusion, these stops also cause the operators to work more and more, due to the high frequency of occurrence and the low repair time (low Mean Time Between Failure, MTBF), to run in the department for solve the problem before production stops. This makes the work shift more tiring and reduces the time available to the operators to devote themselves to maintenance activities on machinery and cleaning.

During the month of March a special paper sheet was created, always present in the department where the operator is required to mark all the micro-stops that occur during the shift, their duration and motivation. This sheet was then transcribed into a database on the company network so that the TPM coordinator through Pareto analysis could analyze it.

The cleaning of the working environment was limited to the washing of the machines at the end of the shift and the work environment by the cleaning companies. During the work shift, there was often a lot of mess and some components showed signs of wear and dirt that were evident before they were cleaned regularly. A precise and clear cleaning plan was therefore stipulated for each machine in the department, which the operators must follow carefully according to the planned schedule. They are the first responsible for the cleaning activities and a check sheet collects the signatures at the end of the activity. Through this check sheet if a machine still shows signs of dirt or poor lubrication or something else and therefore the maintenance activity required by the plan has not been respected, it is possible to easily trace the operator in charge who will respond accordingly.

3.2 The new production sheet

As already mentioned above, the production sheet used before the TPM implementation had the unique purpose of taking note about the production plan of the day. From a TPM perspective, production sheets must be a useful tool for analyzing the performance of machinery and for monitoring the efficiency of the plant. For this purpose, they must contain all the useful information in order to compute the various KPIs and the OEE index.

Each machine has to be carefully monitored and all its activities must be registered in the production sheet. During the month of March the old production sheets used in the department have been modified and improved in order to make it easier for operators to enter data and proceed automatically, using the appropriate formulas, to calculate the indices.

Compared to the past, operators will have to pay more attention to the data entered, which must be more accurate and error-free. Otherwise, the calculated indices will not be true and eventual corrections must be manually made where possible. Since the filling machines can serve different lines the production sheets automatically recognize the ones used and calculate the respective indexes without the operator having to manually insert the links in order to avoid human errors as much as possible.

The production sheets are divided into macro blocks in order to make it easier for the operator to insert the data in the correct positions thanks to a clear visual support.

3.2.1 *Data entry*

The following images show the macro block divided for topic that the operators must complete entering the request data. The first block registers the main times of the machine, automatically calculating set-up, downtime, production and washing time (cell with dark background).

Descrizione	Orario
Start Confezionatrice	
Inizio Produzione	
Fine Produzione	
Inizio lavaggi	
Fine Lavaggi	
Ore Preparazione Confez.	0,00
Ore Produzione	0,00
Ore lavaggi	0,00
Ore Mancata Produzione	0,00

Figure 24 -Time registering block

The second block concerns the stops made by the machine. The stops can be the most varied: from a failure to a stop for setup or format change etc. All these are however registered in the sheet by the operators. Automatically the sum of the times lost in the various lines will be calculated without the operator having to mark the stop in the respective line each time. This is made possible thanks to a careful calculation of the times in which the stop is registered going back on the served line. This will be useful for the calculation of the indexes of the lines which must therefore have the relevant data available.

GUASTI						
al min	CA	ORA FERM	DURA-TA	MOT. FERM	Classe Ferm.	N° Scarti
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					
0	5					

Figure 25 - Stoppages block

Within this block each column corresponds to a different entry, each row instead, will contain all the various stops. The first column automatically provides the minute of the day in which the stop occurred (since it will later be used to calculate the times lost in the line). The second column automatically calculates the case-packer that was served by the filling machine in that minute. The third contains the time in which the stop occurred in "hour:minute" format entered by the operator. The fourth column contains the duration of the stop. The fifth and the sixth contain the reason for the stop and the respective class to which it belongs and finally the last contains the number of packages discarded due to the stop.

CAMBIO CARTA								CAMBIO FETTUCCIA			
Rotolo		Orari	Numero	N° pz	Carta	N° pezzi	Codice	Ora	Oper	Rotolo Fettuccia	
Lotto	Numero	Camb	Pezzi	Riman	Rotta	Consuma	Refer.	Camb		Lotto	Numero
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					
						0					

Figure 26- TetraPak paper and strips block

The third block contains all the useful information regarding the paper rolls and the glue strips useful for packaging used in TetraPak machinery. With precise reference to the lots, the number of pieces used and the hours in which the paper or strip was changed, it is possible to calculate all the reference change times (each reference will have its own paper roll with the appropriate prints).

Certainly, the fourth block is the most complicated from the point of view of the contained formulas but also the most important for the purposes of data collection and successively to the correct calculation of the indices. It is an almost total automatic block where the operator's error has been reduced to the minimum through appropriate control formulas. Each column of this block plays a fundamental role in calculating the KPIs and the OEE index and a simple error could make the calculated indexes totally meaningless.

Unfortunately, sometimes it can happen that the operator incorrectly inserts a datum completely disrupting the meaning of the formulas but it is pretty easy to notice and remedy it. In this block all the references produced during the day by the machine are registered and automatically the lines served by the filling machine with that specific reference are calculated since, as previously described in chapter two, they can be different for the same filling machine. For each reference, the production start time and the total duration in minutes for that specific reference are automatically registered.

In addition, the liters produced, the product formats, the waste and the samples for each reference are calculated. These few lines contain a considerable amount of data useful for calculating KPIs and the OEE index.

					PRODUZIONE LATTE espresso in litri latte							Tot. latte sfrido	lotto latte	CAMPIONAMENTI			
					Cod.	gg.	Descrizione	Tot. latte	Contatore	Contatore	Tot. latte			N° Contr.		N° Camp.	
Carton.	min gio	min	ora inizio		Artic.	scad.	Articolo	Ingresso	Partenza	Finale	Confezion.			Lt	Pz.	Lt	Pz.
3	0	0						0			0			0		0	
3	0	0						0			0			0		0	
3	0	0						0			0			0		0	
3	0	0						0			0			0		0	
3	0	0						0			0			0		0	
3	0	0						0			0			0		0	
							TOTALI	0			0	0		0	0	0	0

Figure 27 - Milk production block

3.2.2 *Key Performance Indicators (KPIs) and the OEE index*

The calculation of the various KPIs and the OEE index is certainly the key point of the TPM implementation work. In this paragraph, the formulas and procedures used for the calculation according to the company method will be illustrated. As already underlined in the first chapter, each company is free to adapt the Japanese theory according to their needs and their targets. It’s the case of *3A Latte Arborea* that chose to modify the Availability index with respect to the one provided by Nakajima.

As shown below, this index includes the operator's entire working day, making the performance analysis more truthful at the expense of a lower OEE. The other KPIs calculated in the production sheet beyond the Availability index are the Performance rate, the Quality rate and the Plant utilization rate.

A special space in the production sheet has been dedicated to writing some formulas that automatically calculate the various indexes and combine them in such a way as to make the subsequent analysis of the TPM coordinator simpler, free of human errors and faster having already outlined each index in a summary table.

Each line that produces during the day has its own indexes and this work is automatically done every day for each month. Every fortnight a further table summarizes the calculated data in order to make it even faster to read. Moreover, the production sheet provides a Pivot chart for the daily, weekly or monthly analysis of the indexes done line by line. In addition, the liters produced, the rejects, the percentage rejects/liters stored, the stops are all data that are automatically calculated and shown with Pivot charts with the frequency chosen by the coordinator TPM. This is precisely the strength of the OEE index: being the combination of several KPIs makes it possible to find very quickly the weak point of the production system and act directly on that.

The following images provide a more detailed explanation of the formulas used in calculating the indexes.

Overall Equipment Effettiveness LINEA	Tempo disponibile linea [min]	Fermate [min]	Tempo Funzionamento	DISPONIBILITA'	EFFICIENZA PRESTAZIONI	TASSO QUALITA' PRODOTTI	OEE	TASSO UTILIZZO IMPIANTO	OEE su giornata lavorativa impianto
CONF.1 - IMW 5 - NPM 3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 2 - IMW 1 - NPM 1	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 3 - IMW 1 - NPM 1	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 3 - IMW 3 - NPM2	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 4 - IMW 3 - NPM 2	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 4 - IMW 1 - NPM 2	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 4 - IMW 4 - NPM 3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 4 - IMW 5 - NPM 3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 5 - IMW 4 - NPM 3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 5 - VALIGETTA - NPM3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 6 - IMW 1 -NPM 1	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 6 - IMW 2 -NPM 1	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 6 - IMW 3 -NPM 2	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
CONF. 6 - IMW 4 - NPM 3	0	0	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Figure 28 - KPIs and OEE automatic table

As previously described in chapter two, the lines underwent a change in June. This does not however entail a substantial modification to the formulas used in the calculation but only a modification to the cells so that the indices are updated automatically with the new references. Therefore, it is noted that the formulas described below have not undergone conceptual changes during the period where this thesis work is inserted (from March to November 2019).

Overall Equipment Effettiveness LINEA
CONF.1 - IMW 5 - NPM 3
CONF. 2 - IMW 2 - NPM 1
CONF. 2 - IMW 3 - NPM 2
CONF. 2 - IMW 4 - NPM 3
CONF. 3 - IMW 1 - NPM1
CONF. 4 - IMW 3 - NPM 2
CONF. 5 - IMW 4 - NPM 3
CONF. 5 - VALIGETTA - NPM3
CONF. 6 - IMW 2 -NPM 1
CONF. 6 - IMW 3 -NPM 2
CONF. 6 - IMW 4 - NPM 3

Overall Equipment Effettiveness LINEA
CONF.1 - IMW 5 - NPM 3
CONF. 2 - IMW 1 - NPM 1
CONF. 3 - IMW 1 - NPM 1
CONF. 3 - IMW 3 - NPM2
CONF. 4 - IMW 3 - NPM 2
CONF. 4 - IMW 1 - NPM 2
CONF. 4 - IMW 4 - NPM 3
CONF. 4 - IMW 5 - NPM 3
CONF. 5 - IMW 4 - NPM 3
CONF. 5 - VALIGETTA - NPM3
CONF. 6 - IMW 1 -NPM 1
CONF. 6 - IMW 2 -NPM 1
CONF. 6 - IMW 3 -NPM 2
CONF. 6 - IMW 4 - NPM 3

Figure 29 - Lines before and after June

Figure 29 shows the lines in the table in the period before and after replacing the filler machine in June. As it is possible to notice, the lines go from being eleven to fourteen. Note that, the word "CONF" stands for filling machine, "IMW" stands for case-packer and "NPM" stands for palletizer.

Tempo disponibile [min]
0
0
0
0
0
0
0
0
0
0
0

Figure 30- Available time [min]

The second column of the table (Figure 30) represents the available time computed for each line. This is basically the second biggest change requested by the company in the calculation of the OEE. In Nakajima's theory, the available time is conceived simply as the entire working day minus the planned downtime. In the Company's concept, the time available also includes set-up, washing and inactivity times, although these are all programmable times. This column is able to recognize all these times inserted by the operator in the production sheet and sums them up avoiding all human errors.

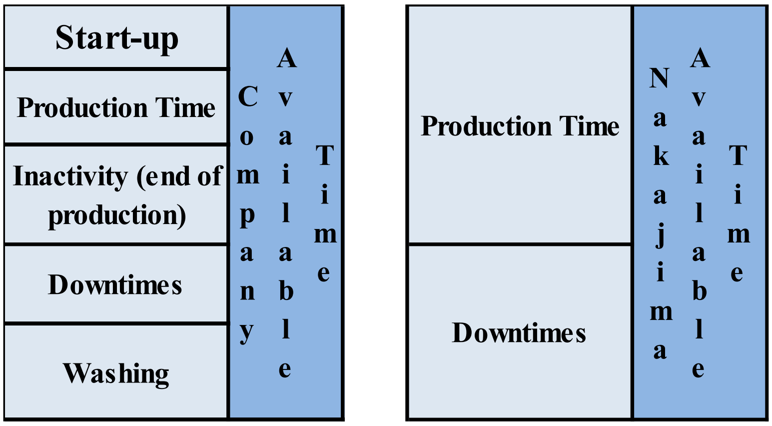


Figure 31-Available Time differences

Fermate [min]
0
0
0
0
0
0
0
0
0
0
0

Figure 32-Downtimes

The second column (Figure 32) is simply the sum of all the downtimes of each line that must be subtracted to the available time in order to get the Operating Time column (Figure 33).

Tempo Funzionamento [min]
0
0
0
0
0
0
0
0
0
0
0

Figure 33-Operating Time

The first KPI to be calculated is the *Availability*. This parameter contains in itself the modification present in the calculation of the Available time, therefore, this makes it different from the Availability index present in literature.

In formula, it is calculated as:

$$Availability = \frac{Operating\ time\ [min]}{Available\ Time\ [min]}\ \%$$

Once that Availability is computed, it is necessary to evaluate the production and the wastes in order to compute the second fundamental index: the *Performance rate*. Again, the production sheet is able to compute automatically both the produced liters and the produced packages and store all these data in a summary table (Figure 34) in order to make production monitoring easier.

scarti pezzi	prod. litri	scarti litri	prod. pz
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0	0
0	0	0,0	0,0
0	0	0,0	0,0
0	0	0,0	0,0

Figure 34-Production and waste monitoring

Once obtained these data it is possible to calculate the *Performance rate*. The Nakajima's formula provides the knowledge of the theoretical cyclical time of each package [min/item]. This is given by the high technology of the TetraPak machines that instantly supply this data during the production hours. The cyclical time is then multiplied by the total production and divided by the operating time of the line. This index is of considerable importance to understand the performance of the machine and how much its maximum capacity is being exploited.

In formula:

$$Performance\ rate = \frac{Theoretical\ cyclical\ time\ \left[\frac{min}{item}\right] x\ Total\ Production\ [item]}{Operating\ time\ [min]}\ \%$$

In the production sheet the sixth column collects these indexes for each line (Figure 35).

EFFICIENZA PRESTAZIONI
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%

Figure 35- Performance rate

Thanks to the data collected in the table in Figure 34, it is possible to calculate the last fundamental index for the calculation of the OEE: the *Quality rate*. This index is simply given by the difference between the total production and the waste divided by the total production.

In formula:

$$Quality\ rate = \frac{Total\ production\ [item] - Waste\ [item]}{Total\ production\ [item]}\ \%$$

TASSO QUALITA' PRODOTTI
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%
0,0%

Figure 36- Quality rate

Finally, all the indexes necessary for the calculation of the OEE are available. It will be the product of the three indexes and its value, in Nakajima's theory, should be at least 85% to have excellent performances.

In formula:

$$OEE = Availability\ x\ Performance\ rate\ x\ Quality\ rate$$

However, *3A Latte Arborea* has requested that the OEE index would be calculated differently. Instead of multiplying the previously calculated *Availability*, a new index, which is a function of the entire working day of the plant and not of the single machine, is multiplied. This is a much more restrictive factor because the working day can be far greater than the availability of the single line, greatly influencing the OEE that will be lower. This is a precautionary approach that the company wanted to include in the production sheet as a means of comparison with respect to the classic OEE. The OEE, the new Availability called "Plant operating rate" and the new modify OEE are illustrated in the last three columns of the table, Figure 37.

The *Plant operating rate* so is calculated as the operating time of the line over the entire working day express in minutes.

$$Plant\ operating\ rate = \frac{Operating\ time\ [min]}{Working\ day\ [min]}\ \%$$

Being the new modified OEE:

$$OEE_{mod} = Plant\ operating\ rate\ x\ Performance\ rate\ x\ Quality\ rate$$

OEE	TASSO UTILIZZO IMPIANTO	OEE su giornata lavorativa impianto
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%
0,0%	0,0%	0,0%

Figure 37-Plant operating rate, classic and modified OEE

3.3 The micro-stoppages sheet

As already seen in the previous chapters, micro-stoppages are those less than five minutes. They influence chiefly the productivity of the plant in terms of reduction of velocity. Production does not stop every time a micro-stoppage occurs but it is strongly influenced as it increase the real cyclical time and makes the work of the operator assigned to that line more frenetic as it has to restore the anomaly before the line stops. From a practical point of view the micro-stoppage is even worse than the failure as it is much more frequent and sometimes more difficult to notice. Although the recovery time is much lower, it could occur even two or three times every half hour if the line is not perfectly maintained in a TPM perspective.

Since marking each micro-stoppage of a line in the production sheets described above would be impossible from a practical point of view, it would be necessary for the machine to mark them automatically in its own internal software. Nevertheless, the machines of the packaging department do not have this automatism, except for the TetraPak filling machines.

For this reason, in the month of March, a new sheet (Figure 41) was created and distributed in the department. The operator has to mark the type of micros-stoppage, the machinery involved, the time, the duration, the intervention performed and the person in charge. In the following zoom of the micro-stoppages sheet is here proposed:

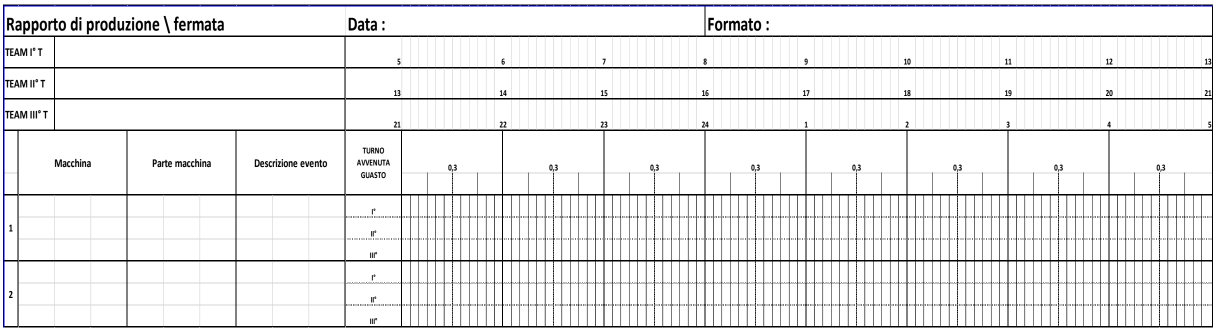


Figure 38 - Zoom of micro-stoppage sheet

As it's possible to notice, in the upper part on the left the operators are marked during the three working shifts. Through a specific time scanning method it is possible to divide the working day into cells where each one represents five minutes of time. The micro-stoppage must be marked, according to the time of the event, through a black mark in the specific cell. In the three left columns instead the machines involved, the type of anomaly and the description will be specified.

Every day these sheets once compiled are collected and registered in a database on the company network. The TPM coordinator for the analysis then uses this database and present the necessary improvements. The analysis of the micro-stoppages is mainly based on the study of the three fundamental parameters: MTTF, MTTR, MTBF.

- **MTTF (Mean Time To Fail):** Is the mean time in which a machine failure is expected to recur after the previous one has been repaired.
- **MTTR (Mean Time To Repair):** Is the necessary mean time for the maintainer to repair the machine.
- **MTBF (Mean Time Between Failure):** Is the sum of the previous two and it represents the mean time between two failure considering also the time to repair.

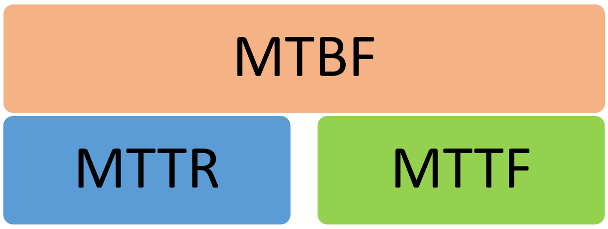


Figure 39- MTBF=MTTR+MTTF

Another fundamental tool for the analysis of micro-stoppages is the Pareto chart. It is a graph as simple as it is effective and indispensable. Once the micro-stops sheets have been registered in the database it is possible to construct the graph by grouping similar anomalies under the same heading. The Pareto diagram is simply a histogram that presents the anomalies occurred on the abscissa and the sum of the duration of the anomaly on the ordinate.

Obviously, the sum of the durations is based on a period of time that depends on the type of the analysis, but the structure of the chart is always the same. Another fundamental element of the diagram is the cumulative line. Thanks to this line, it is possible to understand visually the percentage that that particular anomaly has on the total. This diagram is also called "80-20": the vast majority of cases require that 80% of the total stop's minutes is given by the 20% of the anomalies occurred. This means, in other words, that by acting on that 20% of headings you can already reduce the total stop's minutes by 80.

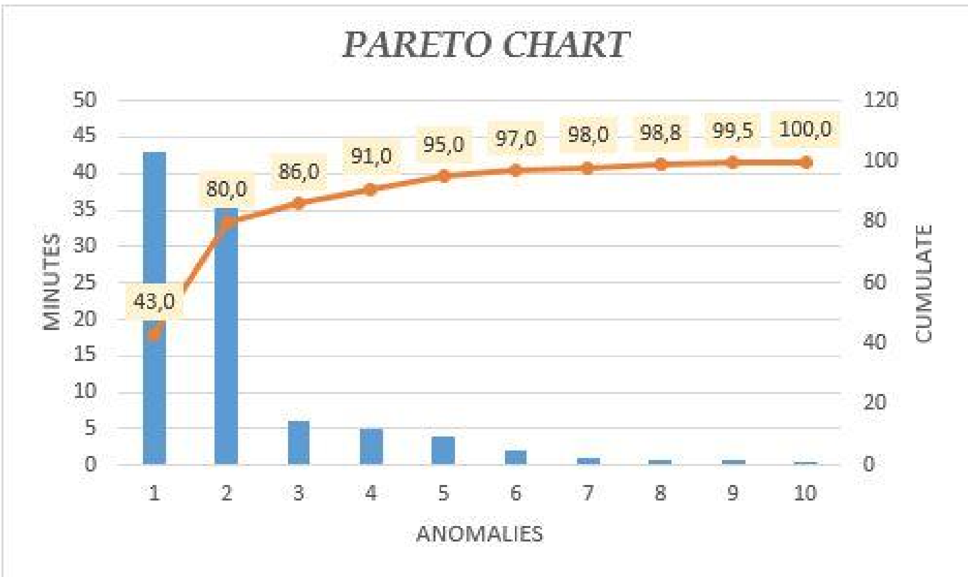


Figure 40 -Generic Pareto chart

In figure 41, the complete micro-stoppages sheet actually used in the departments is shown.

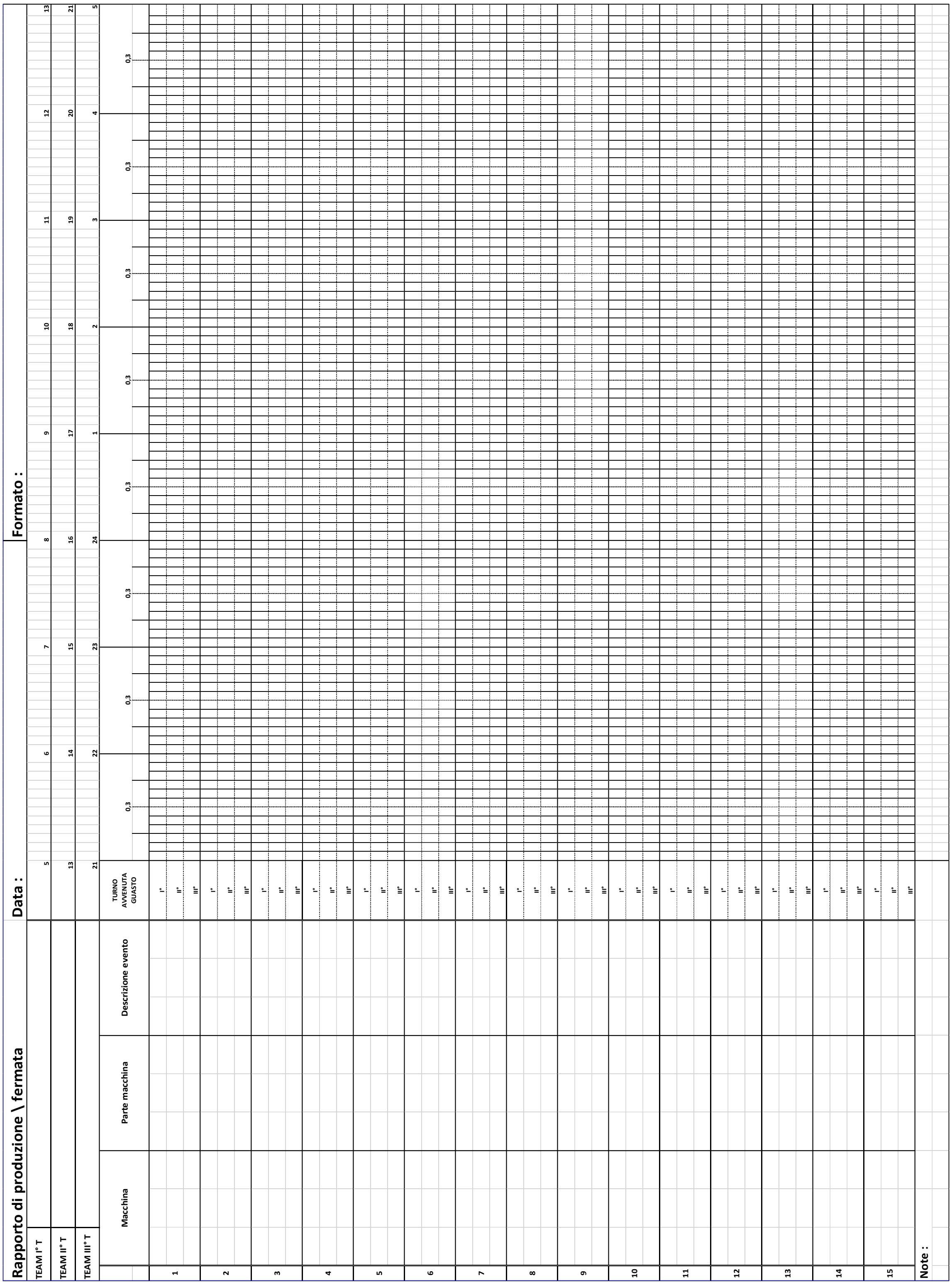


Figure 41 - Micro-stoppages sheet

3.4 The anomalies tags and their database

The TPM provides all those activities that are essential for the correct functioning of the machinery. It is impossible to get high performance from a poorly maintained equipment. Cleaning then becomes a key and strictly necessary element. Any sign of wear or dirt in the machinery indicates a poor aptitude for cleaning and therefore certainly the implementation of the TPM will be unsuccessful. The cleaning activity is not only the removal of filth; it is a much more elaborate and less banal process: it becomes the first means for the inspection of the equipment. As previously seen, with TPM, each operator becomes the direct manager of the machine on which he works. Through the cleaning activity at the end of the shift, it can personally inspect its machine, so it can detect all signs of wear, poor lubrication, poor tightening, and etcetera. All these anomalies, once resolved, ensure a much more efficient machine operation. From a TPM perspective, each machine must be able to work in its maximum conditions, as if it had just been installed in a factory.

However, sometimes it is not always possible for the operator to resolve any anomalies found during the cleaning and inspection activity. In this case the maintenance department must be involved. It is very important, however, that the operator realizes the anomaly in time and communicates it to the maintenance department who will fix it. Within the *3A Latte Arborea*, the use of tags for resolving anomalies has been therefore used since April.

The anomaly tag is a very valid tool to inform the maintenance department of the anomaly found and that cannot be solved instantaneously during the cleaning activity. Through the use of distinct colors it is possible to visually recognize the type of anomaly:

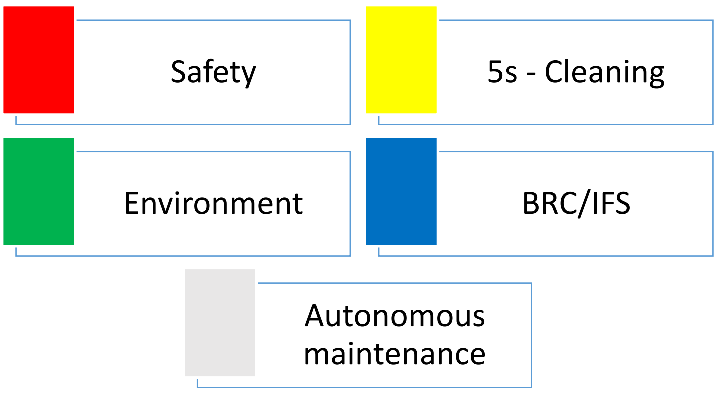


Figure 42 - Tags colors

Each card is numbered and it presents a special space for the description of the anomaly found, the area of the department and the machinery involved.

Figure 43 - Security Tag

Once the card has been filled out, the operator will have a copy of the card to be displayed on the DMS (daily management system) board in the department. The other copy will be directly attached to the machine so as to visually signal the presence of the anomaly to the other operators and to the maintenance department.

Figure 44 - Environment Tag attached in the machine

However, such use of tags is not sufficient. An issued tag must be solved as soon as possible from the maintenance department but this would not be possible if the latter was not notified of the presence of the anomaly since it is not always physically present in the production department. Therefore, each card must be registered in a database on the company network that notifies the issue to the other departments involved.

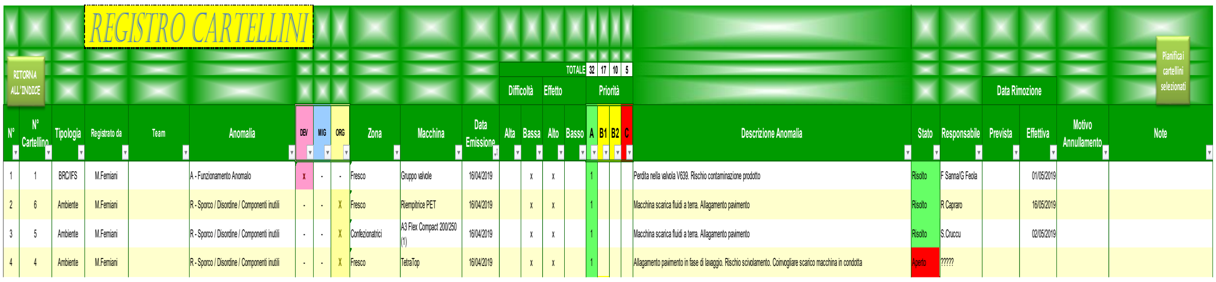


Figure 45 - Tags database

Analyzing more in detail:

Figure 46 - Tags database's first columns

The first column represent the total number of tags issued. The second one contains the specific number of the respective tag. The third is the typology of the tags physically indicated by the different colors. The forth and the fifth contains respectively the name of the operator that issue the tags and the name of the team leader of the group working in that line (**Note**: the two golden rectangles has been inserted for privacy reasons). The sixth describes the type of anomaly registered, it can be:

- A- Abnormal operation
- B- Worn/broken part

- D- Difficult cleaning
- J- Oil/grease loss
- K- Product loss
- L- Air/CO2/Vapor loss
- M- Exposed electrical cables
- R- Dirty/mess/useless parts
- S- Electrical
- V- Improvements

The last three columns shows the type of intervention to be carried out: DEV stands for "standard condition deviation", MIG stands for "ameliorative" and ORG stands for "organizational". The system automatically assigns them in function of the anomaly reported.

Then, there are:

			Difficoltà		Effetto		Priorità			
Zona	Macchina	Data Emissione	Alta	Bassa	Alto	Basso	A	B1	B2	C
Fresco	Gruppo valvole	16/04/2019		x	x		1			
Fresco	Riempitrice PET	16/04/2019		x	x		1			
Confezionatrici	A3 Flex Compact 200/250 (1)	16/04/2019		x	x		1			
Fresco	TetraTop	16/04/2019		x	x		1			

Figure 47- Tags database's central columns

The first two central columns are respectively the zone and machine involved and reported in the tags. Then there is immediately the date of emission followed by a first evaluation done by the operator about the difficulty of the intervention and the effect that the anomaly has on the production. The combination of the difficulty and the effect gives the priority matrix so computed:

- Low difficulty + High effect = Priority A
- Low difficulty + Low effect = Priority B1
- High difficulty + High effect = Priority B2
- High difficulty + Low effect = Priority C

			Data Rimozione			selezionati
Descrizione Anomalia	Stato	Responsabile	Prevista	Effettiva	Motivo Annullament	Note
Perdita nella valvola V639. Rischio contaminazione prodotto	Risolto			01/05/2019		
Macchina scarica fluidi a terra. Allagamento pavimento	Risolto			16/05/2019		
Macchina scarica fluidi a terra. Allagamento pavimento	Risolto			02/05/2019		
Allagamento pavimento in fase di lavaggio. Rischio scivolamento. Coinvogliare scarico macchina in condotta	Aperto					

Figure 48 - Tags database's last columns

The last columns are respectively the anomaly description, the current state of the tag (issued or closed), the maintainer in charge, the planned and actual removal date, the eventual annulment reason, and the optional note.

This file, in addition to collecting all the tags issued and closed during the course of the months, also offers the TPM coordinator a valid tool for analysis through Pivot charts, histograms, etc. calculated automatically as it will be shown in the following chapters. Moreover, these graphs make the visual management of progress made over the months quicker and simpler also for the operators, offering a great stimulus for continuous improvement.

3.5 Autonomous maintenance

3.5.1 The training period

In the previous paragraphs, it was shown how fundamental the training period is for operators who approach TPM for the first time. Through training sessions and seminars held during the first few weeks, attempts are made to familiarize the TPM and to inculcate to all employees, from operators to top management, the idea that all new planned activities are not superfluous work added to production but both an integral and necessary part of the entire production process.

After this first period of theory, the TPM provides for the practical training of the operators: they must be able to recognize and resolve the simplest anomalies such as the wear of a component, the poor greasing of a bearing, a too slow tightening that induces noise and vibrations and etcetera. The Japanese methodology teaches that the anomaly is not inevitable over time but it is always avoidable if the basic autonomous maintenance rules are respected.

When a defect is found during the inspection / cleaning activity, the operator must ask how the anomaly came about and what can be done to prevent it from happening again in the future. This process is defined as *continuous improvement* and it allows the company to achieve excellent quality standards over the years. This progressive improvement in the skills of workers results in continuous improvement of the company. Once this concept has been acquired at all company levels, the TPM will be a much simpler and more welcome process.

The so called One Point Lessons (OPLs) have been spread in the plant in order to teach some specific ability. These offer the possibility of giving instructions rapidly and clearly for a specific job. Following the instructions illustrated in the OPL, the operator will be able to carry out the planned activity autonomously, even if this was not his job until recently and he turned to the maintenance department.

In the following images, just two of them are shown by way of example:

Figure 49 - OPL service

Figure 50 - OPL Masterbatch

3.5.2 *The cleaning activities*

The following step is the teaching of inspection/cleaning activities. Cleaning is divided into two main types: the Total Clean Out (TCO) and the programmed cleaning plan. Both these two type of activities are followed by the *Kaizen* activity. The latter means all those precautions to be adopted in the machine in order to prevent anomalies, dirty or future failures.

3.5.2.1 *The Total Clean Out (TCO)*

The Total Clean Out activity provides to restore to the initial condition the equipment of the plan. TCO has to be done first the other TPM activities in order to set the standard from which start the future cleaning/inspection. Once the standard has been defined, this must be maintained over time in order to make better use of the machinery. During the TCO activity, all the areas of the department are taken one at a time and a full day is spent with two or three operators and a maintenance technician for the complete cleaning of the machinery. In addition, the maintenance technician will completely restore the conditions of best operation of the machine through lubrication, tightening, replacement of defective parts, etc.

In the following images some interventions carried out during the TCO of some critical areas of the plant are shown. Due to their difficulties in accessibility, these areas were too often neglected by cleaning activities until recently.

Figure 51 - TCO drain recovery tank

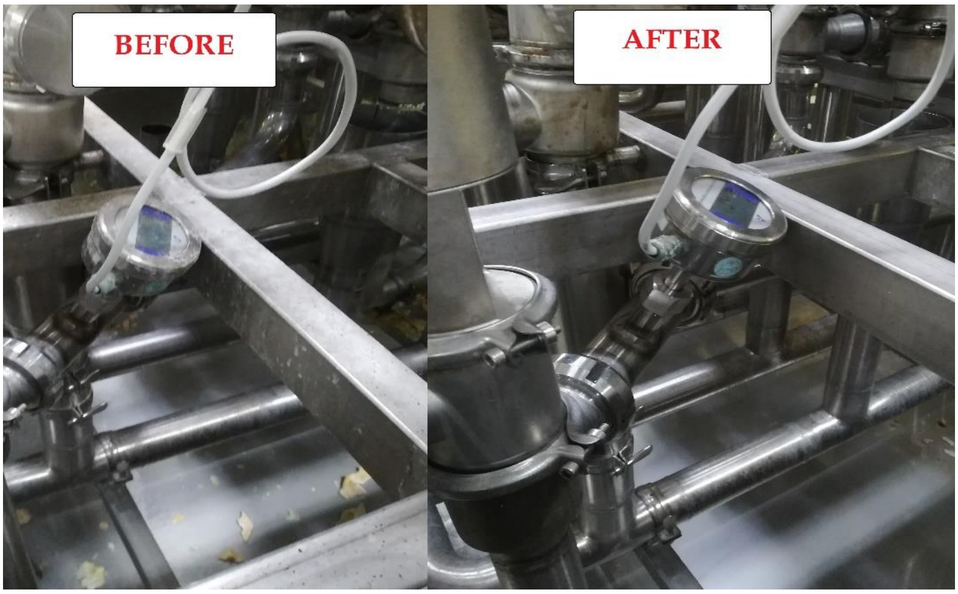


Figure 52 -TCO valve area

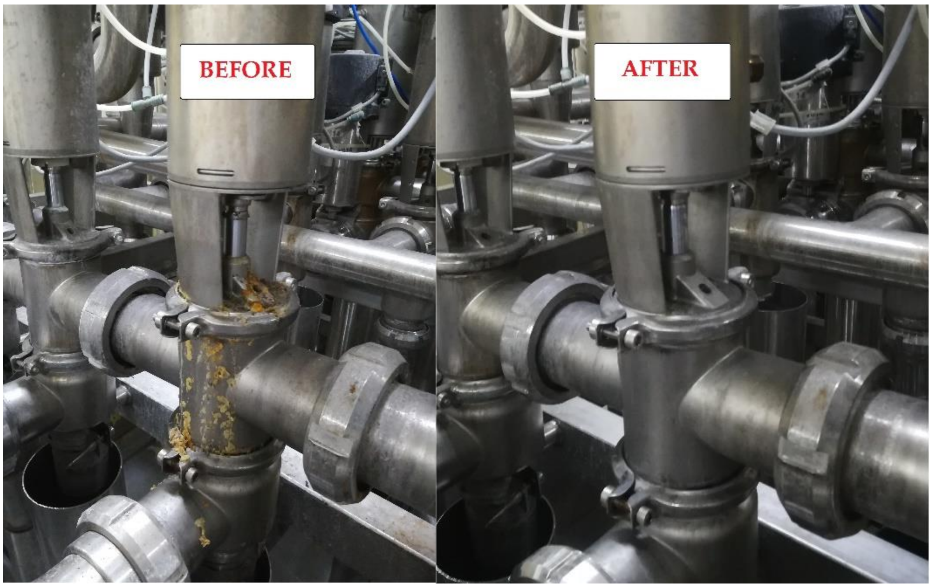


Figure 53 - TCO piping zone

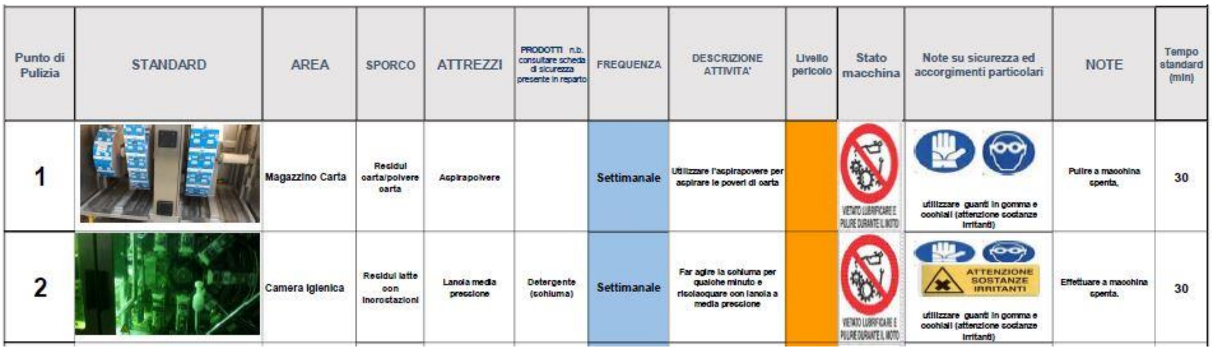
Figure 54 - TCO filling machine's upper part

3.5.2.2 The programmed cleaning plan

Once the optimal conditions of the machine have been restored with the TCO activity, the new standard has to be maintained over the years through the programmed cleaning plan. It is a list of cleaning/maintenance activities to be carried out with a predetermined frequency that can be daily, weekly, monthly etc.

The operator at the end of its shift has to strictly follow the instruction and the steps highlighted in the cleaning plan. Inside the plan it is possible to find the order in which the activities are carried out, the image of the machine part involved, the procedure of the activity, the tools to be used, the necessary PPE (Personal Protective Equipment), and the grade of risk of the activity. The latter has to be established by the plant security officer that will assign a more or less large number depending on the risk associated. The drafting of these cleaning plans was carried out in the month of April inside the Company.

As shown in Figure 55 each column has its own specific function.



Punto di Pulizia	STANDARD	AREA	SPORCO	ATTREZZI	PRODOTTI n.b. consultare scheda di sicurezza presente in reparto	FREQUENZA	DESCRIZIONE ATTIVITA'	Livello pericolo	Stato macchina	Note su sicurezza ed accorgimenti particolari	NOTE	Tempo standard (min)
1		Magazzino Carta	Residui carta/polvere carta	Aspirapolvere		Settimanale	Utilizzare l'aspirapovere per aspirare le poveri di carta		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Pulire a macchina spenta.	30
2		Camera igienica	Residui latte con incrostazioni	Lancia media pressione	Detergente (schiuma)	Settimanale	Far agire la schiuma per qualche minuto e risciacquare con lancia a media pressione		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Effettuare a macchina spenta.	30

Figure 55 - Cleaning plan's zoom

The first column is the number of the activity to be executed. The second shows the standard condition in which the machine should be brought back at the end of the activity. The third puts on evidence the area of the machine involved. The forth and the fifth and the sixth are respectively a description of the type of dirty that is present in that area, the tools that are necessary to the cleaning and the type of chemical product to use. Then there is the frequency column: each frequency has its own color (in the figure the light blue stands for "weekly"). Then there is the description of the activity. The ninth show with a color, defined in the upper part on the right of the plan, the grade of risk assigned for that specific activity with a visual alarm on the tenth and eleventh columns. The last two are finally used for some specific note and for the standard time that that activity requires.

In Figure 56, the complete cleaning plan for machine "TT3" is reported by way of example:

Arborea	REPARTO DI CONFEZIONAMENTO PIANO PULIZIA A CURA DEL CONDUTTORE										P	
									Livello di pericolo: "R1" = Grave non moderato "R2" = Significativo non moderato "R3" = Guardia non moderato "R4" = Accettabile tollerabile non moderato "R5" = Irrilevante moderato			
Revisione	n°0	TEAM-->	LINEA TT3								TEMPO TOTALE STANDARD (min) -->	470
Data emissione	4-mag-19	Codice documento		EMESSO:		Responsabile di Reparto						
Punto di Pulizia	**STANDARD**	**AREA**	**SPORCO**	**ATTREZZI**	**PRODOTTI** n.b. consultare scheda di sicurezza presente in reparto	**FREQUENZA**	**DESCRIZIONE ATTIVITA'**	**Livello pericolo**	**Stato macchina**	**Note su sicurezza ed accorgimenti particolari**	**NOTE**	**Tempo standard (min)**
1		Magazzino Carta	Residui carta/polvere carta	Aspirapolvere		Settimanale	Utilizzare l'aspirapovere per aspirare le poveri di carta		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Pulire a macchina spenta,	30
2		Camera igienica	Residui latte con incrostazioni	Lancia media pressione	Detergente (schiuma)	Settimanale	Far agire la schiuma per qualche minuto e risciacquare con lancia a media pressione		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Effettuare a macchina spenta.	30
3		Formazione carta	Residui carta/polvere carta	Aspirapolvere		Settimanale	Pulire con aria e Utilizzare l'aspirapovere per aspirare le poveri di carta		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	utilizzare guanti in gomma e occhiali	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	30
4		Pavimento sotto nastri	Limo, latte, residui scorrimento nastri	Lancia media pressione	Detergente	Settimanale	Risciacquare		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma butilica o nitrilica e occhiali	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	90
5		Vetri pareti Macchina	Residui latte con incrostazioni	Spugna	Detergente	Mensile	Pulire con spugneta e detergente		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	60
6		Nastri	Limo, latte, residui scorrimento nastri	Lancia media pressione	Detergente	Quidicinale	Far agire la schiuma per qualche minuto e risciacquare con lancia a media pressione		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	60
7		Pavimento in ingresso macchina/corridoio	Limo	Lavapavimenti	Detergente	2/settimana	Pulire il pavimento con l'utilizzo della lavapavimenti e il detergente		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO			60
8		Incartonatrice	Polvere e residui di carta	Tubo aria		GIORNALIERO	Pulire con aria e con panno umido all'occorrenza entrambi i lati		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	utilizzare guanti in gomma e occhiali	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	30
9		Vetri pareti Macchina	Residui latte con incrostazioni	Spugna	Sgrassatore	Settimanale	Pulire con acqua e sgrassatore, utilizzare un panno		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	20
10		Pavimenti	Latte e limo	Lancia media pressione	Detergente	Settimanale	Pulire con il detergente		VIETATO LUBRIFICARE E PULIRE DURANTE IL MOTO	ATTENZIONE SOSTANZE IRRITANTI utilizzare guanti in gomma e occhiali (attenzione sostanze irritanti)	Pulire a macchina spenta, verificare che la macchina sia in regola. In caso di anomalia emettere il cartellino.	60

Figure 56 - TT3 Cleaning plan

3.5.2.3 *The check paper*

The cleaning plan is not sufficient if it is not followed by the check paper. In the latter, the execution of the activities has to be reported by the operator in charge that has to sign the check paper to declare that the work was done.

In Figure 57, the check paper of machine "TT3" is shown:

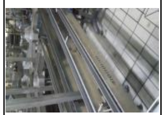
ARBOREA THE ITALIAN DAIRY COMPANY SINCE 1956	SCHEDA DI PULIZIA A CURA DEL CONDUTTORE													2019
Data emissione		Revisione		LINEA TT3										
Frequenza	Settimanale		Settimanale		Settimanale		Settimanale		Mensile		Quidicinale		2/settimana	
Foto														
minuti standard	30		30		90		60		20		60		60	
Punto di pulizia	1		2		3		4		5		6		7	
AREA	Magazzino Carta		Camera igienica		Formazione carta		Pavimento sotto nastri		Vetri pareti Macchina		Nastri		Pavimento in ingresso macchina/corridoio	
	Tempo	Firma	Tempo	Firma	Tempo	Firma	Tempo	Firma	Tempo	Firma	Tempo	Firma	Tempo	Firma	Tempo	Firma
Gennaio 1																
Gennaio 2																
Gennaio 3																
Gennaio 4																

Figure 57 - TT3 check paper

As it is possible to notice the first colored raw shows the frequency of the activity: light blue is "weekly", green is "monthly", orange is "fortnightly" and the last is "twice a week". Under the pics, which illustrate the machine's part involved in the activity, there is the raw of the standard time. It sets the standard time that is required to carry out the activity, a higher execution time will not be positive and it will mean that something is not going right.

Then the cleaning plan sets the areas of the activities previously graphically identified by the pics. The last part collects for every week the signs of the operators in charge and the execution times.

3.5.3 *The maintenance board*

Another indispensable element in the TPM is the maintenance board. Small teams of operators headed by a team leader carry out the autonomous maintenance activities. In order for all these activities to be well coordinated and clear to all groups, it is necessary to have a maintenance board in the department. The board collects a series of indispensable information for the TPM activities. It is divided by macro areas: each area identifies a different sector such as safety, product quality, cleaning, and etcetera. For each area there is space for the issued and closed tags, the graphs related to their performance, the improvement activities planned with the operators in charge and the scheduled dates. It is very important that the board is in a strategic position: it must be easily visible to all operators and must be located at a point where it is possible to hold the morning meeting where the department head establishes the daily schedules and monitors the progress of the previous day's activities. In addition, all the charts useful for OEE and quality analysis, Pareto diagrams, etc. are posted inside the board.

Figure 58 - 3A Latte Arborea maintenance board

4 The analysis

Once the work done from March to September for the TPM implementation has been presented and illustrated in the previous chapter, it is necessary to show and analyze the first result obtained by the spreadsheet created in the first months and actually used by the Company.

4.1 The OEE indexes from March to November 2019

The production sheets previously illustrated have the main advantages to offer daily the possibility of monitoring the principal indexes. This type of analysis makes easier for the TPM coordinator to have a complete view about the trend of the performance during the months. It is so possible to easily figure out the best/worst day of productivity and rapidly act on it putting on evidence the main anomalies that characterized it. Due to the fact that the Company ask for its own modified OEE (taking into account the entire working day of the operators instead of the machines' one) the volume of productions strongly influence the OEE index that can assume very different values during the months affecting the monthly average.

In the Appendix, it's possible to see the trend and the daily results of each machine month to month from March to November (please, note that for the month of June some lines are affected by the substitution of the TetraPak filler machine as previously described).

4.2 A sample OEE analysis

By way of example, in this paragraph, a complete OEE analysis for the month of September 2019 is shown. The first step to conduct an in-deep analysis is to monitor the trend of the OEE index during the month.

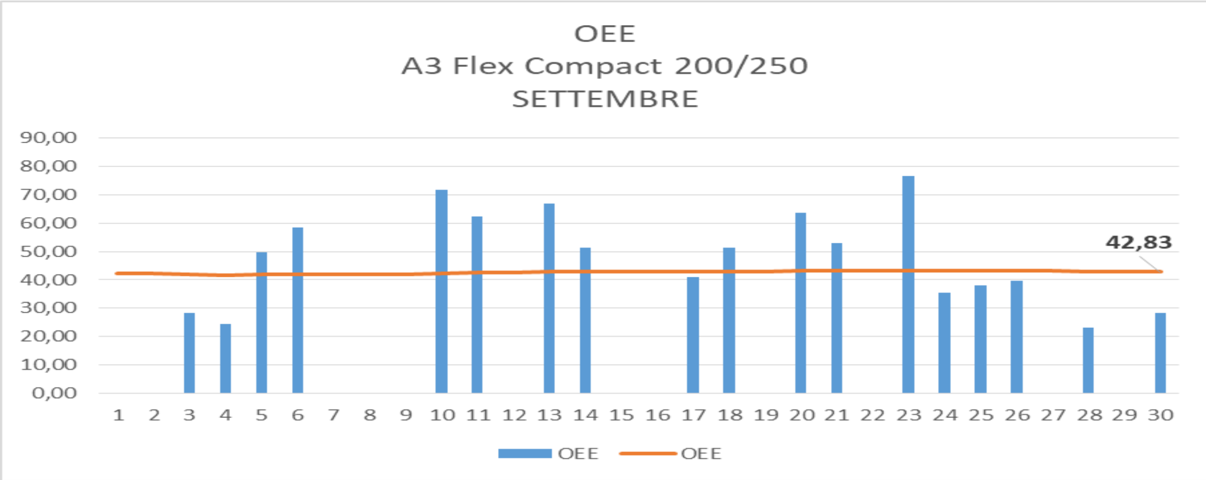


Figure 59- OEE trend in September for filler machine (3)

It's possible to notice that in the 1st, 2nd, 7th, 8th, 9th, 12th, 15th, 16th, 19th, 22nd, 27th, 29th the filler machine (1) didn't work and so the OEE index is zero (note the OEE equals to zero does not influence the mean value). The first value that rapidly stands out is the OEE of the 28th, roughly 20%.

This value is quite distant from the monthly average of 42.83% suggesting that something probably went wrong. The first thing to do is to check that there were no errors during the data transcription by the operator. Then, established that there are none, the production sheet that has been modified in March, allows to monitor how the productivity went. In the following figures, the relevant data for the filler machine (1) in the production sheets are shown:

Start Confezionatrice	**5**	**0**
Inizio Produzione	**5**	**58**
Fine Produzione	**8**	**22**
Inizio lavaggi	**14**	**16**
Fine Lavaggi	**15**	**1**
Ore Preparazione Confez.	**0,97**	
Ore Produzione	**2,32**	
Ore lavaggi	**0,75**	
Ore Mancata Produzione	**0,08**	

Figure 60- Times of machine (1) in 28-09-2019

GUASTI						
al min	CAR	ORA FERM	DURA-TA	MOT. FERM	Classe Ferm.	N° Scarti
434	5	07:14	2	CCA	C	31
442	5	07:22	1	CCA	C	31
0	5		2	FMC	C	61

Figure 61- Machine (1) stops in 28-09-2019

Tempo disponibile linea	Fermate [min]	Tempo Funzionamento	DISPONIBILITA'	EFFICIENZA PRESTAZIONI	TASSO QUALITA' PRODOTTI	OEE	TASSO UTILIZZO	OEE su giornata lavorativa
611	5	149	24,4%	93,0%	97,9%	22,2%	10,3%	9,4%

Figure 62- Principal Machine (1)'s KPIs in 28-09-2019

scarti pezzi	prod. litri	scar ti	prod. pz
442	4.202	88,4	21.010,0

Figure 63- Production of Machine (1) in 28-09-2019

Once checked all the fundamental data collected in the production sheet it is very easy to carry out the analysis of the performances of the line. First of all, the OEE (=22,2%) is, as it's possible to see, affected by the low Availability of the machine (=24,4%). 5 minutes of stops almost nothing influence the availability of the line but the operating time results equal to 149 minutes. This means many inactivity times that strongly influence the performances.

The performance rate (=93,0%) and the Quality rate (=97,9%) are two very high values ensuring that there were not any kind of problem in terms of production speed or defects. At this point, the TPM coordinator with the help of the production director has to revise the times of inactivity of the machine and the plant utilization rate (=10,3%) looking for a solution that can increase the Availability and so the OEE.

In addition, the OEE analysis is complete if it is accompanied by the production and stoppages graphs.

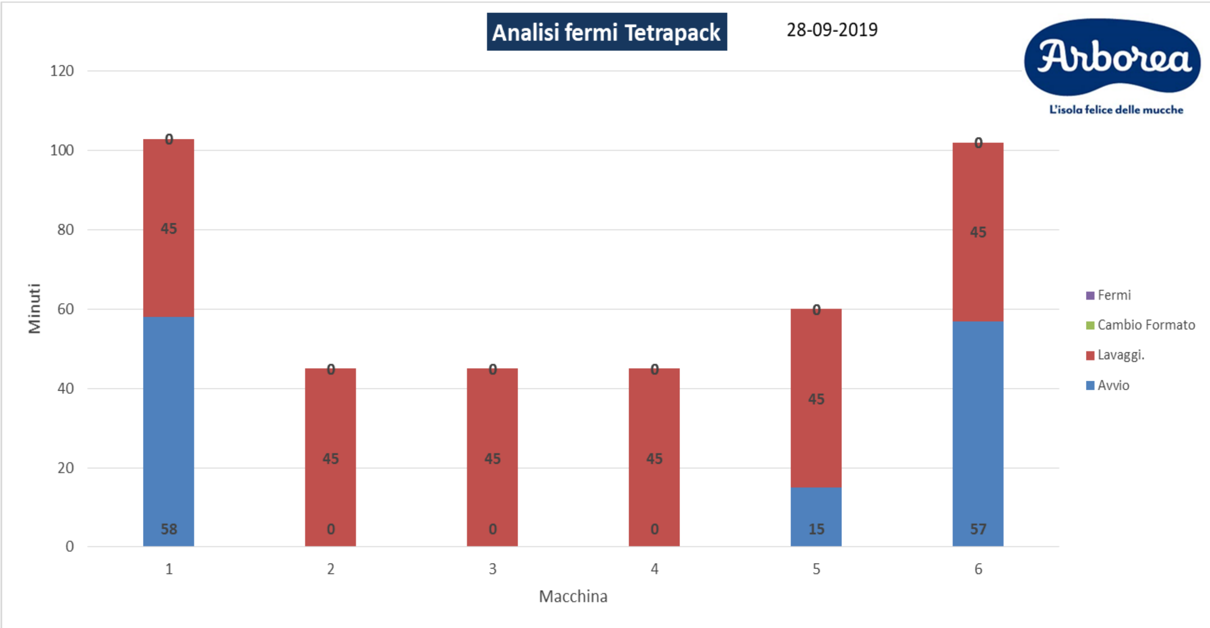


Figure 64- Stoppages in 28-09-2019

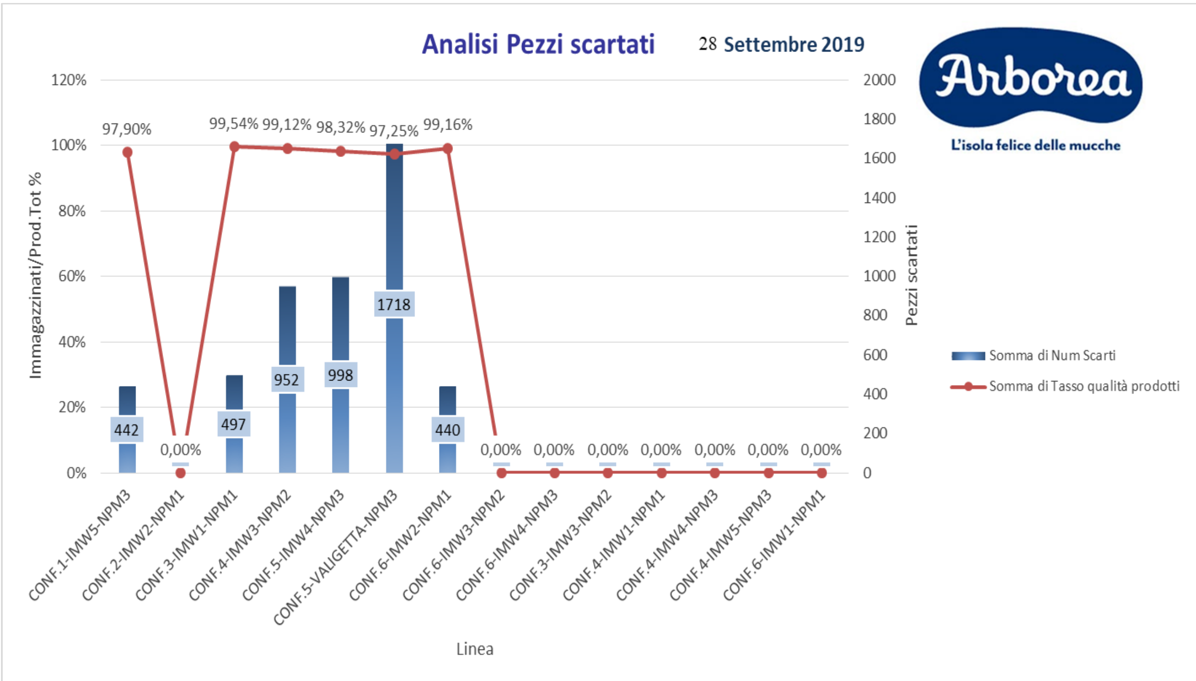


Figure 65-Production graph in 28-09-2019

As it's possible to see the in Figure 64 it's possible to see that the set-up time was 58 minutes and the cleaning time 45 minutes. In Figure 65 the waste for filler machine (1) were 442 items and the Quality rate 97.9% coinciding with the data previously reported.

4.3 Micro-stoppages from March to November 2019

Another fundamental tool for the performance analysis is the Pareto chart. As already mentioned in the previous chapters, it allows evaluating which anomalies are the worse in terms of performance losses. The structure of this diagram is usually the same: the 20% of anomalies contribute for the 80% of the total loss.

The micro stoppages here reported were collected through the micro-stoppages sheet (illustrated in paragraph 3.3) over the months in which this thesis work is inserted. Please, note that the month of June is missing because the works in the departments have momentarily suspended the data collection.

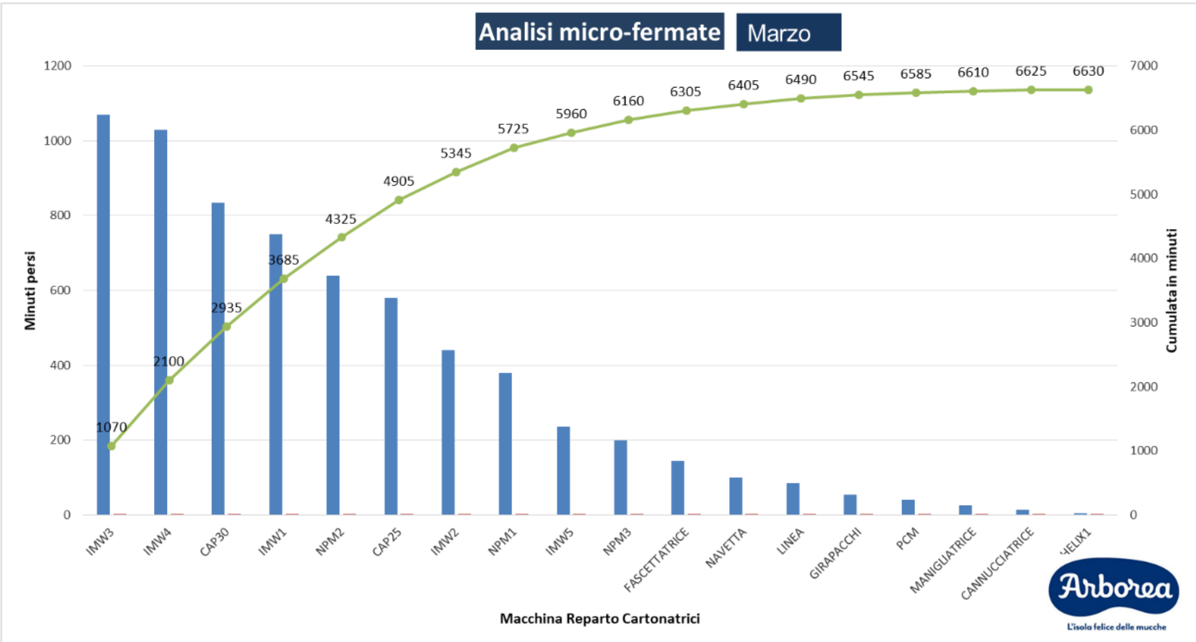


Figure 66 - Micro-stoppages in March 2019

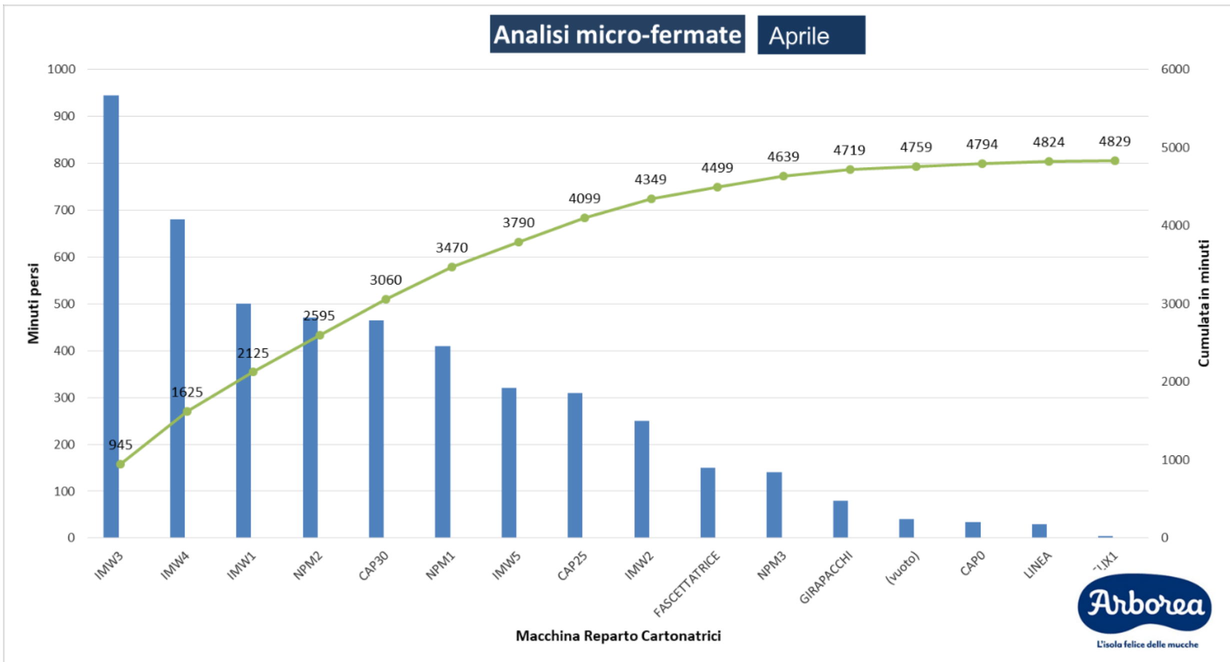


Figure 67 - Micro-stoppages in April 2019

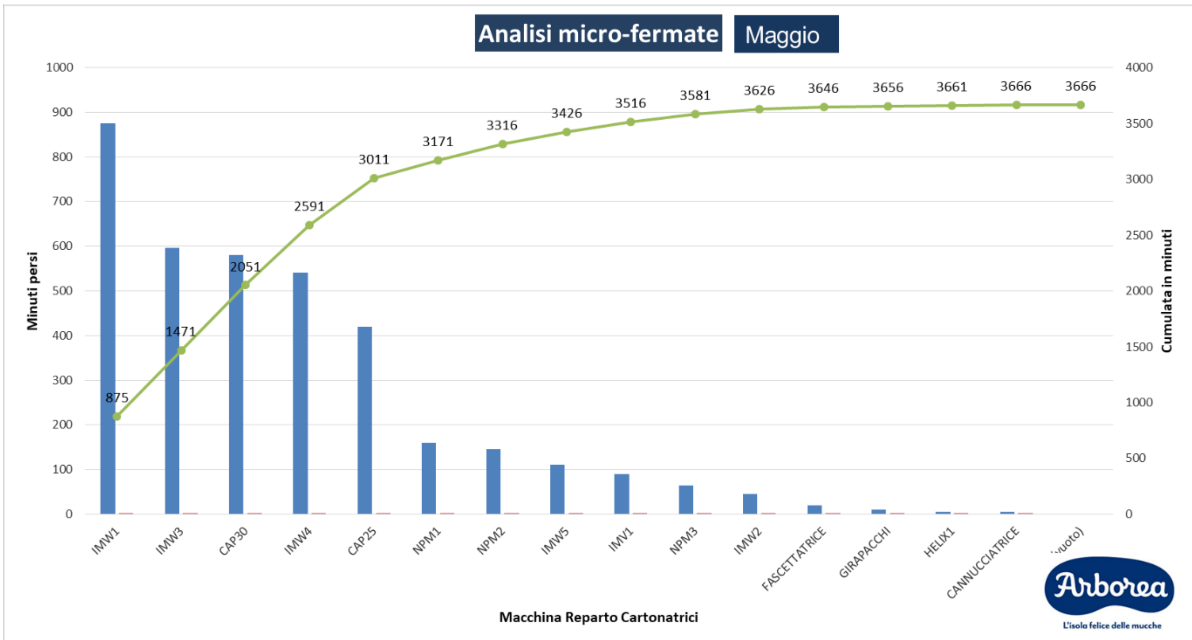


Figure 68 - Micro-stoppages in May 2019

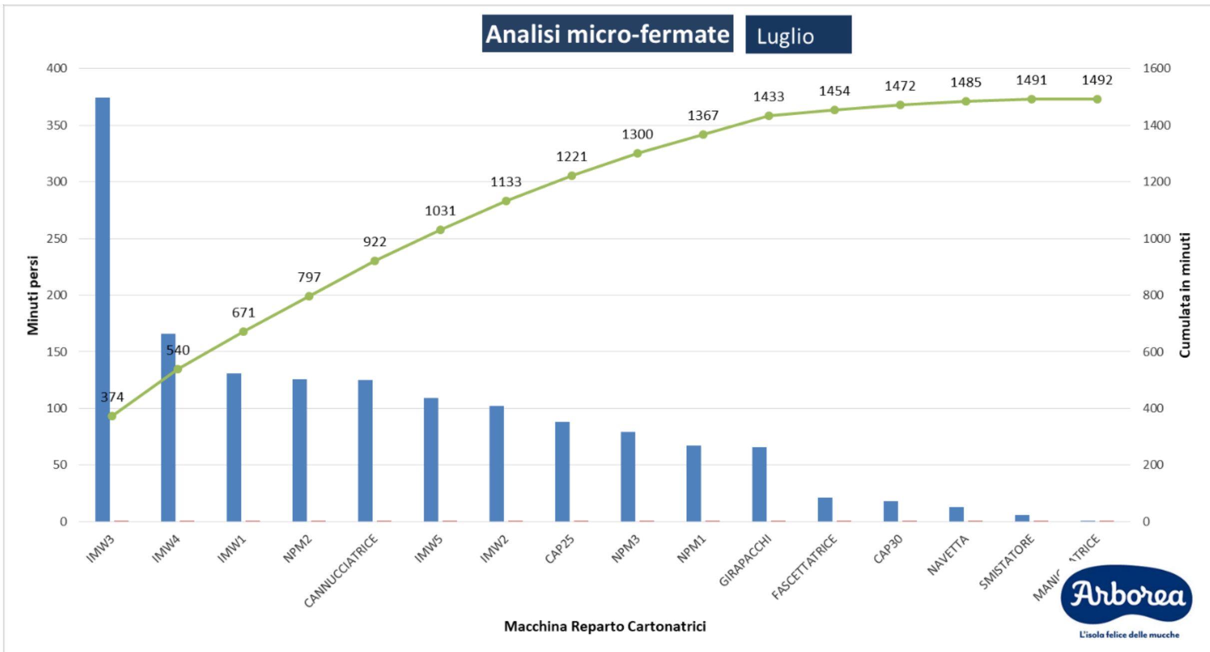


Figure 69- Micro-stoppages in July 2019

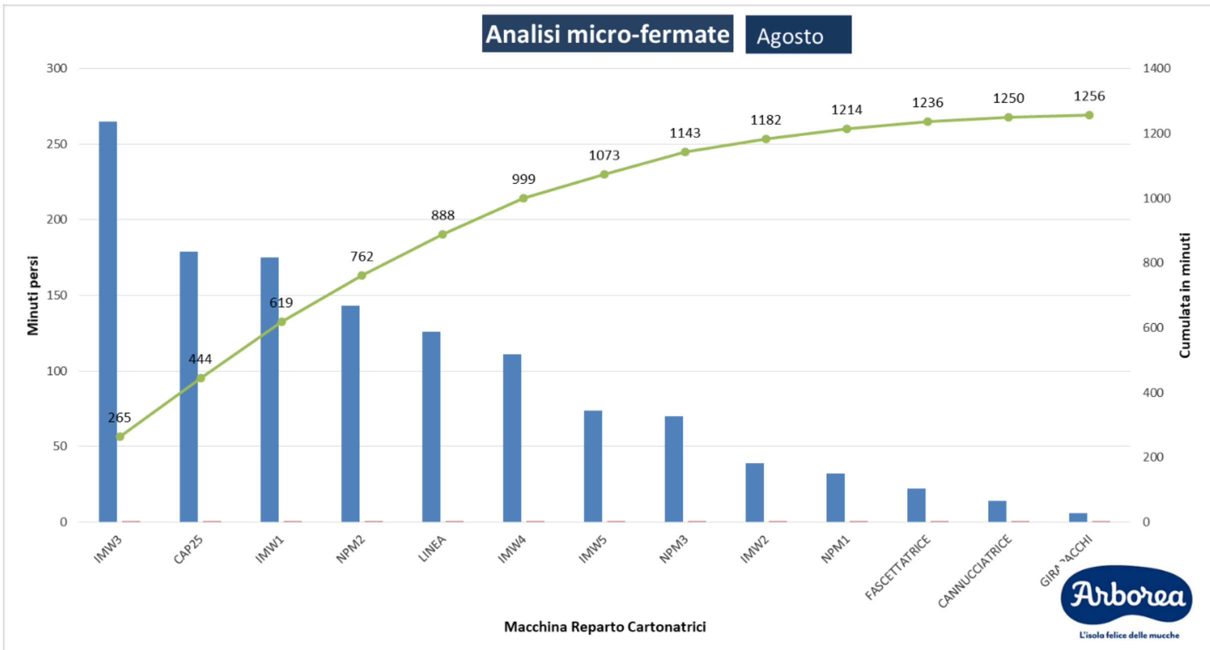


Figure 70 - Micro-stoppages in August 2019

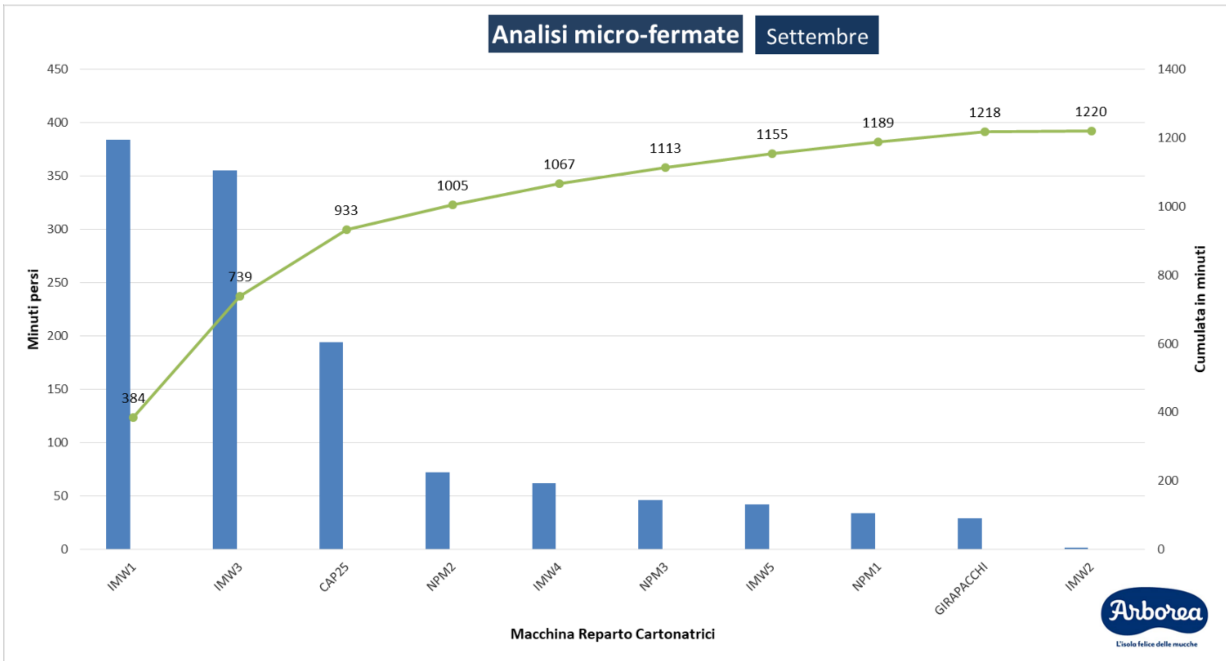


Figure 71 - Micro-stoppages in September 2019

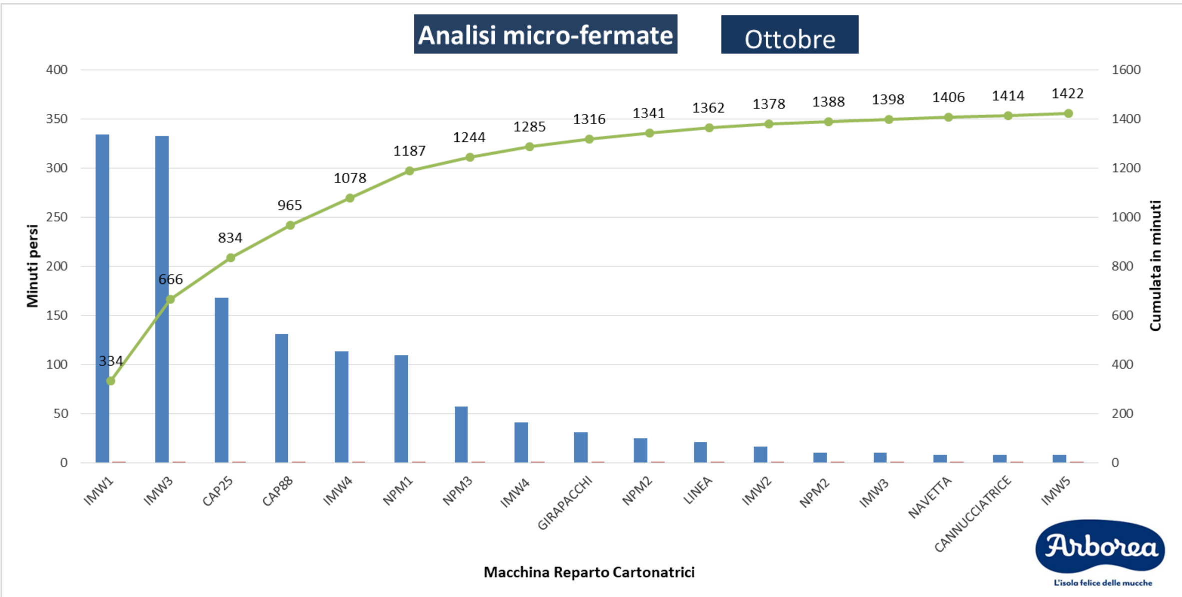


Figure 72 - Micro-stoppages in October 2019

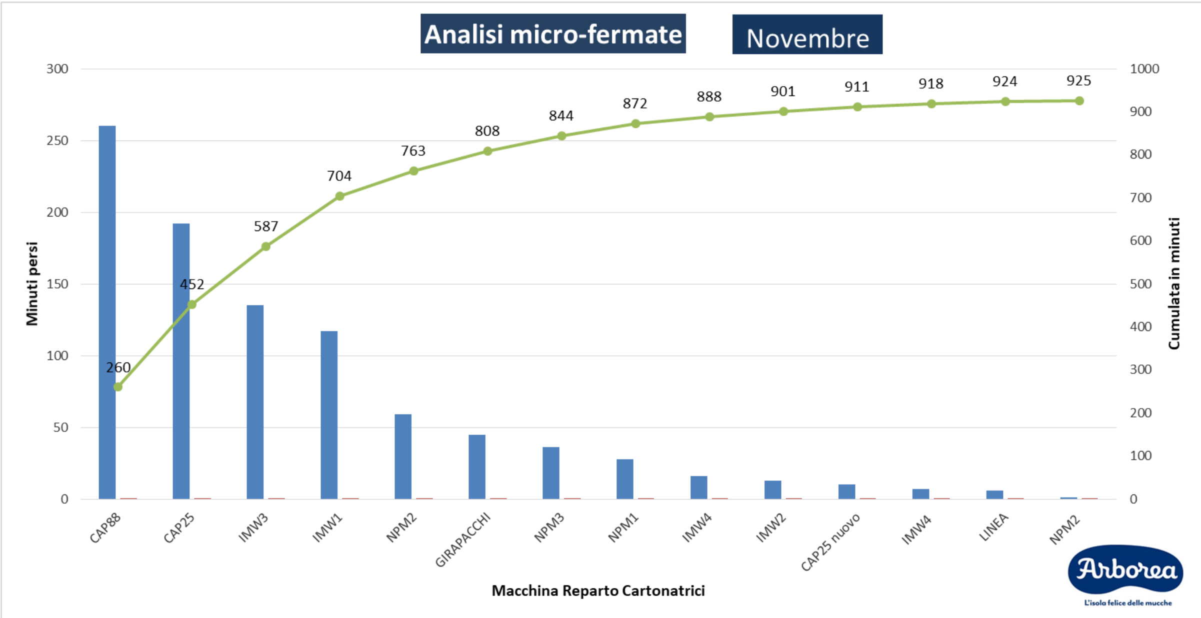


Figure 73- Micro-stoppages in November 2019

4.4 A sample micro-stoppages analysis

Once the data are collected in the database and the Pareto charts are available, the TPM coordinator can now conduct the analysis.

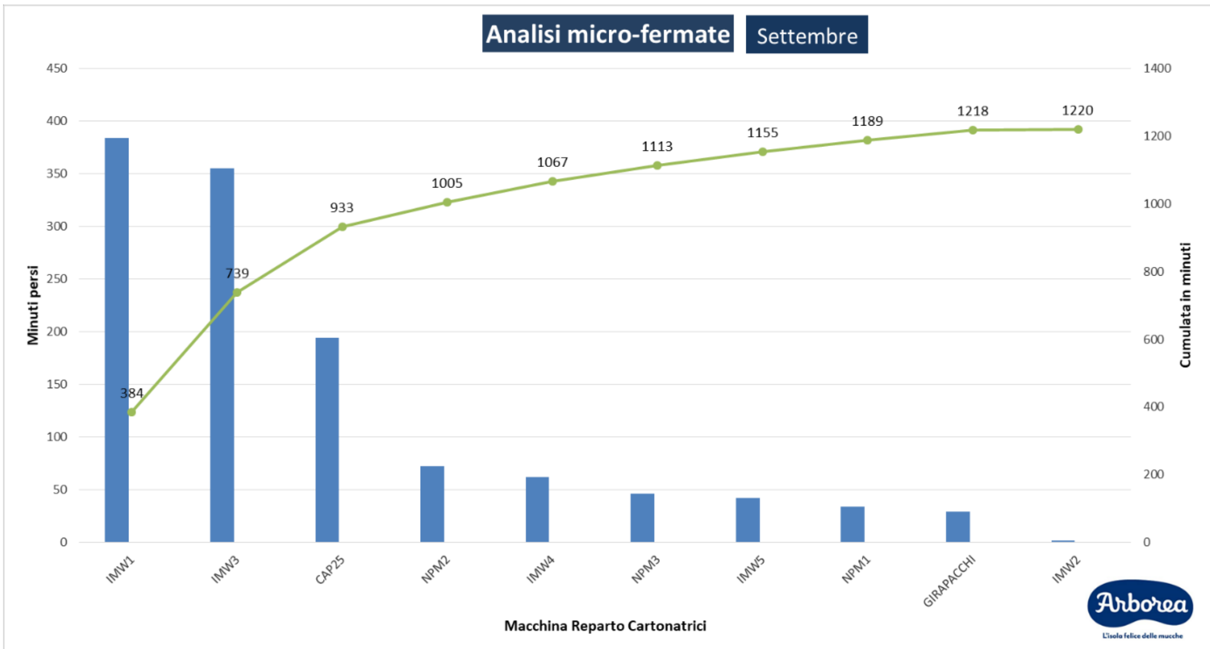


Figure 74 - Sample Pareto for September

The first step to conduct a micro-stoppages analysis is to note the 20-80% rule previously described. This rule is usually respected during the months and it establishes that by solving about two or three anomalies it is possible to reduce the 80% of the wasted time. Analyzing September, for example, it's possible to notice that the first three anomalies (30% of the total) contributes for the 76,47% of the total wasted minutes. This data suggests that solving, or at least reducing, the problems of IMW1, IMW3 and CAP25 (respectively case packer 1, 3 and capper25) it is possible to avoid the 76,47% wasted minutes.

Please, note that the 76,47% of the total wasted minutes in September is equal to 1220 minutes, roughly 20 hours, more than two working shift of 8 hours each!

Once that the TPM coordinator, thanks to the Pareto diagram, has pointed out the most problematic machines it can proceed with the second step, the Anomalies' Pareto chart. This new Pareto allows analyzing for each most problematic machine (IMW1, IMW3 and CAP25) which are the most influential anomalies. The logic of the chart is exactly the same but now, in the abscissa, there are not the machines anymore but the anomalies. Again, once pointed out the most influential anomalies for each most problematic machine, and solved them, finally it ends with the reduction of the wasted minutes in a sort of chain process.

For example, for IMW1, IMW3 and CAP25:

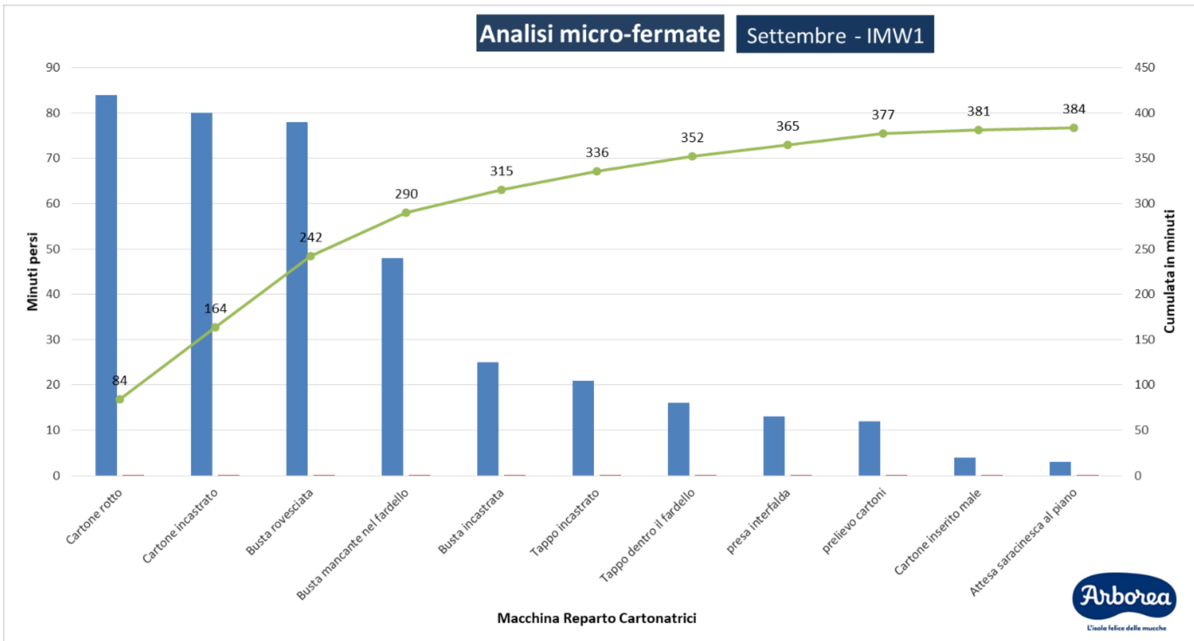


Figure 75 - IMW1 Anomalies'Pareto in September

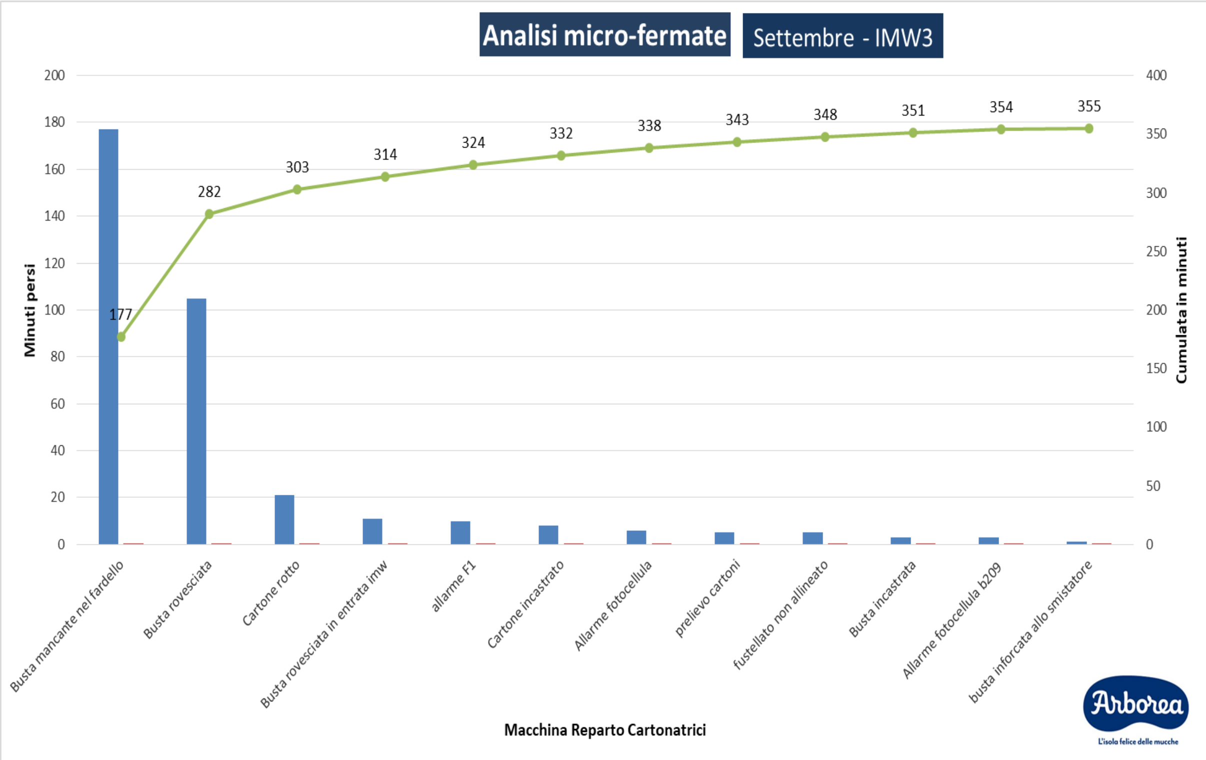


Figure 76 - IMW3 Anomalies'Pareto in September

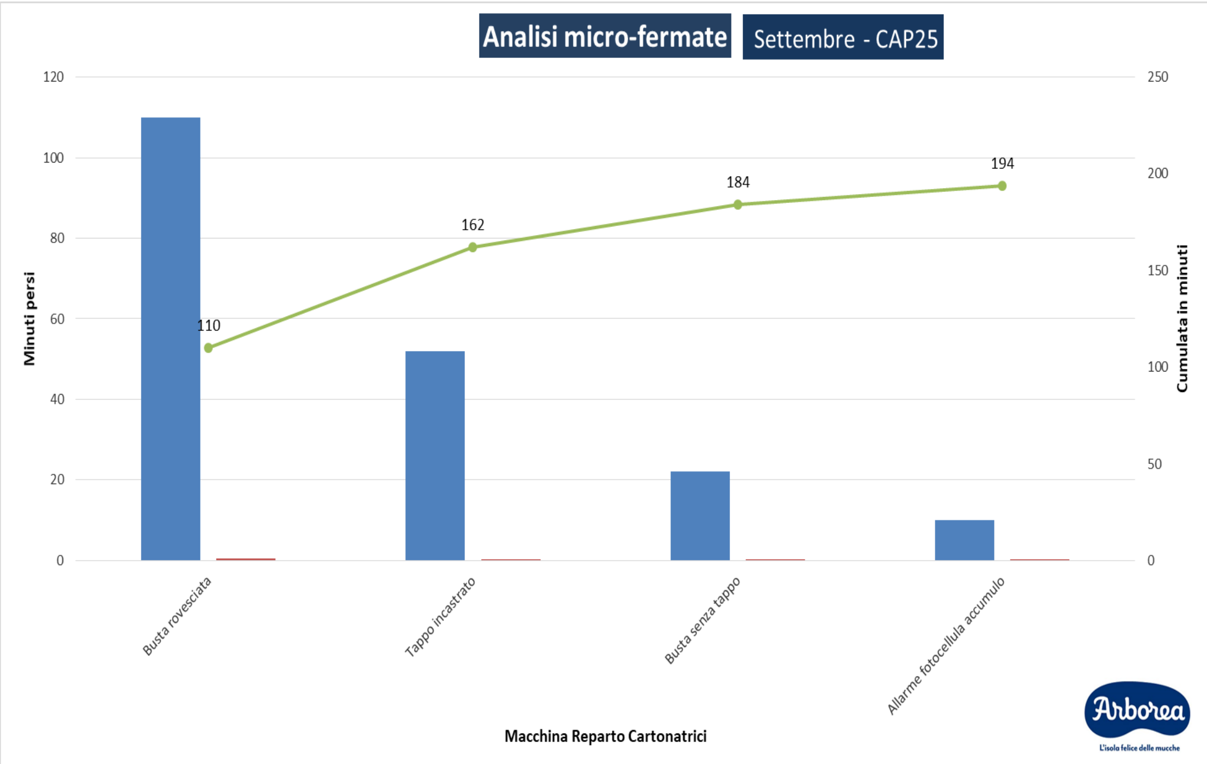


Figure 77 - CAP25 Anomalies' Pareto in September

As the Anomalies' Pareto charts suggest, the three most problematic machines lead to a total of 933 minutes, confirming the data in Figure 128:

$$IMW1 + IMW3 + CAP25 = 384 + 355 + 194 = 933\ minutes$$

Furthermore, the TPM coordinator is now able to analyze the most influential anomalies for each machine that are, in the 20-80% rule's logic:

MACHINE	ANOMALY	WASTED MINUTES	TOTAL MINUTES
IMW 1	-Broken box -Stuck box -Fallen package	-84 -80 -78	**242**
IMW 3	-Missing package in the box -Fallen package	-177 -105	**282**
CAP 25	-Fallen package	-110	**110**

Table 5 - Anomalies from Pareto

So, this type of analysis lead to point out the most influential anomalies of the most problematic machine and makes possible to carry out some specific operations to make up for lost time during the production due to these micro-stoppages.

4.5 The Ishikawa diagram and 5-why analysis

The Pareto chart is not sufficient if it's not followed by the Ichikawa diagram (or fishbone diagram) and the 5-why analysis. The Pareto chart allows to identify the most problematic machines in a very rapid way but it does not say nothing about how to reduce the wasted minutes. To this purpose, the TPM coordinator can use the Ishikawa diagram and the 5-why analysis. The first one allows to point out the anomaly by analyzing all the fundamental parts of the process: personnel, machine, measure, methods, material and environment.

For each part the Ishikawa diagram offers a possible cause of the anomalies and then, for each possible cause, its own cause and so on. This type of investigation method is really similar to the 5-why analysis that through a cascade process leads to continuously ask "why" to the possible cause of an anomaly. The TPM coordinator should do this type of analysis with the help of an operator and a maintainer that have a lot of experience more working every day in the machines of the plant.

In the following image, the Ishikawa diagram for the anomaly "Fallen package" is show:

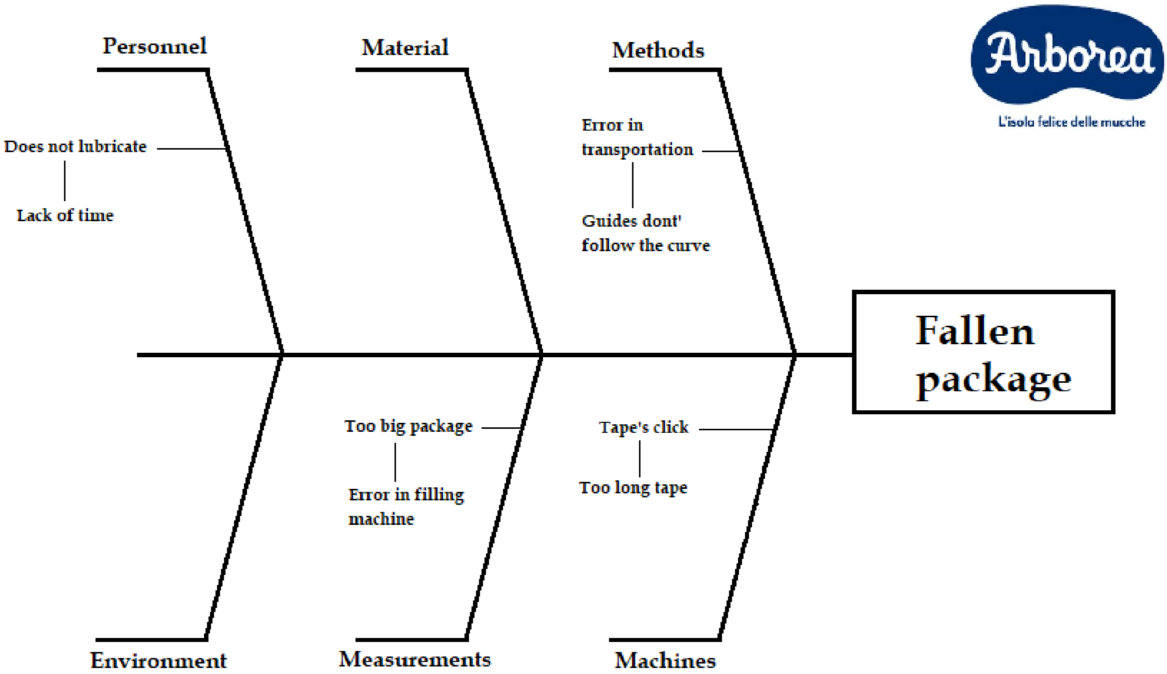


Figure 78 - Ischikawa "Fallen package"

Furthermore, the 5-why analysis for the anomaly "broken chain" is here reported in a schematic way for the sake of clarity and in the official version in Figure 80 (please, note that the golden rectangles in the figure were introduced for privacy reasons):

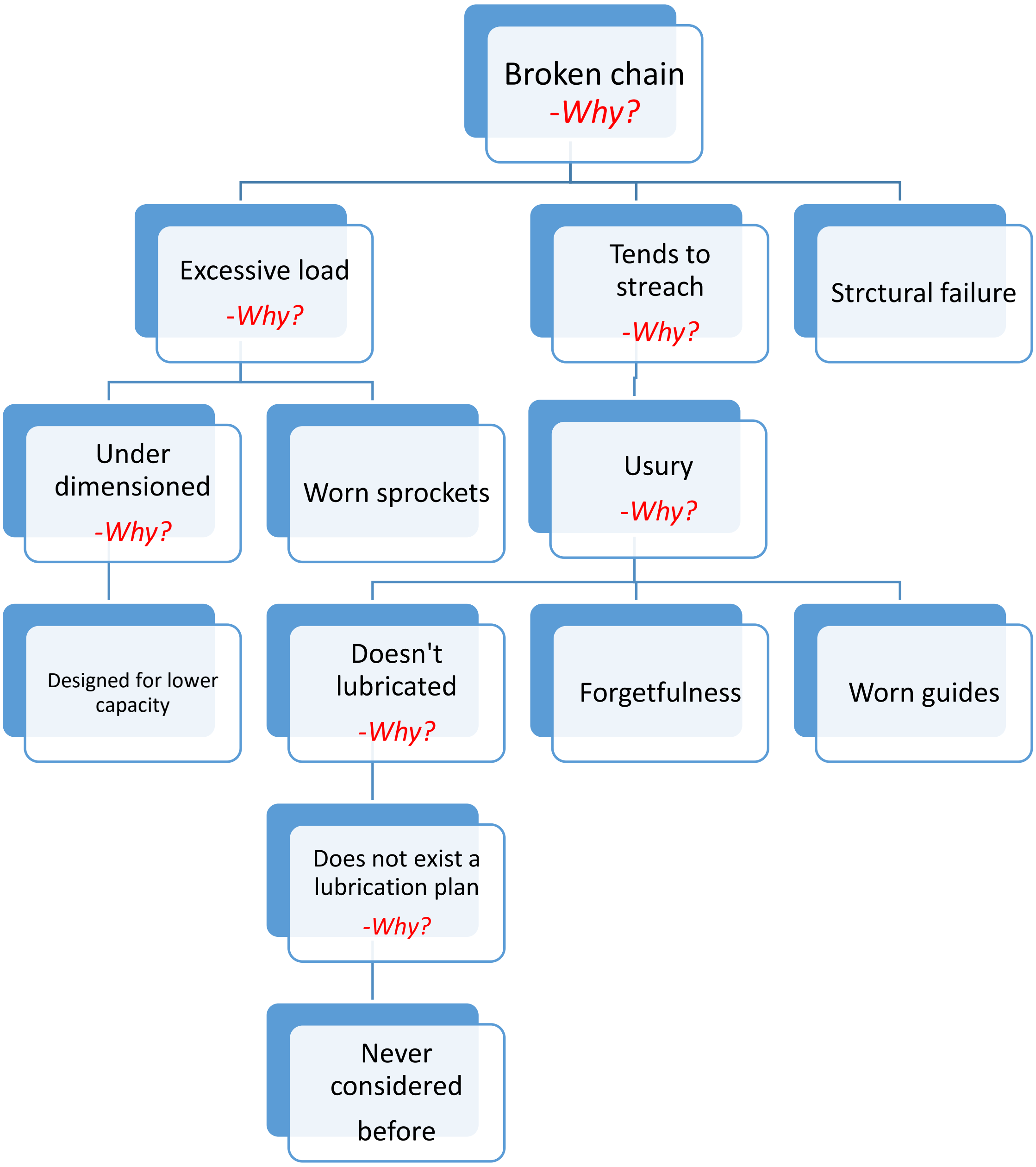
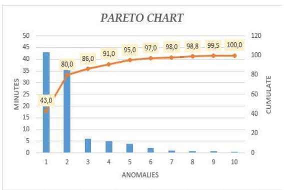


Figure 79 - 5-why schematic analysis for "Broken chain"



KAIZEN N°*01* – *BROKEN CHAIN*
UPS – Unified Problem Solving

Area di lavoro e tipo di perdita (guasti, micofermate, extract losses, ecc):
Imballaggio UHT
KPI e target:
30 MINUTI DI FERMO (ERADICARE LA PERDITA)
Leader & Membri:
Auditor/Coach: | Inizio: 10/05/2019 | Fine: 30/07/2016
Deployment

1. Descrizione del problema
Descrivere il fenomeno in termini di difetto funzionale (functional failure)
Rottura della catena di traino dei rulli
☐ Ricerca di informazioni e verifica delle di Good Practices esistenti tra i colleghi di altre fabbriche e sui Database (TPM Italy, One2Share, ...)

2. Comprensione del funzionamento & Ripristino delle condizioni di base
Spiegare il principio di funzionamento e descrivere il modo di difetto, usando disegni o diagrammi.
Descrivere il ripristino delle condizioni di base
Durante il trasferimento delle pedane piene, i rulli vengono trainati da una catena apparentemente debole per supportare lo sforzo richiesto

3. Analisi delle cause alla radice
Analisi delle cause alla radice → verifica delle ipotesi → 4M

Modo di difetto:	Why? 1	Why? 2	Why? 3	Why? 4	Why? 5	4 M	Verifica	Azione preventiva	Azione correttiva
Rottura Catena	SFORZO ECCESSIVO	sotto dimensionata	è stata progettata per una minore capacità produttiva					piano di ispezione	ripristinato la catena
		Pignoni usurati						Modifica sistema di traino	
	TENDE AD ALLUNGARSI	usura	non viene lubricata	non esiste un piano di lubrificazione	Mai preso in considerazione			non esiste un piano di lubrificazione (Inserire lubrificazione automatizzata)	
			ci si dimentica di eseguirlo						
			Guide consumate						
	Cedimento strutturale								verificala la fattibilita' di inserimento telecamera.

4. Contromisure & Monitoraggio
Definire le contromisure per ogni causa alla radice -> Implementare le azioni -> Monitorare i risultati e reagire se ci sono deviazioni

Azioni (Preventive / Correttive)	Chi	Quando	Status	Loss eradication
Modifica sistema di traino				
Preparae unn piano di ispezione				

☐ Validare ogni azione che ha impatto su Sicurezza, Qualità e Ambiente

30 MINUTI DI FERMO (ERADICARE LA PERDITA)

	Iniziale	Week 1	Week 2	Week 3	Week 4	Finale
Risultato	0,29	0,25	0,17	0,17	0	0
Obiettivo	0,2	0,2	0,2	0,2	0,2	0,2

5. Standardizzazione & Espansione
Standardizzare le contromisure, fare formazione, espandere l'implementazione (se applicabile) e integrare il trigger point nel DCS

Standard creato	tipo di standard*	Training	Espansione orizzontale

* Poka Yoke, OPL/SOP, Visual management, Trigger Point

Figure 80 - 5-why analysis "Brocken chain"

4.6 The tags analysis

The last fundamental instrument to carry out an in-deep analysis is the tags monitoring. As in the previous chapters illustrated, the tags utilization is a very useful support to report the anomaly's presence to the appropriate department. The database that collects all the issued tags allows to create some diagrams to monitor the tags emission.

The first chart is exactly the "tags emission": it offers the possibility to see which is the operator who mostly uses the tags and which uses it less. To understand if all the operators have understood the importance of this instrument, the difference in percentage between those who emit more and those who emit less should not be more than 50%. In addition, each operator should on average issue at least one tag per week. If these two conditions are not met, it means that within the department some operators have not sufficiently understood the importance of the tags or vice versa, some operators abuse this tool.

The following figure shows the trend of the tags in a period from the 15th of April to the 10th of July 2019 and it can be noted that one operator in particular has issued a number of tags that is vastly superior to the others (27). In this case, he is the department manager, who obviously uses this tool more than the other operators do because he is the first person in charge of production. Here, the difference between him and the operator who issues fewer cards is 96% (much higher than 50%).

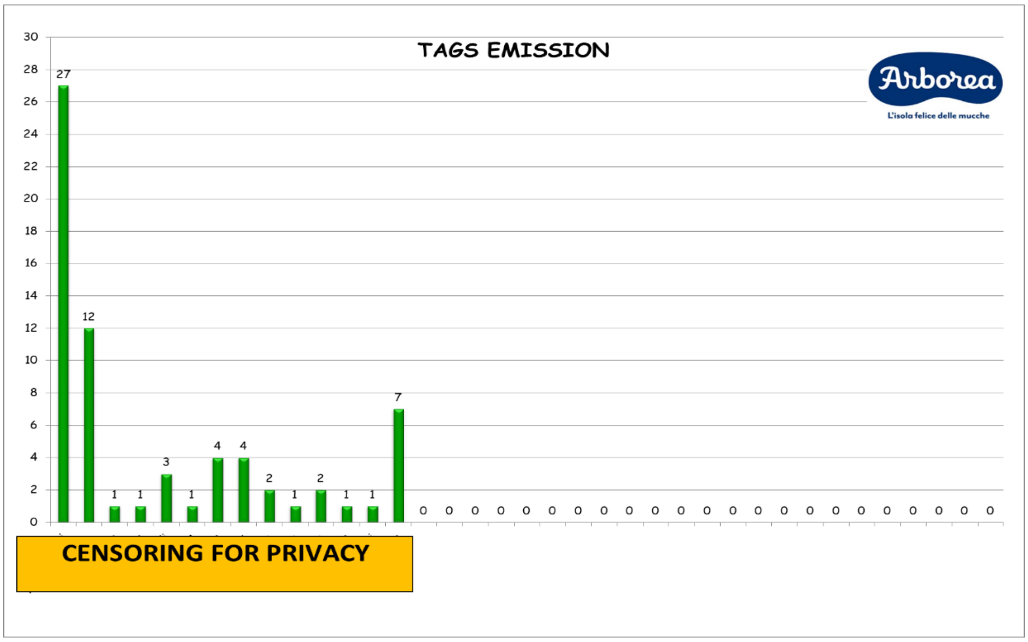


Figure 81- Tags emission chart

The second fundamental chart available to the TPM coordinator is the trend of the issued and closed tags. This graph, allows to monitor the amount of tags issued and closed over the months so that there is a check on how many jobs were planned and how many are still to be done.

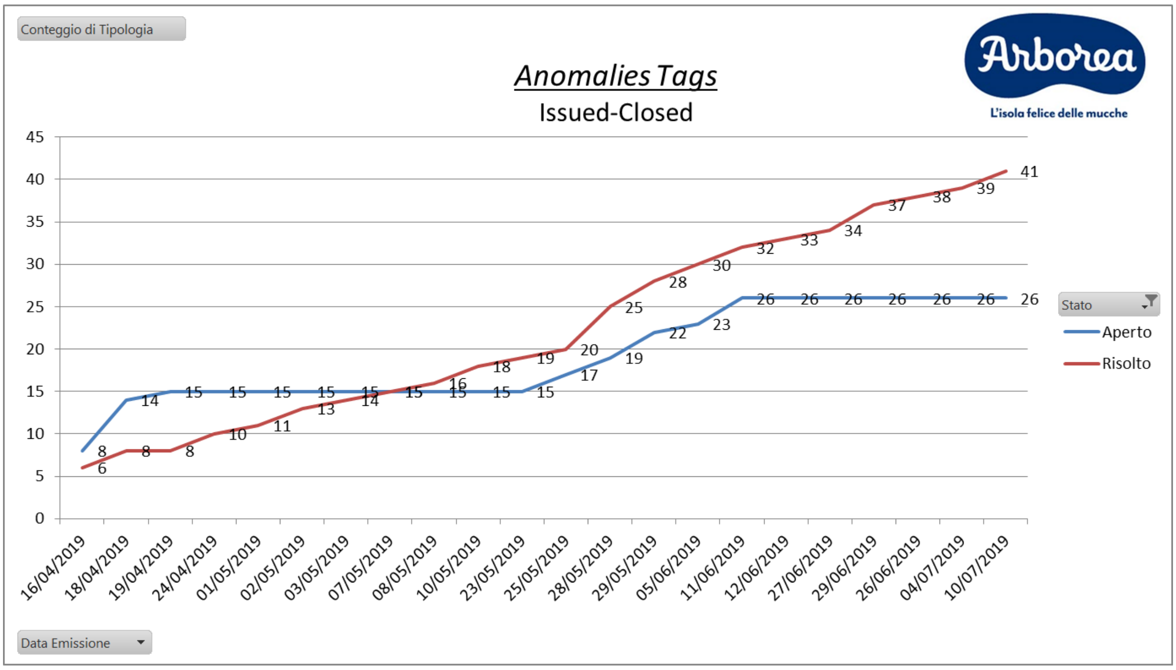


Figure 82- Issued-closed tags chart

Finally, it is also possible to see for the same period of time how many tags for each area (ORG/MIG/DEV, see paragraph 3.4) were issued.

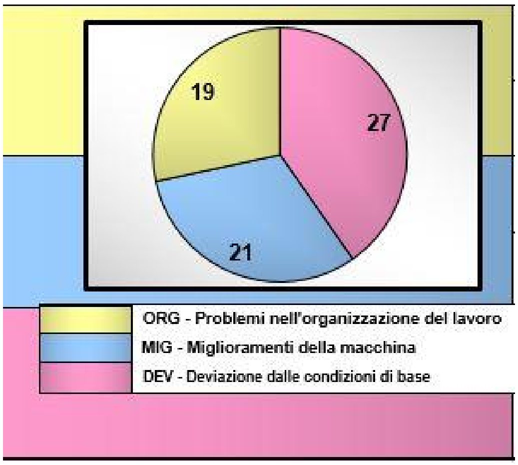


Figure 83 - Tags area chart

5 An economic investment evaluation under the certainty regime

It is not always possible to resolve the main anomalies through autonomous maintenance and TPM activities. Sometimes, a non-optimal layout is the cause of innumerable delays, unnecessary transport, stops, injuries, and etcetera. TPM then, is no longer sufficient to maximize the efficiency of the plant if it is not accompanied by a project of redefining the spaces and / or a modification of the equipment present in the department. The economic evaluation that follows was taken into consideration within the Company in the months prior to the modifications to the machinery in the months of June. The obsolete and inefficient machinery has been replaced by a more performing and technological one and, as already seen in the previous chapters, the lines have been redefined and reprogrammed in such a way as to simplify production programming and reduce transport costs and times. However, **the data entered in the presentation of the investment valuation are completely fictitious, and do not represent in any way sensitive company data**. This analysis has the sole purpose of showing in a general and simplified way the main methods of evaluating an investment under certainty regime.

Assuming to analyze the investment for the replacement of machinery number (3) where the OEE index has gone from 59,42% for the month of May to 61,48% for the month of September it is possible to note an improvement of 2,06 percentage points. It is assumed in a **completely fictitious way** that 2,06 percentage points of OEE correspond to a recovery on the production of 16’000 liters. For each liter, a unit contribution margin of € 0.50 per unit is **hypothetically assigned**. Finally, the total cost of the investment intended as the sum of the project cost and the cost of the equipment is taken into account for the calculations. Assuming a discount rate equal to 7% and 10 years of depreciation:

Unit Contribution Margin	0,50 €
Investment	30.000 €
Project cost	5.000 €
Total investment	35.000 €
Recoverable production [liter]	16000,00
Total U.C.M	8.000,00 €
Discount rate	0,07
Depreciation years	10

Figure 84 - Investment data

Ignoring the influence of inflation (certainty regime) in this first analysis, five of the main investment evaluation methods are analyzed below. First, the net cash flow is calculated for each year using the formula:

$$Cash\ flow_i = Total\ U.C.M\ x\ \frac{1}{(1+0{,}07)^i}$$

Being i the i-th year.

Then the Cumulative cash flow is computed from the first to the tenth year:

Year	Cash flow	Cumulative Cash Flow
0	-35.000 €	-35.000 €
1	€ 7.476,64	-27.523,36 €
2	€ 6.987,51	-20.535,85 €
3	€ 6.530,38	-14.005,47 €
4	€ 6.103,16	-7.902,31 €
5	€ 5.703,89	-2.198,42 €
6	€ 5.330,74	3.132,32 €
7	€ 4.982,00	8.114,32 €
8	€ 4.656,07	12.770,39 €
9	€ 4.351,47	17.121,86 €
10	€ 4.066,79	21.188,65 €

Figure 85 - Cash flow in the 10 years

Through this first analysis it is possible to study the 5 main methods:

1. **Ratio of net increase of profit and disbursement of capital (R):** It is the relative index (% or fractional) obtained by dividing the profit variation generated globally by the project, in a representative year (in this case it is assumed constant), by the amount of the investment. It is the inverse of the PBP.

$$R = \frac{Annual\ profit}{Total\ investment} = \frac{8000€}{35000€} = 22{,}85\%$$

2. **Payback-Period (PBP):** or "Period of reintegration" of the invested capital is the period of time in which the invested capital is repaid by the profit obtained. It is normally measured in years.

$$PBP = \frac{Total\ investment}{Annual\ Profit} = \frac{35000€}{8000€} = 4{,}37 = 4\ years\ and\ 3\ months$$

3. **Present Value (PV)**: It is the difference between revenues and actualized costs throughout the life of the project. The "Actualization" technique is defined as the technique that allows comparing amounts of money disbursed at different times. In formula:

$$PV = \sum_{i=1}^{Depreciation\ years} Total\ U.C.M\ x\ \frac{1}{(1 + discount\ rate)^i} =$$

$$= \sum_{i=1}^{10} 8000€\ x\ \frac{1}{(1 + 0{,}07)^i} = 56188{,}65€$$

Then, the Net Present Value (NPV) is defined as:

$$NPV = PV - Total\ investment = 56188{,}65€ - 35000€ = 21188{,}65€$$

4. **Internal rate of return (IRR**): It is the discount rate that nullifies the net present value of the project. It looks for the value of the discount rate capable of eliminating the net economic result of the entire investment transaction. It's computed by linear interpolation of the two discount rates that give NPV>0 and NPV<0. In formula:

$$IRR \xrightarrow{yields} NPV = 0$$

5. **Rate of Return (ROR):** It is the ratio between the Net Present Value of the project and the invested capital:

$$ROR = \frac{NPV}{Total\ investment} = \frac{21188{,}65€}{35000€} = 60{,}54\%$$

Summarizing:

NPV	ROR	IRR	PBP (const in 10 years)	R
€ 21.188,65	60,54%	13,89%	4,375	22,85%

Figure 86 - Principal methods

As already mentioned, none of these methods is exhaustive if considered individually, but should be understood as a useful tool if integrated with the others. In fact, each of these methods has its own advantages but also limitations that can be overcome only with the help of other evaluation tools. Generally it is worth that:

- PBP (and R) is used as a cut-off;
- NPV and ROR analyze different aspects, by integrating them together and relating them with company directives, risk appetite, etc.
- IRR provides an interpretative key to the risks associated with fluctuations in the cost of money

6 Conclusions

This thesis work tried to be a valid help for the company *3A Latte Arborea* during the implementation of the Total Productive Maintenance at its departments. Over the years, the company has undergone rapid expansion, bringing its markets also to Extra-European Countries such as America or China, where today it is recognized as a great Italian excellence.

In order to do this, the production of dairy products has been greatly expanded and consequently the company's turnover has rapidly and enormously grown in the last five years. Then, the company has expanded beyond the regional borders by purchasing several Italian brands and thus becoming a true multisite company. However, in such an increasingly global and growing reality, it is not enough to concentrate all the forces and the attention only on the production of goods. *3A Latte Arborea* thus decided at the beginning of 2019 to implement Total Productive Maintenance (TPM) internally, thus passing from mainly a Breakdown Maintenance to a Total one.

For this purpose, also thanks to this thesis work started in March 2019, all the fundamental steps for a correct implementation of TPM were applied. Taking mainly inspiration from the theory of Seiichi Nakajima, and thanks to the valid experience of the managerial class of the company, this thesis work had the task of starting all those activities necessary for a correct management of maintenance from a TPM perspective. During the development of all the activities the focus was on following the famous Deming cycle or PDCA (Plan-Do-Check-Act). The purpose of this approach was reaching the best conditions as possible in the equipment of the plant (DO) and, by checking the activities and studying the data (CHECK-ACT), planning structured improvements (PLAN) to maintain those standards.

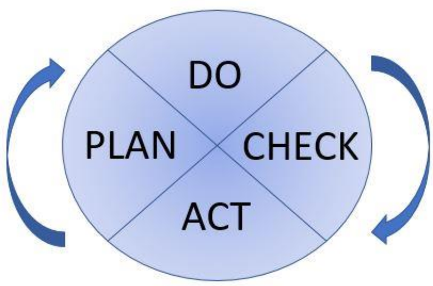


Figure 87 - PDCA or Deming cycle

Today, after about nine months, the main activities are progressing successfully and the company is starting to collect the first results of such long and constantly updated work.

It can be noted that, analyzing the OEE index, the main TPM key performance indicator, from March to November for machine number (3), there have been considerable progresses and improvements in terms of machine performance.

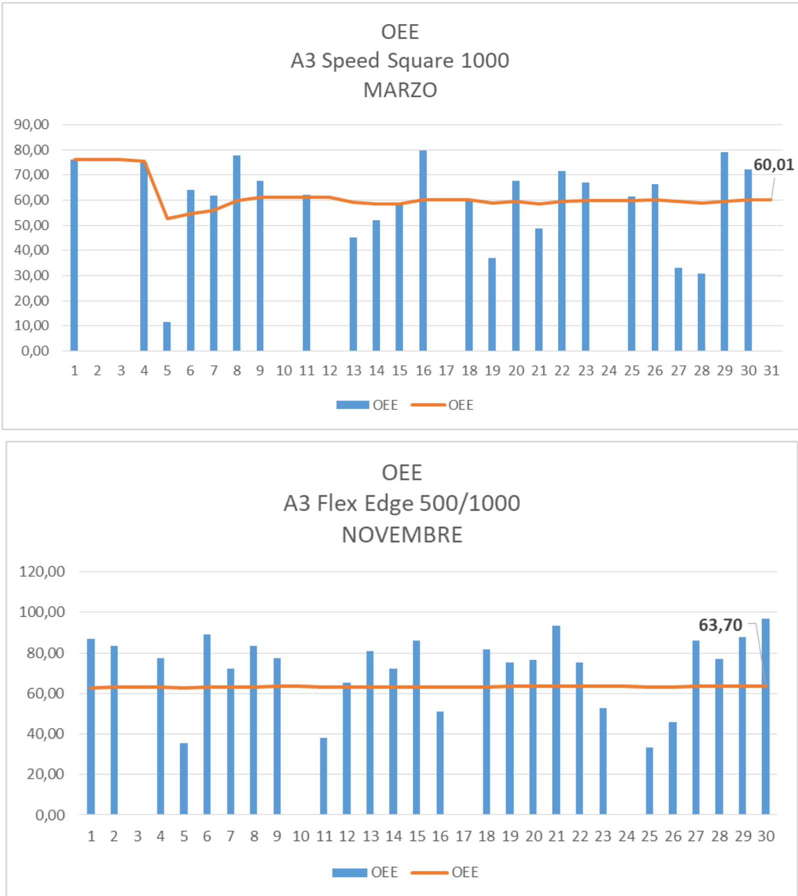


Figure 88 - Progress of machine (3)

The index passed to 60,01% in March to 63,70% in November leading to an increase of 3,69% percentage points in just eight months. This means that significant progress has been made over the months that are bringing the expected results at the beginning of the year when the TPM was just an idea. Obviously, it's not easy to make incredible progress in such a short time as the TPM is a methodology that takes years to show great improvements: operators need to change their way of working and think about TPM activities not as an additional job but as their natural way of working. The following table summarizes the progress of all packaging machines:

Filling Machines	MARCH 2019	NOVEMBER 2019	INCREMENT
A3 Flex Compact 200/250 (1)	43,89%	44,72%	+0,83%
A3 Flex Base 500/1000 then A3 Speed Square 1000 (2)	51,74%	55,14%	+3,4%
A3 Speed Square 1000 then A3 Flex Edge 500/1000 (3)	60,01%	63,70%	+3,69%
A3 Flex Edge 500/1000 (4)	73,69%	65,12%	-8,57%
A3 Flex Edge 500/1000 (5)	60,55%	62,04%	+1,49%
TBA Base 8 1000 (6)	55,40%	56,29%	+0,89%

Table 6 - Results summarizing table

All the machines have therefore seen improvements that are sometimes truly remarkable and sometimes more moderate, with the exception of the number machine (4). The reason is that during the month of June this machine was overloaded to make up for the lack of production of machines (2) and (3). Moreover, the index is often slightly distorted because the machine has often been used for testing new formats and new products (sometimes a few hundred liters) that have made the machine work only for a few minutes and as explained in the previous chapters this results in very low OEE indexes. It can be also noted that the machines (2) and (3) have the highest increments reflecting the goodness of the investment that brought to a significant performance increasing with respect to the previous conditions.

Another very important conclusion is the comparison of the Pareto chart of March and November for the micro-stoppages: it can be noted that the total wasted minutes for March were 6630 and in November 925. This very significant result means a reduction of 86,05% percentage points and 5705 minutes in absolute value in just eight months. This surprising result is synonymous with the commitment of all operators in wanting to improve their working conditions and the condition of the machines on which they work. Moreover, it means that the method of working is correct and that all the choices made were fundamental for the correct implementation of the TPM.

	MARCH 2019	NOVEMBER 2019	REDUCTION
Total wasted minutes	6630	925	-5705 -86,05%

Table 7 - Micro-stoppages results

Among the future developments of this work, surely there is that to recover the points inevitably lost for the machine number (4). In addition, in the coming months the TPM will also be implemented in the other departments of the plant and in the offices of the company where no work has yet been done. The results obtained in these months were standardized and they must be kept constant over the coming months and years, always looking for new improvements that can be adopted. The OEE index should be raised continuously trough the Japanese *Kaizen* ("Continuous improvement") in order to achieve the excellent value set by Nakajima (about 85%). This value will be the target to obtain JIPM certification in the coming years consequently reaching the ideal condition of zero failures, zero defects and zero accidents.

7 Bibliography

- “Applichiamo il TPM. Guida operativa alla realizzazione del Total Productive Maintenance”, JIPM, Franco Angeli, 1995.
- “An FMECA-based approach to process analysis”, Bertolini, 2006.
- “Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system", Nachiappan, Anantharaman, 2006.
- “Manutenzione autonoma con il TPM”, JIPM, Franco Angeli, 1995.
- “Manutenzione produttiva. L'esperienza del TPM in Italia”, Furlanetto, Cattaneo, Mastriforti, ISEDI, 2003.
- “Miglioramento specifico con il TPM”, JIPM, Franco Angeli, 2008.
- “Total productive maintenance implementation in a manufacturing organization”, Ahuja, Khamba, 2008.
- “TPM Total Productive Maintenance”, Nakajima, ISEDI, 1988.

8 Sitography

- https://it.wikipedia.org/wiki/Total_Productive_Maintenance
- https://it.wikipedia.org/wiki/Automanutenzione
- https://www.arborea1956.com
- http://www.lattearborea.com
- https://www.jipm.or.jp/en/

9 Appendix

-A3 Flex Compact 200/250 (1)

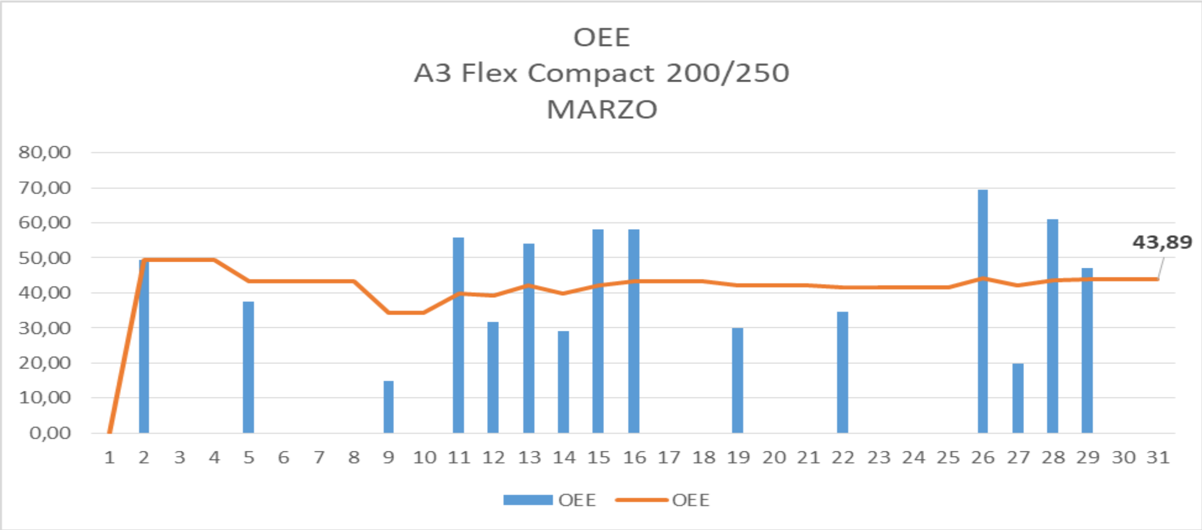


Figure 89 - OEE March (1)

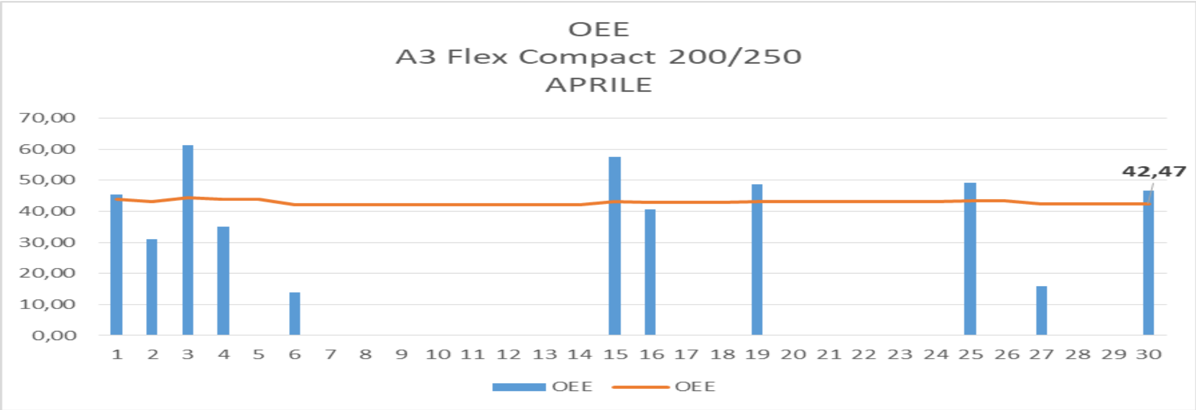


Figure 90 - OEE April (1)

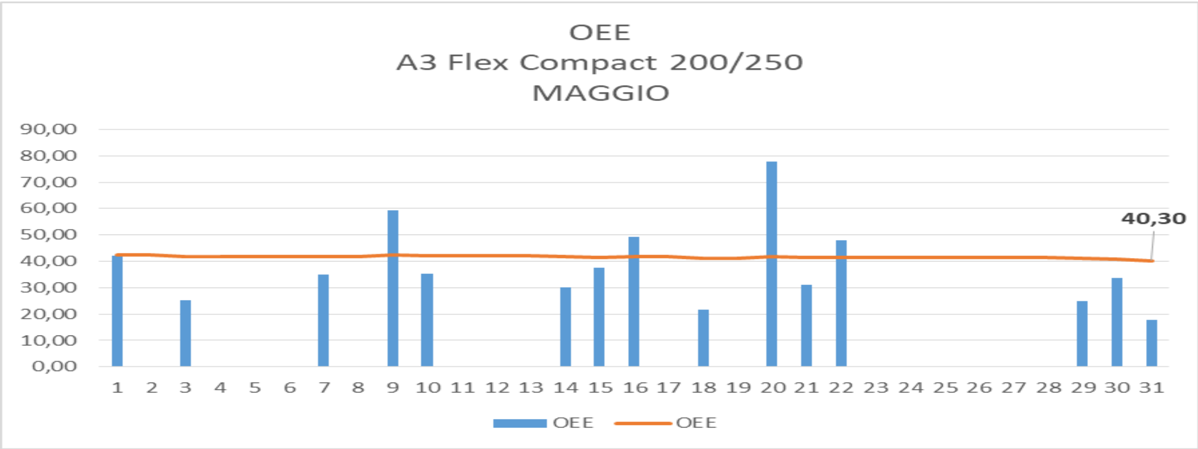


Figure 91- OEE May (1)

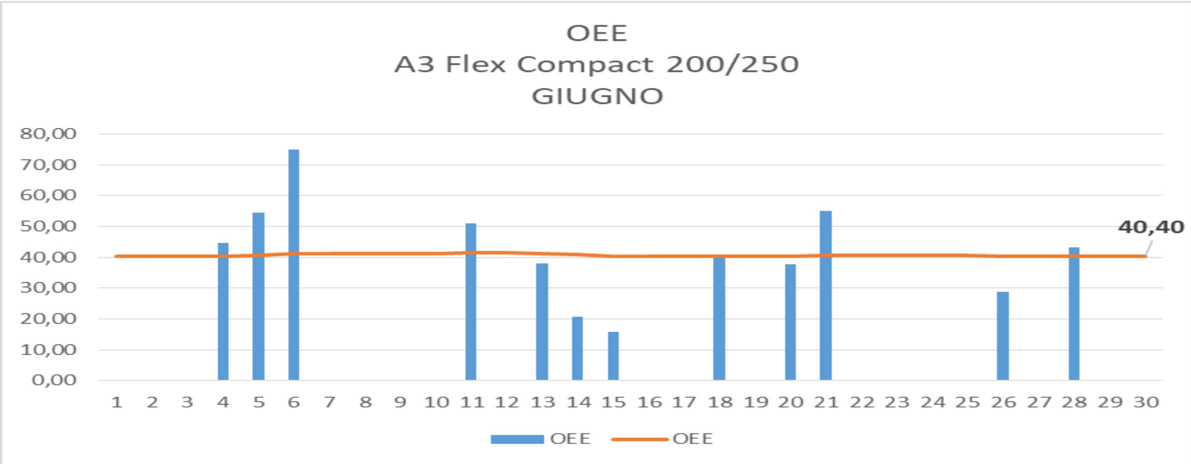


Figure 92 - OEE June (1)

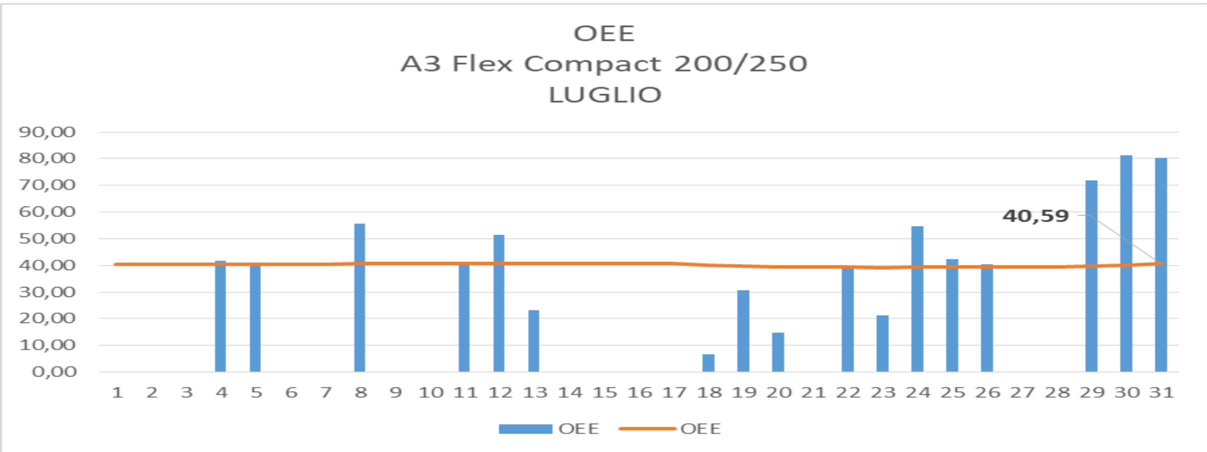


Figure 93 - OEE July (1)

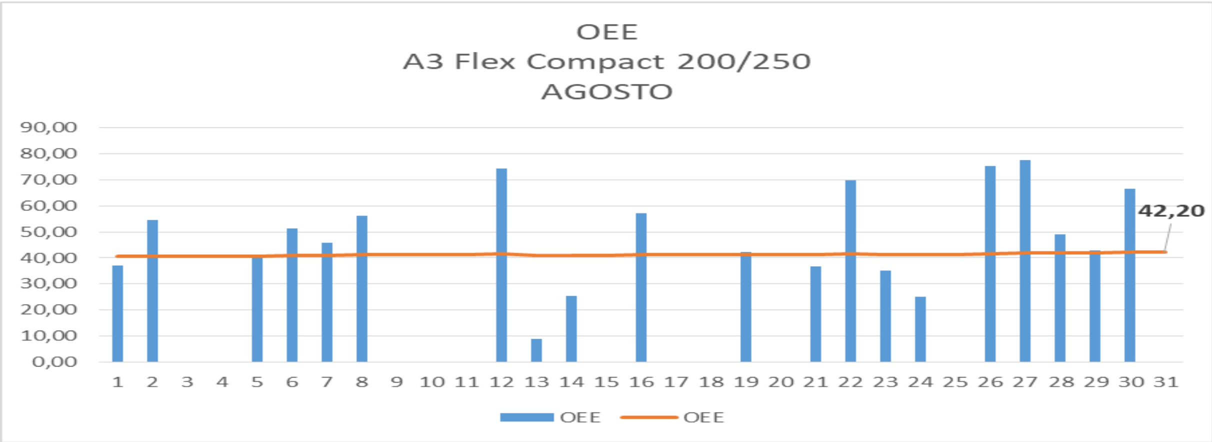


Figure 94- OEE August (1)

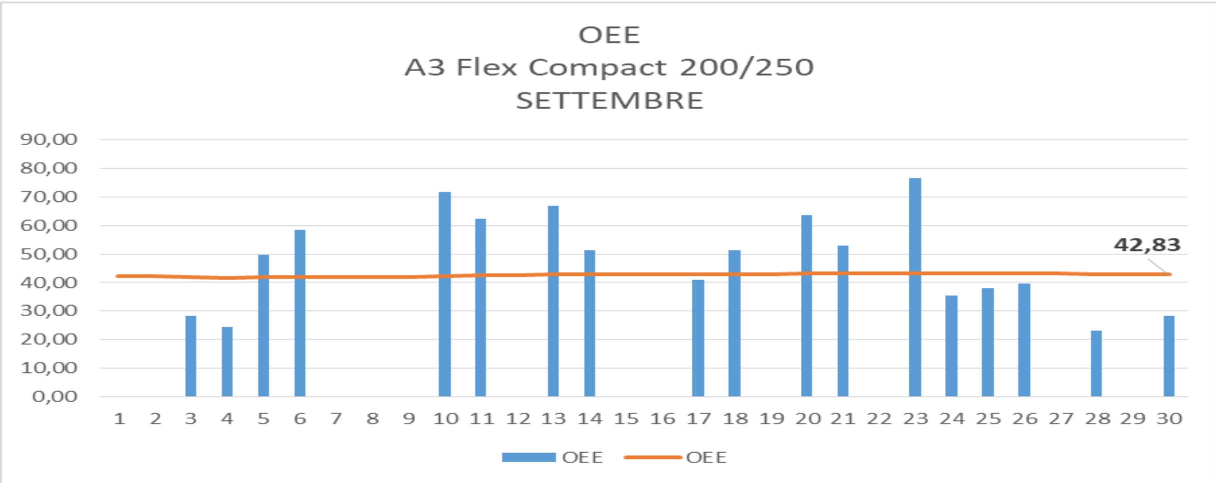


Figure 95-OEE September (1)

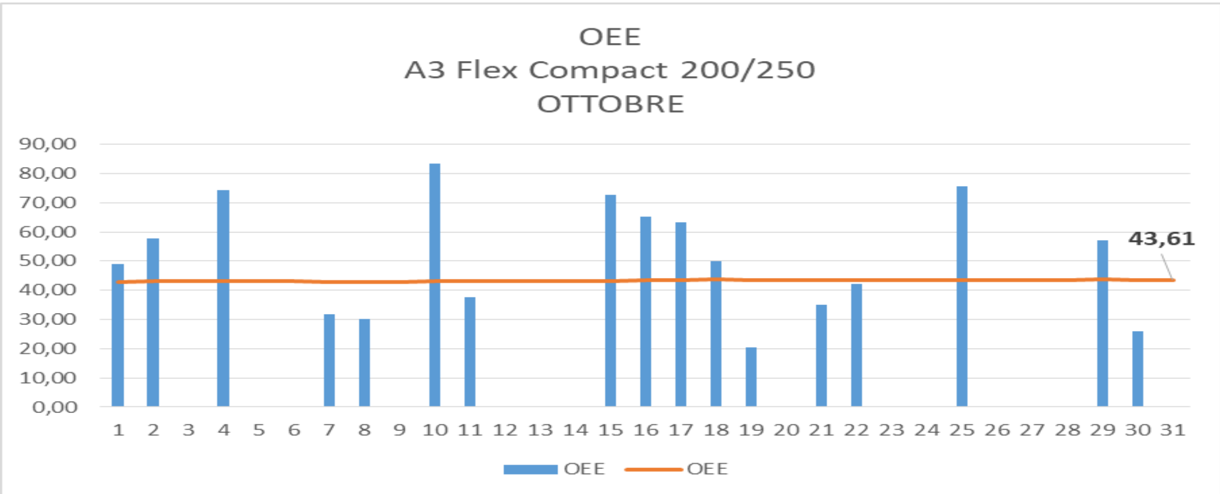


Figure 96 - OEE October (1)

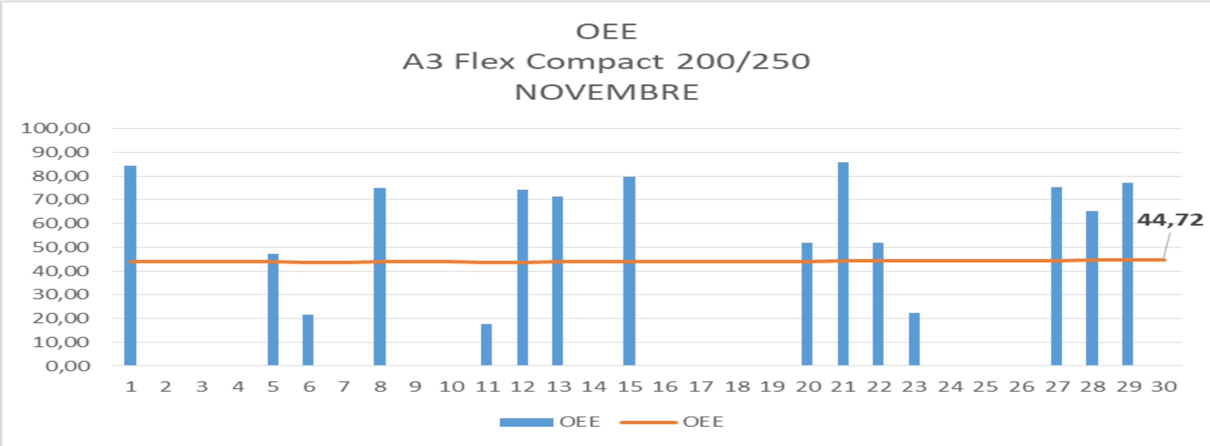


Figure 97 - OEE November (1)

-A3 Flex Base 500/1000, then A3 Speed Square 1000 (2)

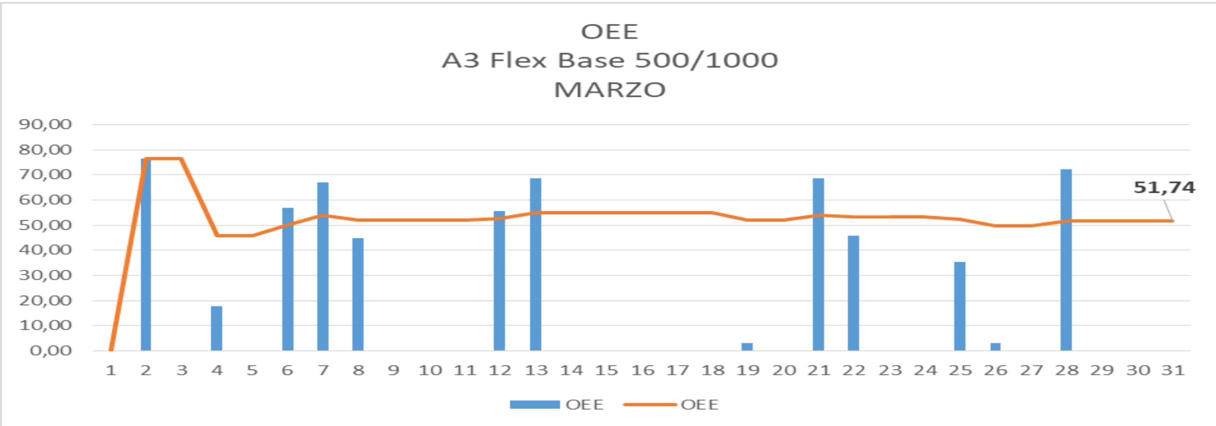


Figure 98- OEE March (2)

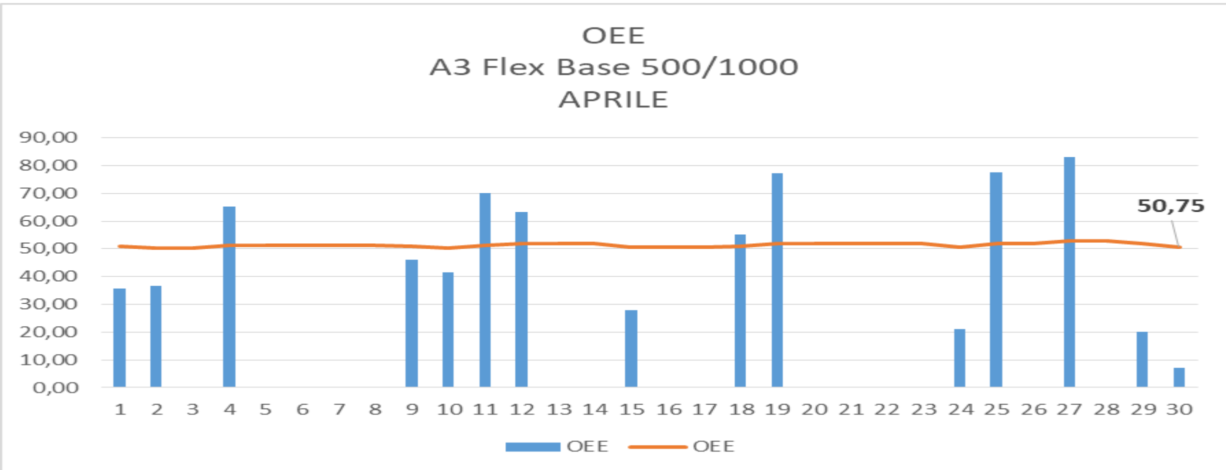


Figure 99- OEE April (2)

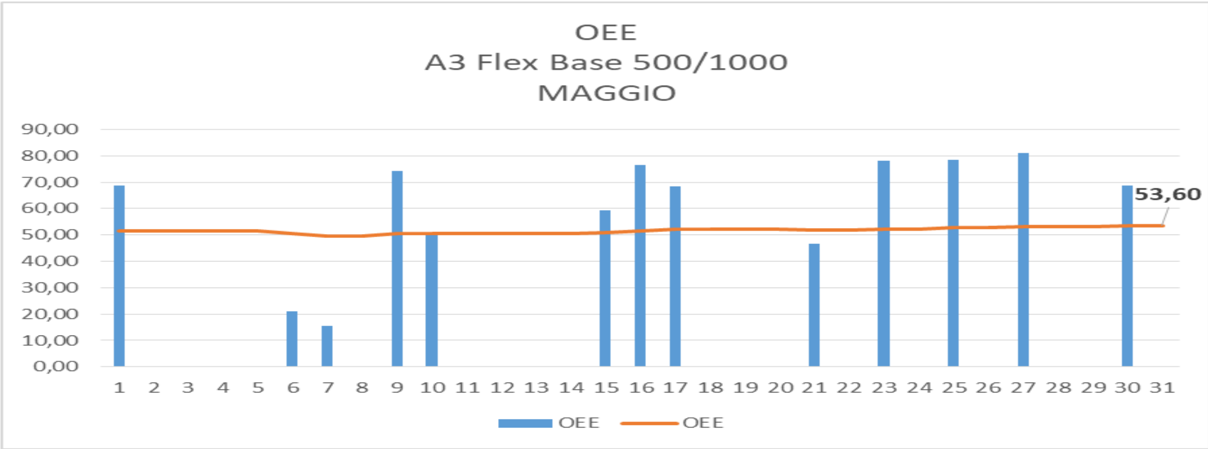


Figure 100-OEE May (2)

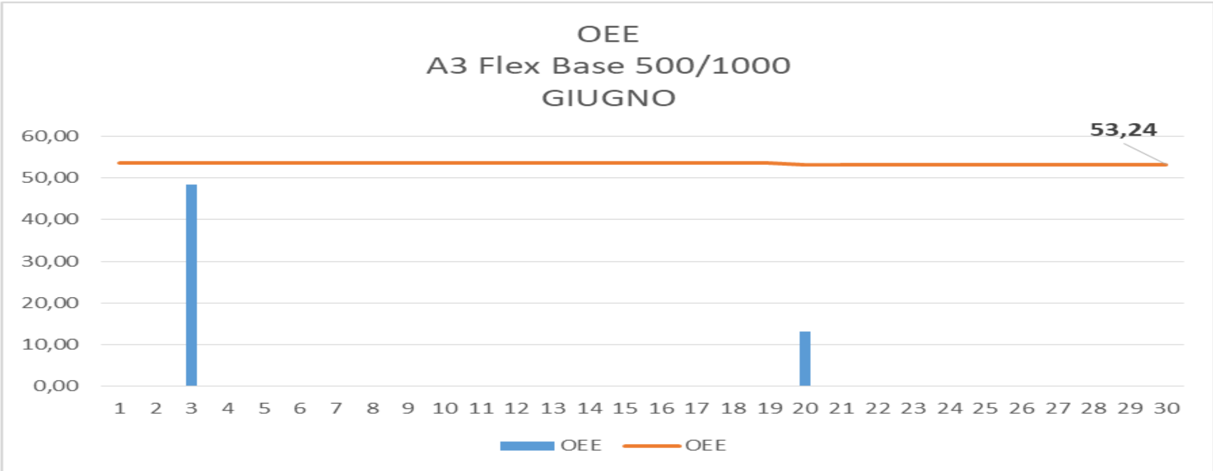


Figure 101-OEE June (2)

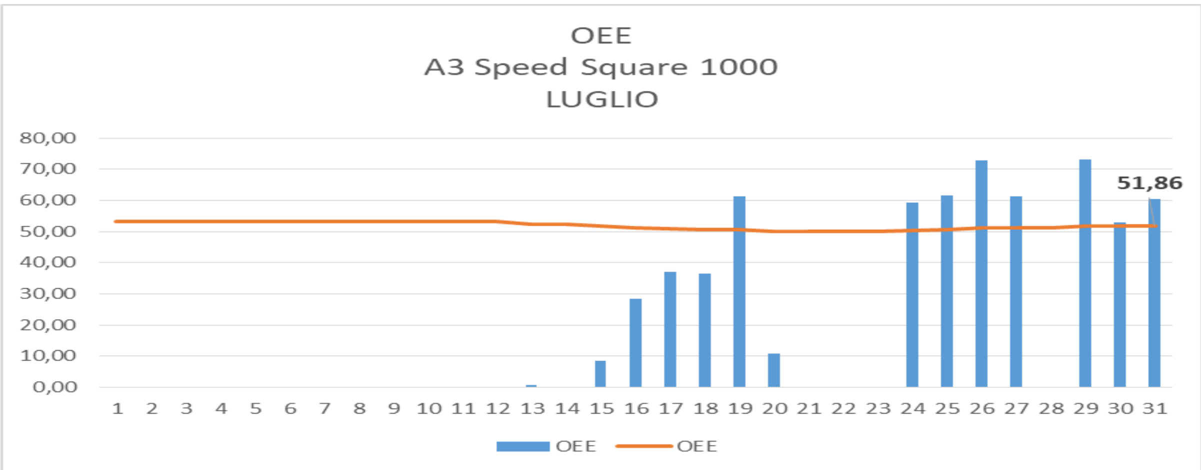


Figure 102-OEE July (2)

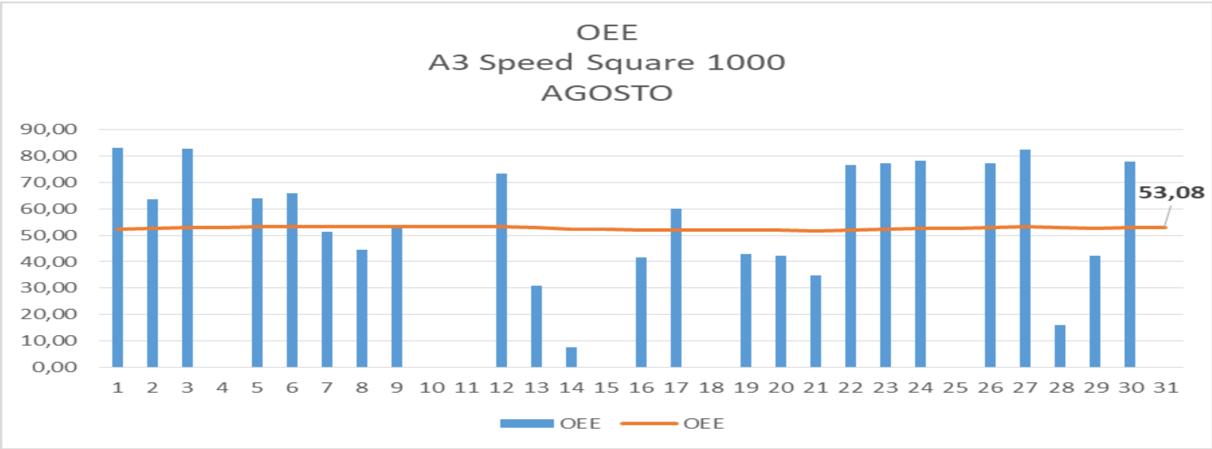


Figure 103- OEE August (2)

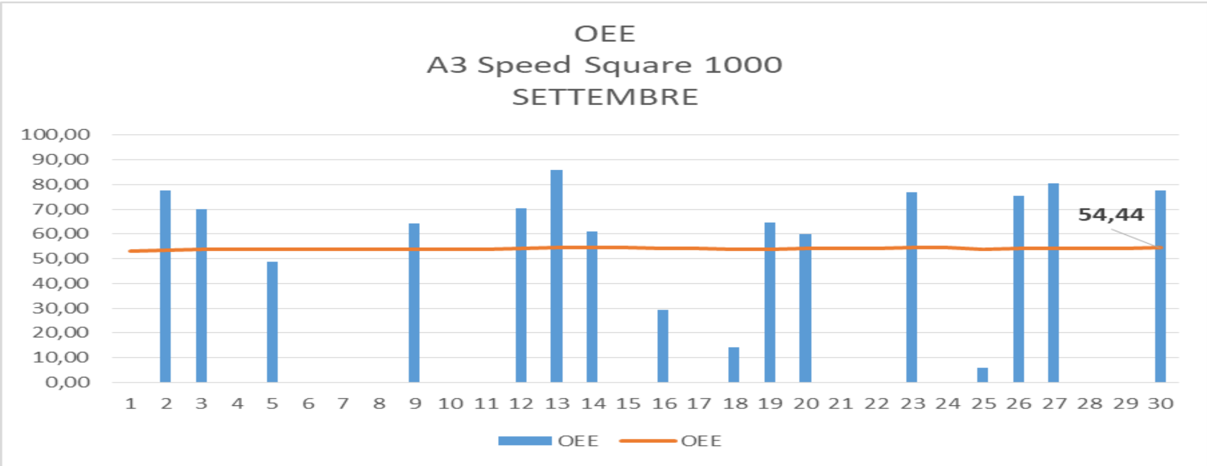


Figure 104- OEE September (2)

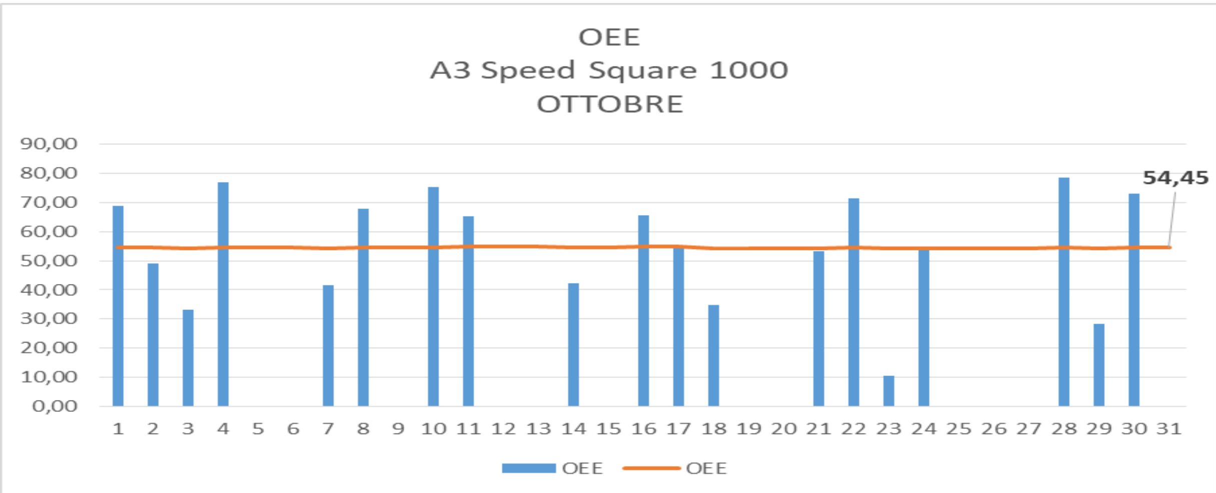


Figure 105 - OEE October (2)

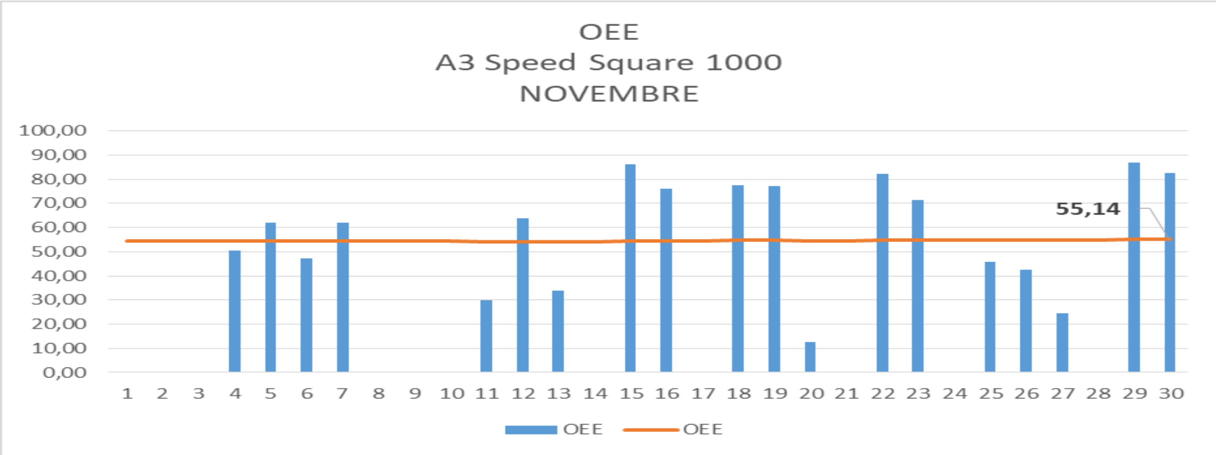


Figure 106 - OEE November (2)

-A3 Speed Square 1000, then A3 Flex Edge 500/1000 (3)

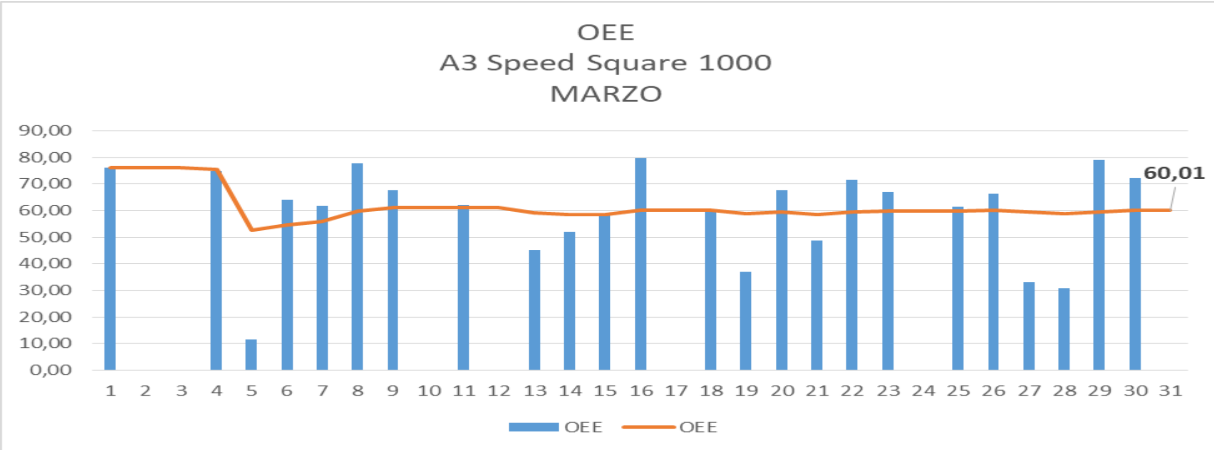


Figure 107-OEE March (3)

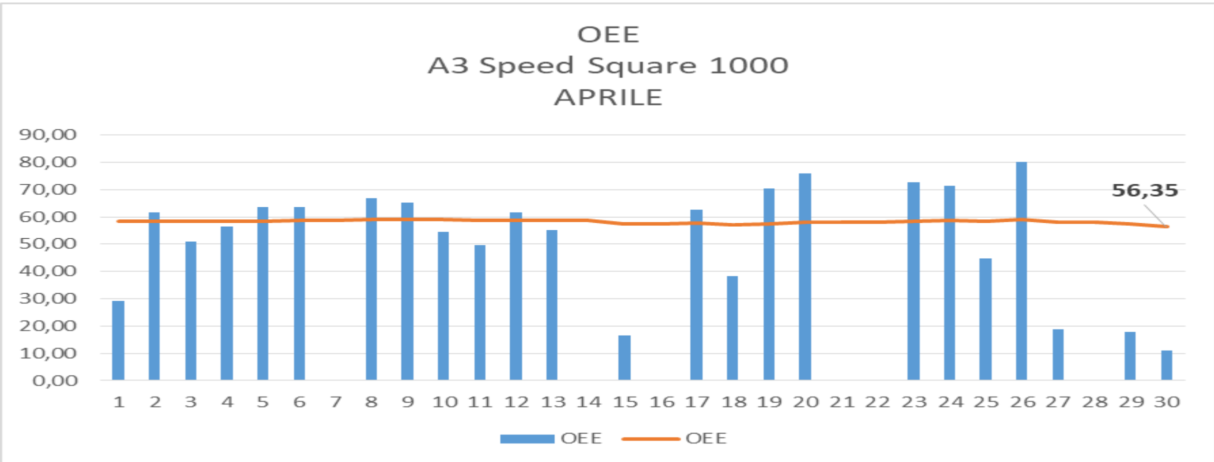


Figure 108-OEE April (3)

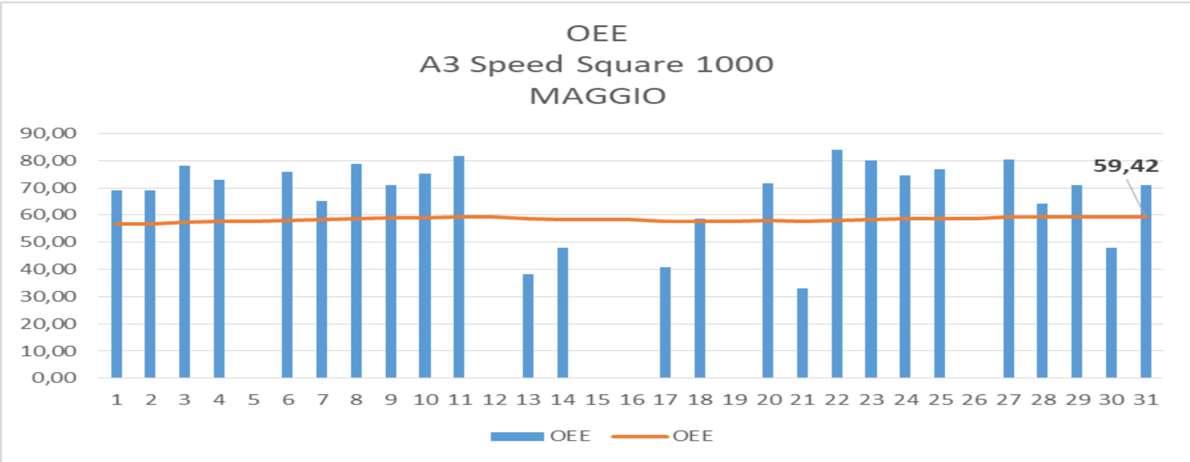


Figure 109-OEE May (3)

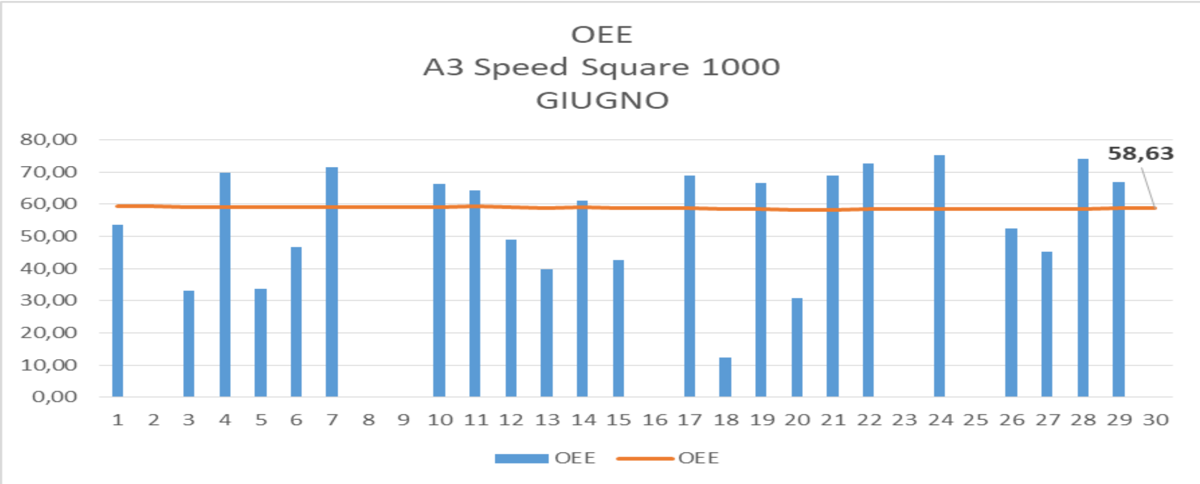


Figure 110-OEE June (3)

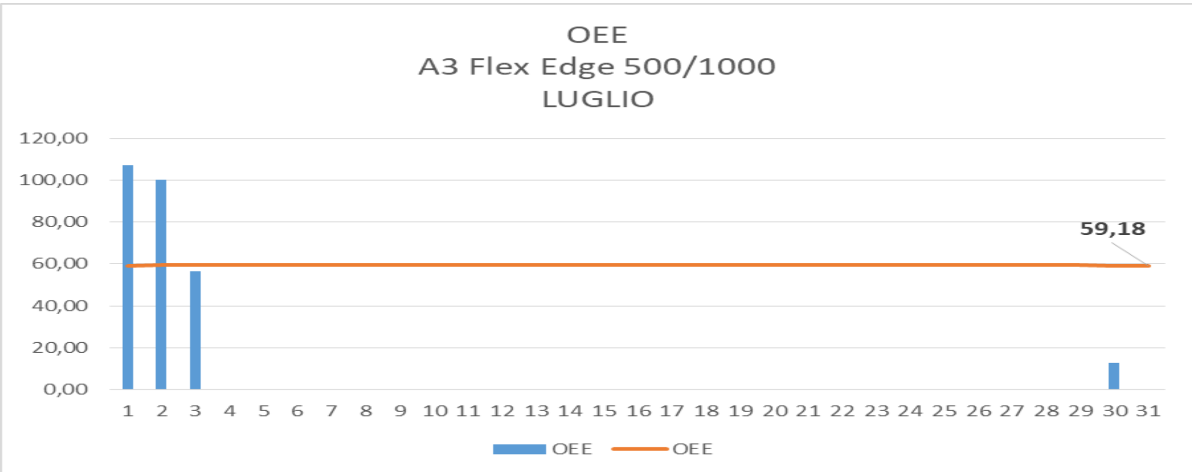


Figure 111-OEE July (3)

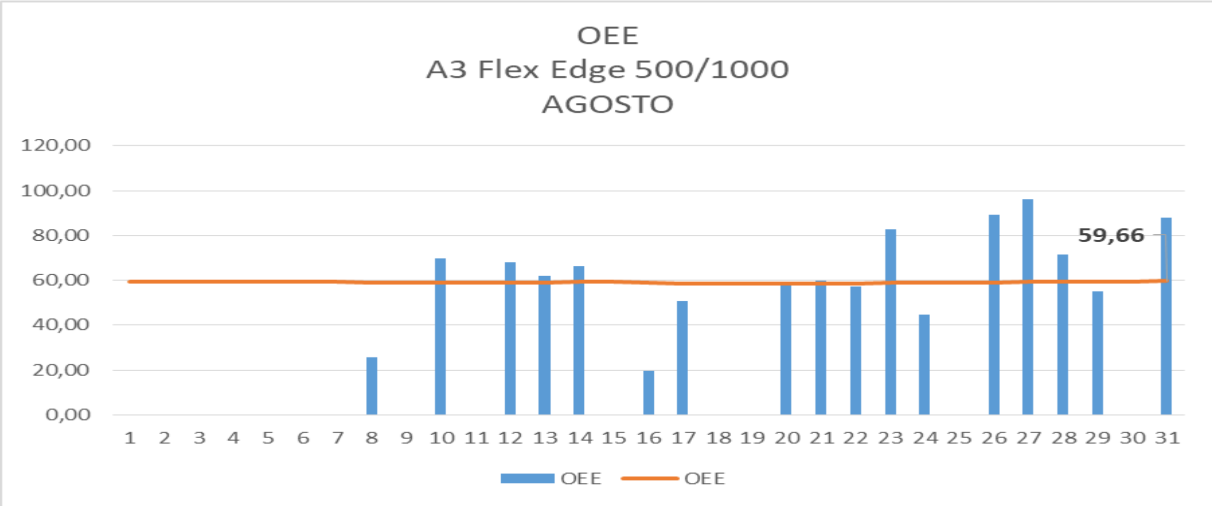


Figure 112- OEE August (3)

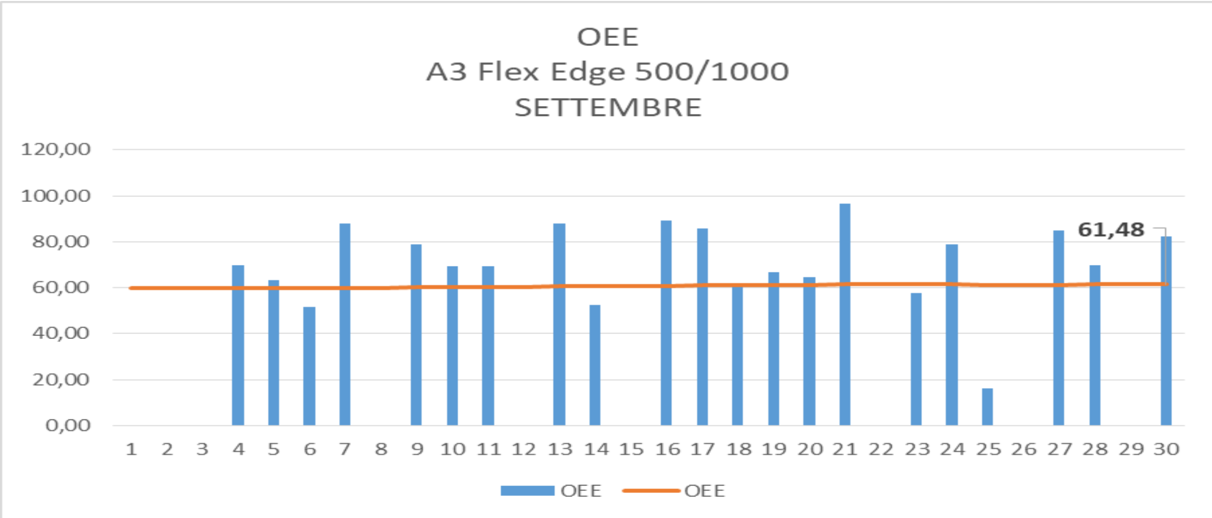


Figure 113- OEE September (3)

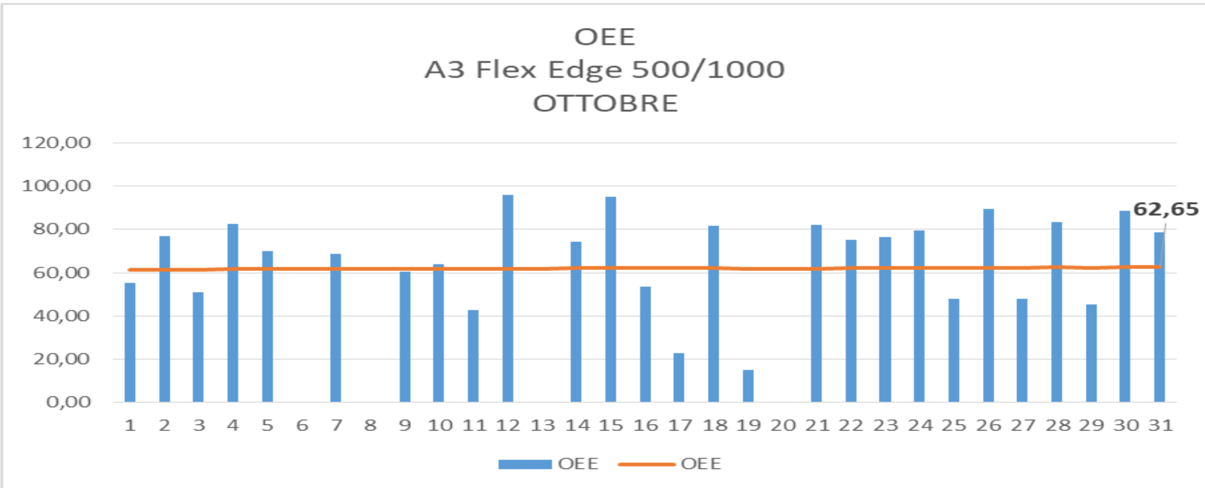


Figure 114 - OEE October (3)

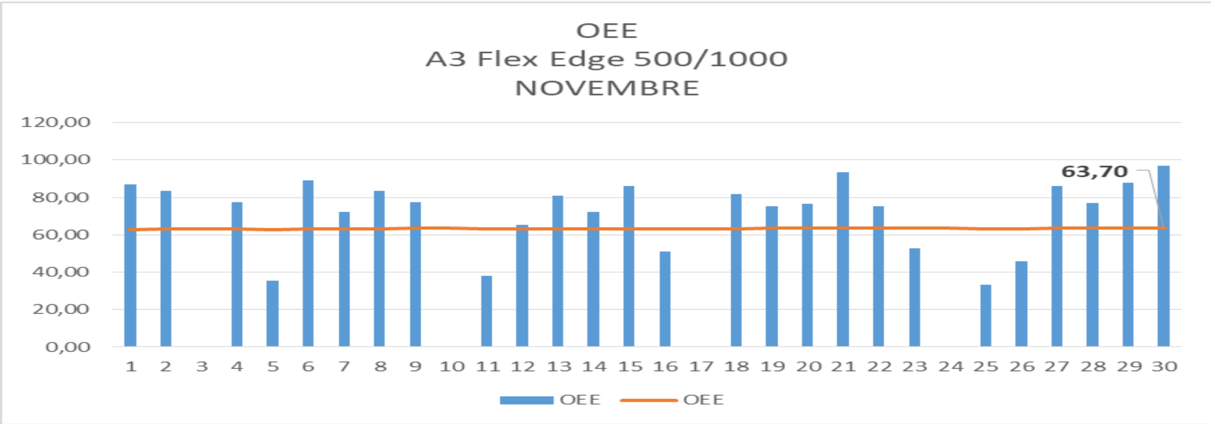


Figure 115 - OEE November (3)

-A3 Flex Edge 500/1000 (4)

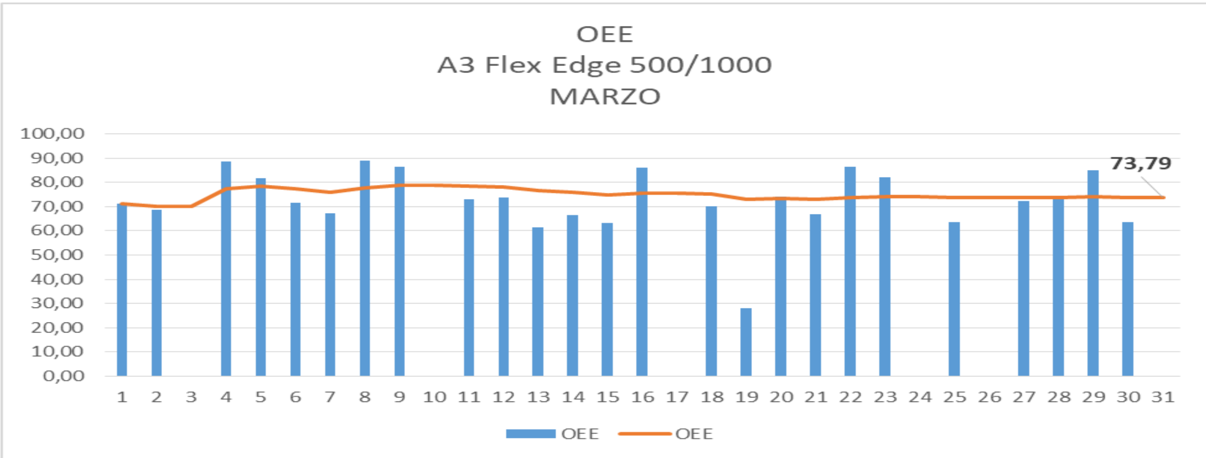


Figure 116- OEE March (4)

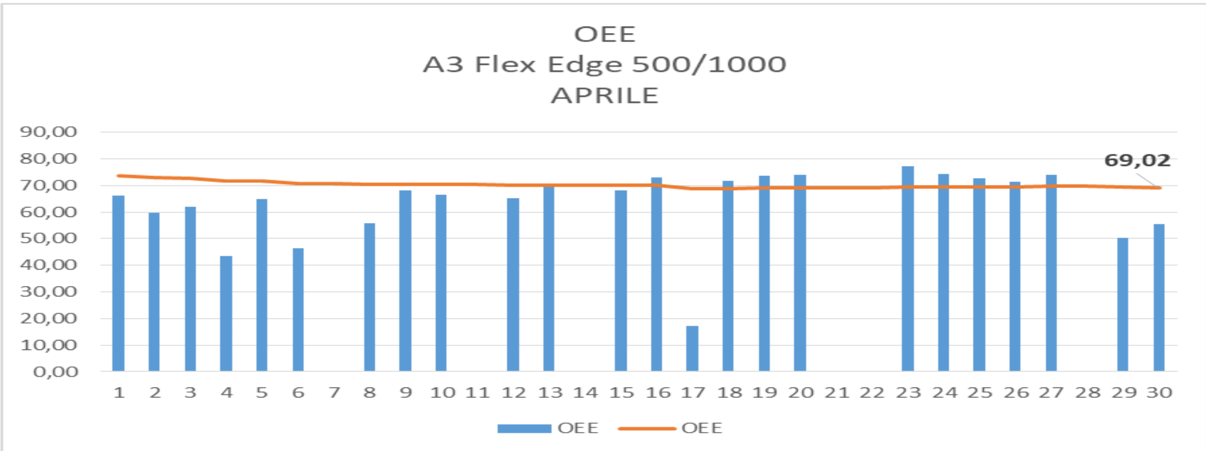
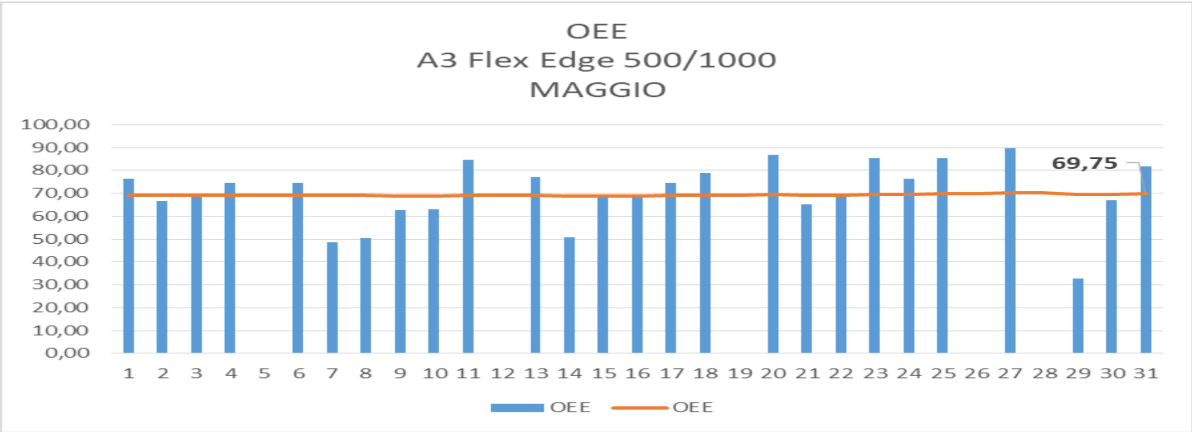


Figure 117-OEE April (4)



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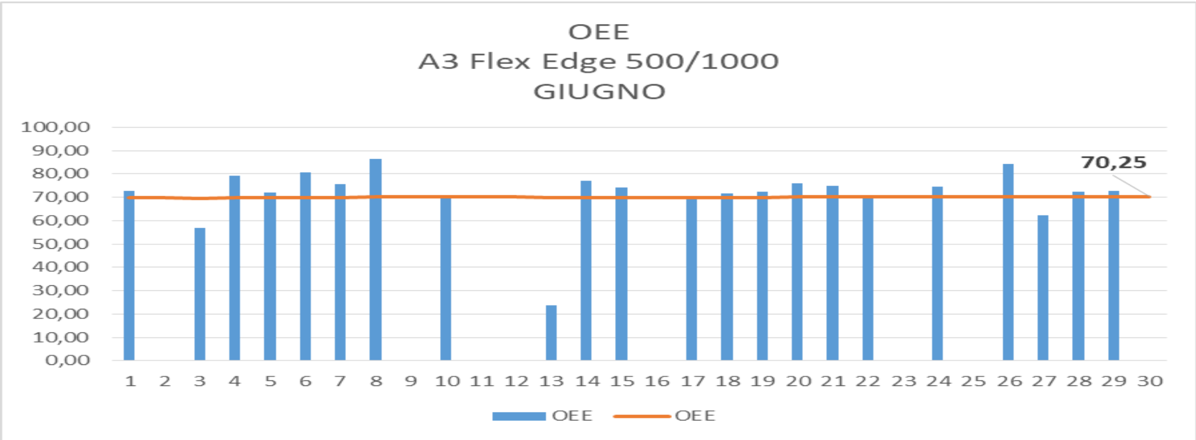

Figure 119- OEE June (4)

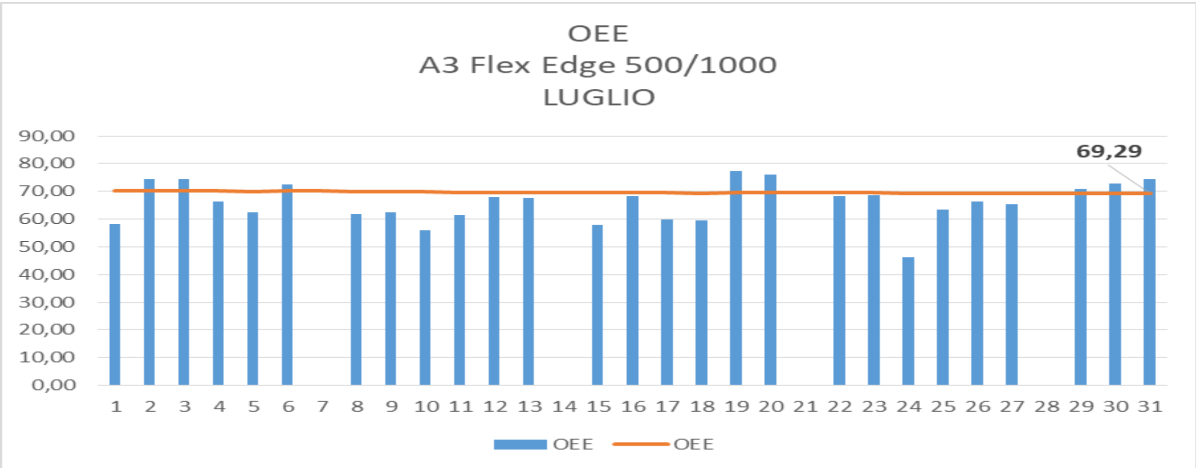

Figure 120-OEE July (4)

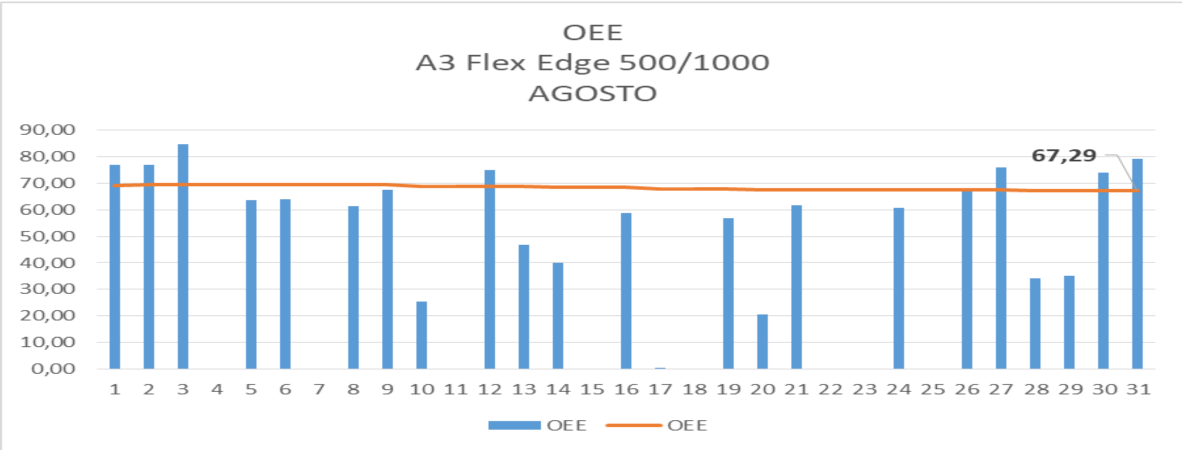

Figure 121- OEE August (4)

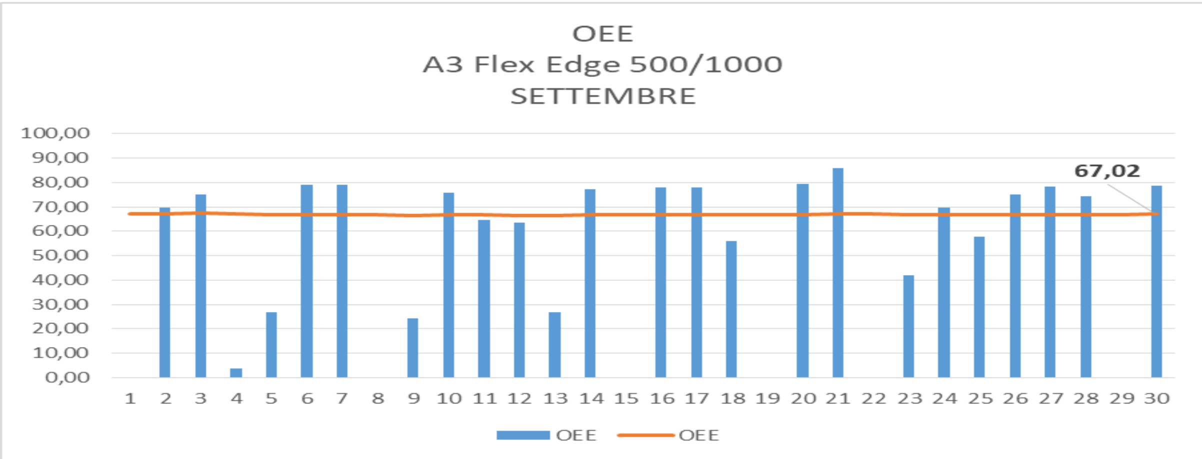

Figure 122- OEE September (4)

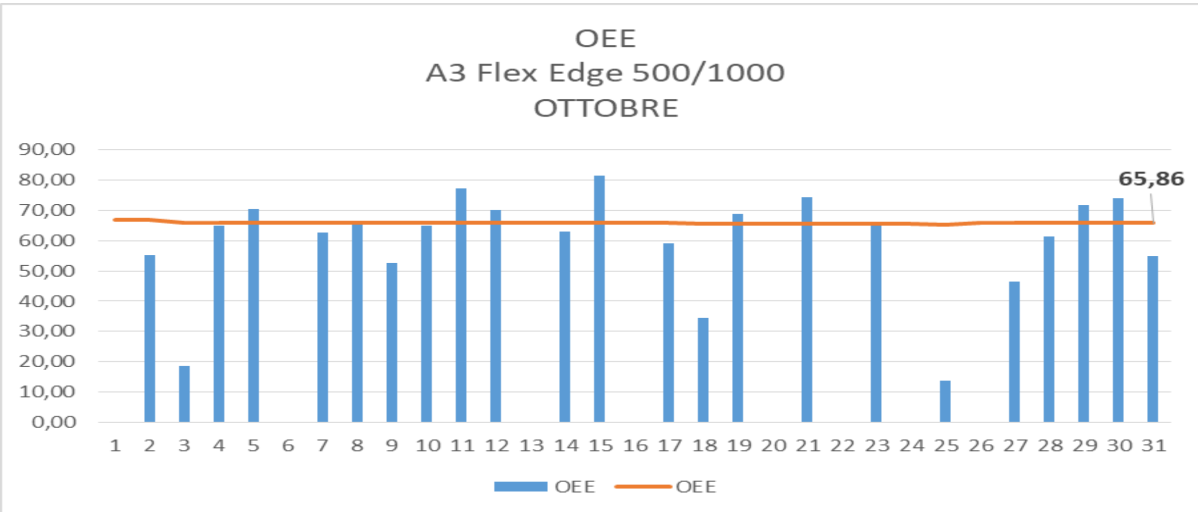

Figure 123 - OEE October (4)

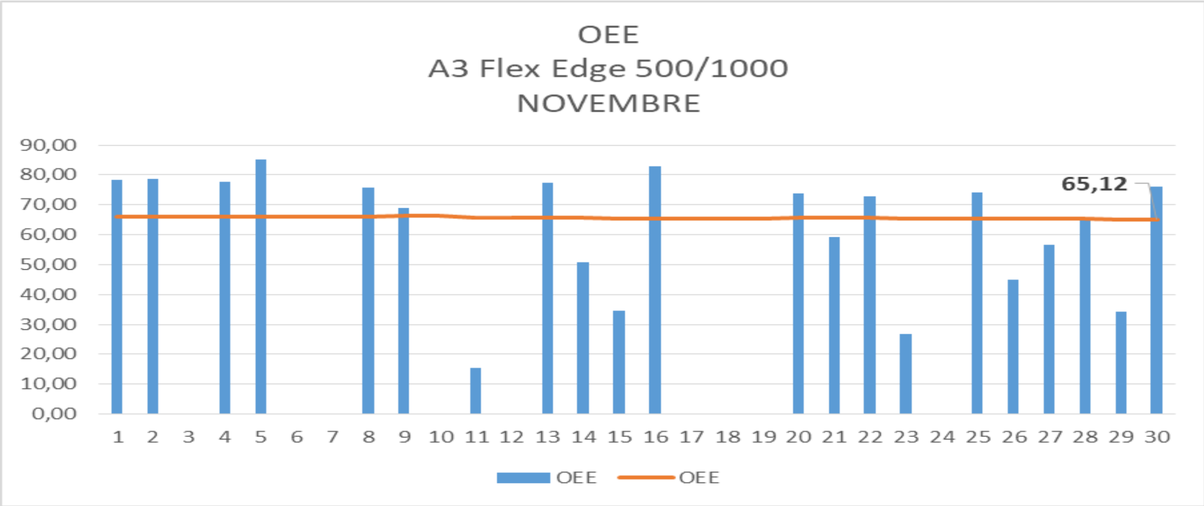

Figure 124 - OEE November (4)

-A3 Flex Edge 500/1000 (5)

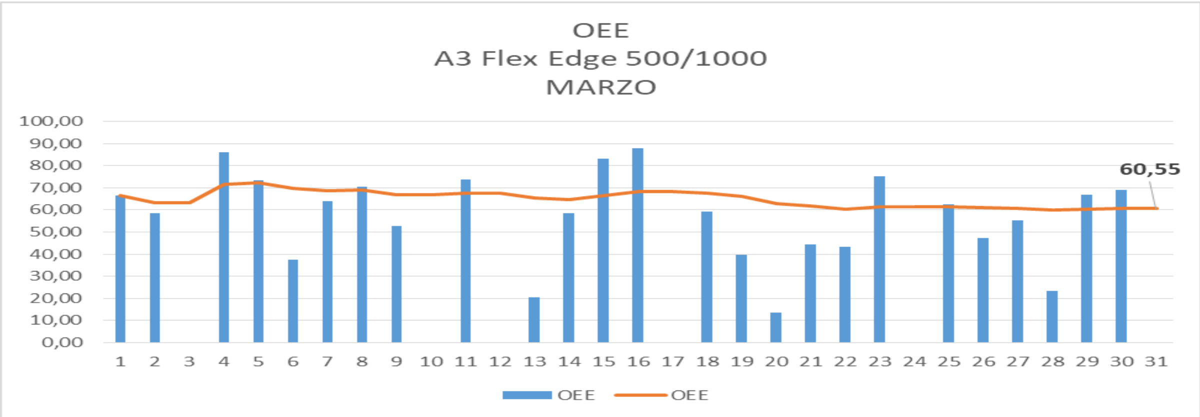

Figure 125-OEE March (5)

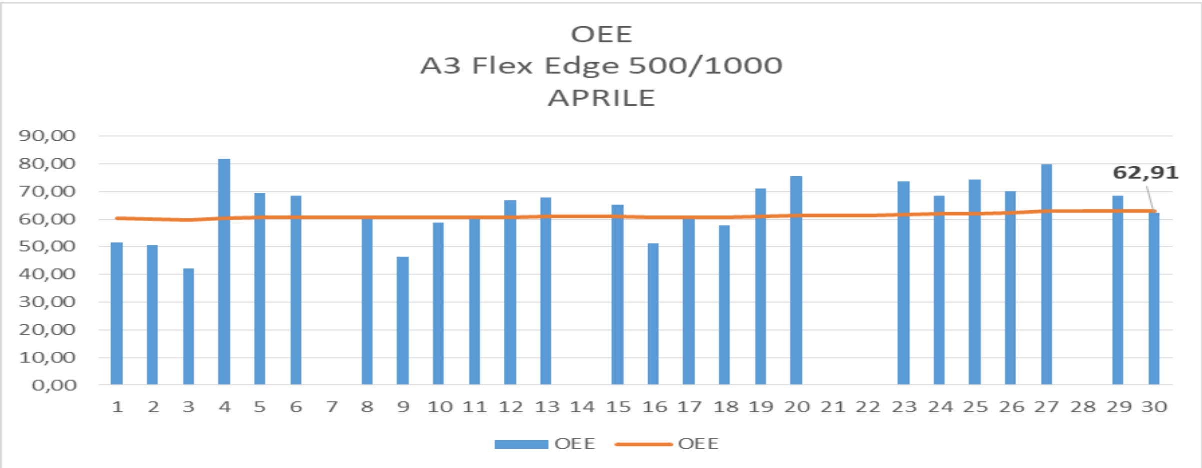

Figure 126-OEE April (5)

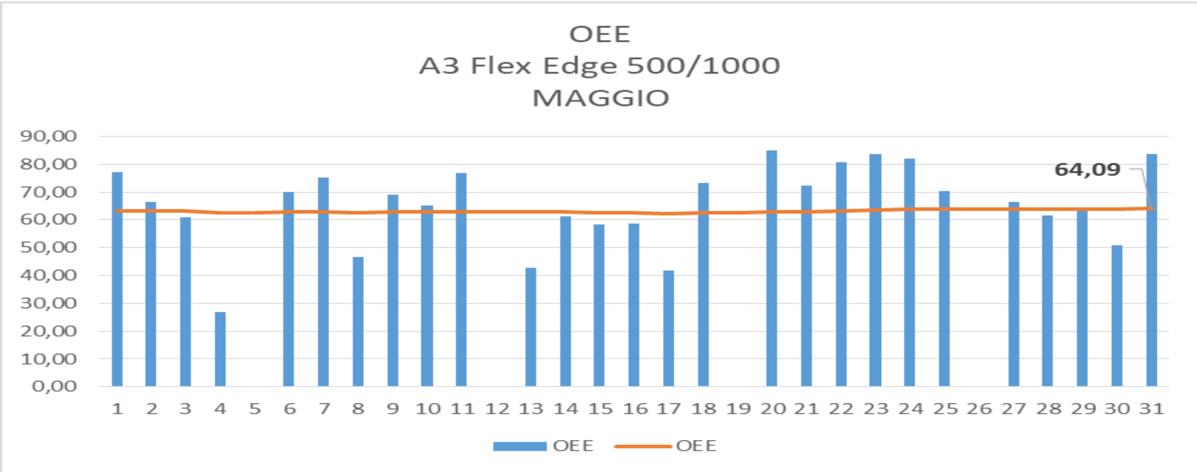

Figure 127-OEE May (5)

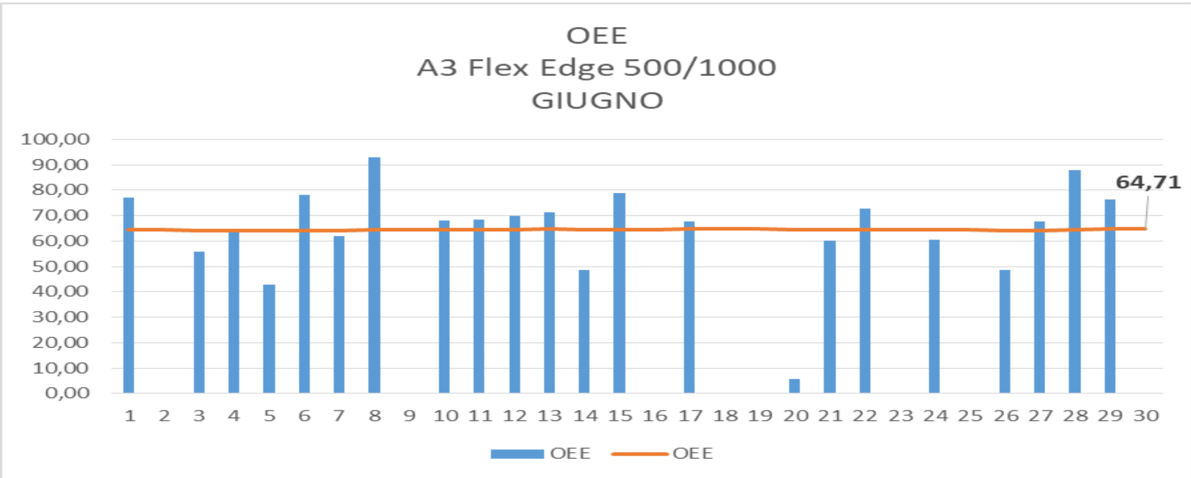

Figure 128-OEE June (5)

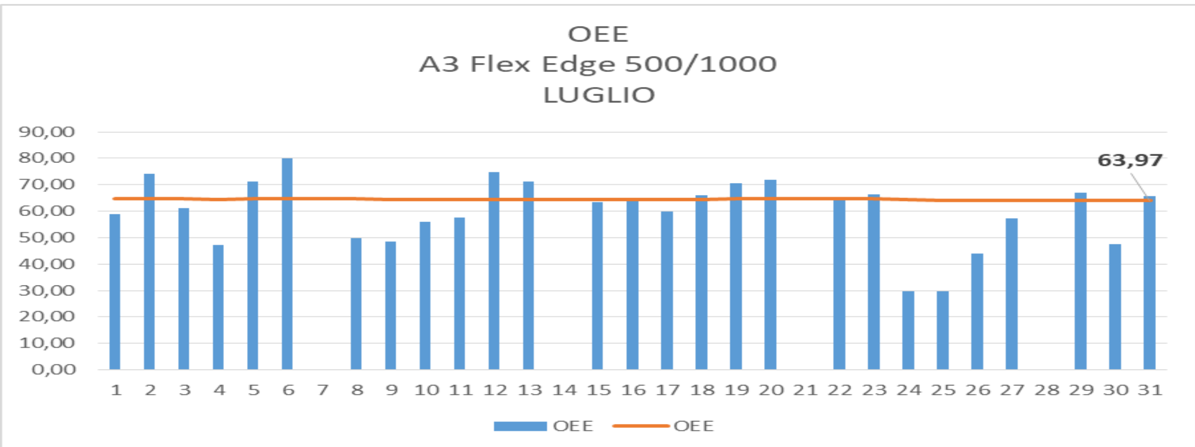

Figure 129-OEE July (5)

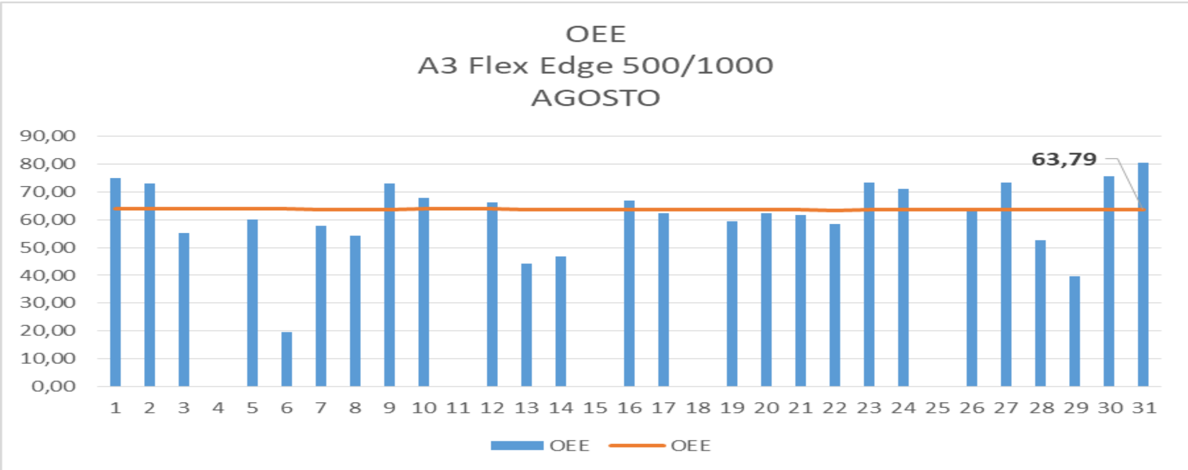

Figure 130-OEE August (5)

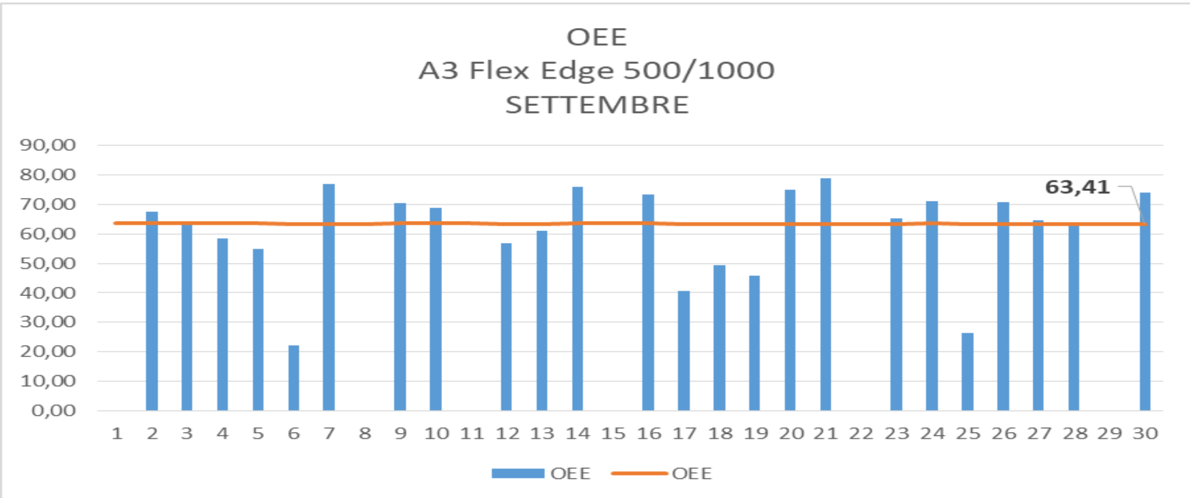

Figure 131- OEE September (5)

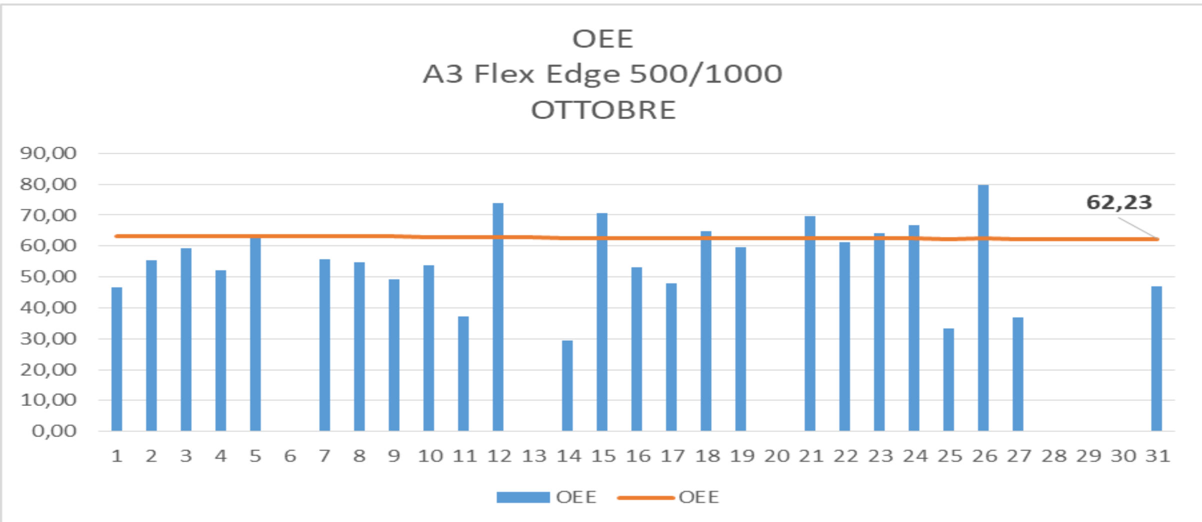

Figure 132 - OEE October (5)

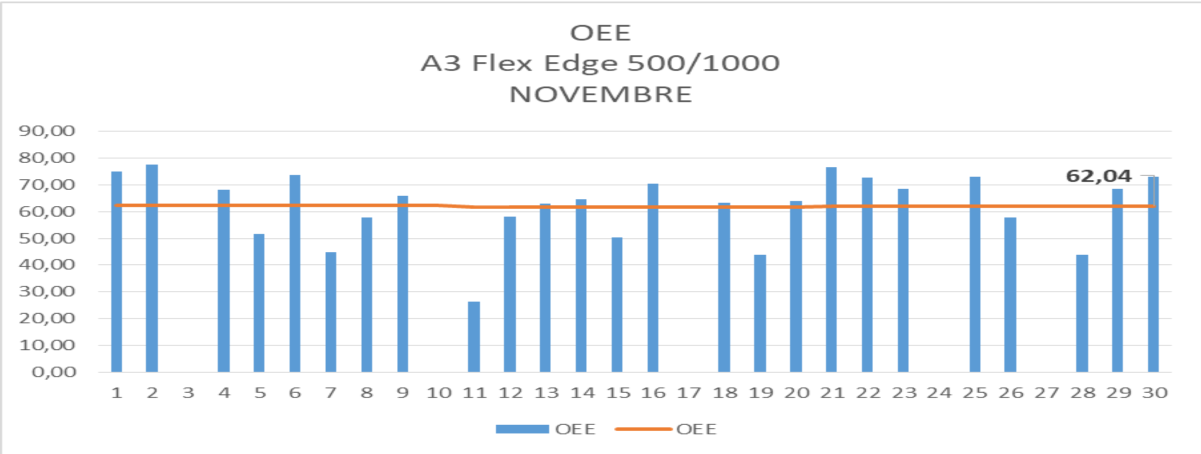

Figure 133 - OEE November (5)

-TBA8 Base 1000 (6)

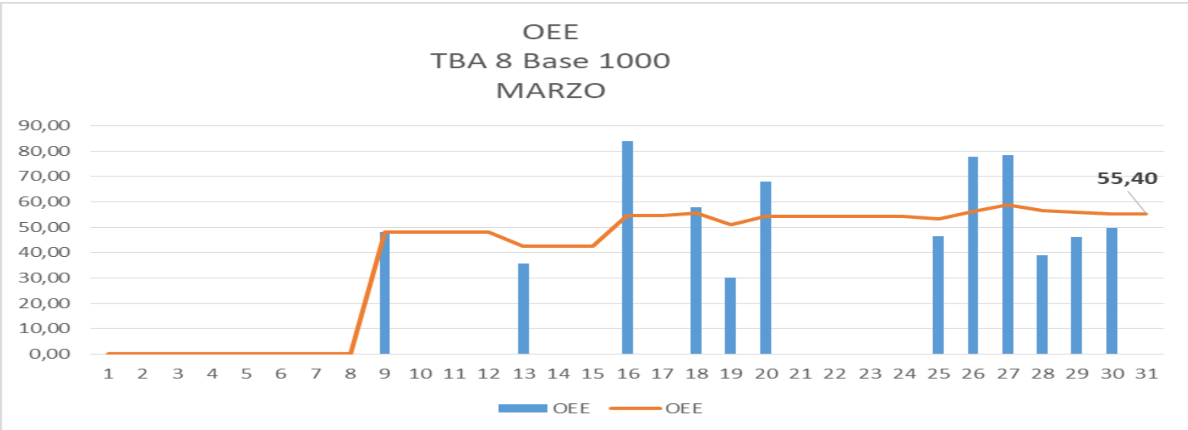

Figure 134- OEE March (6)

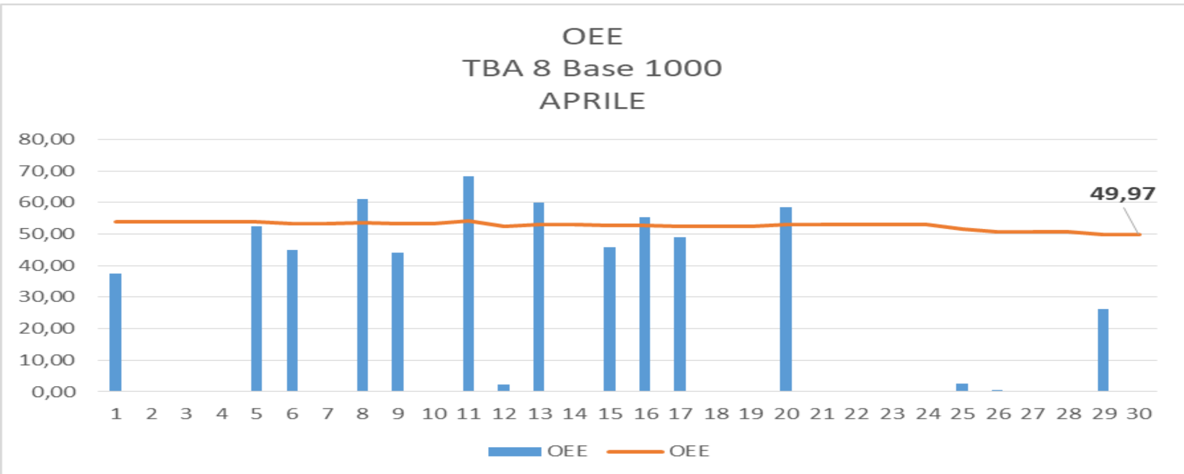

Figure 135-OEE April (6)

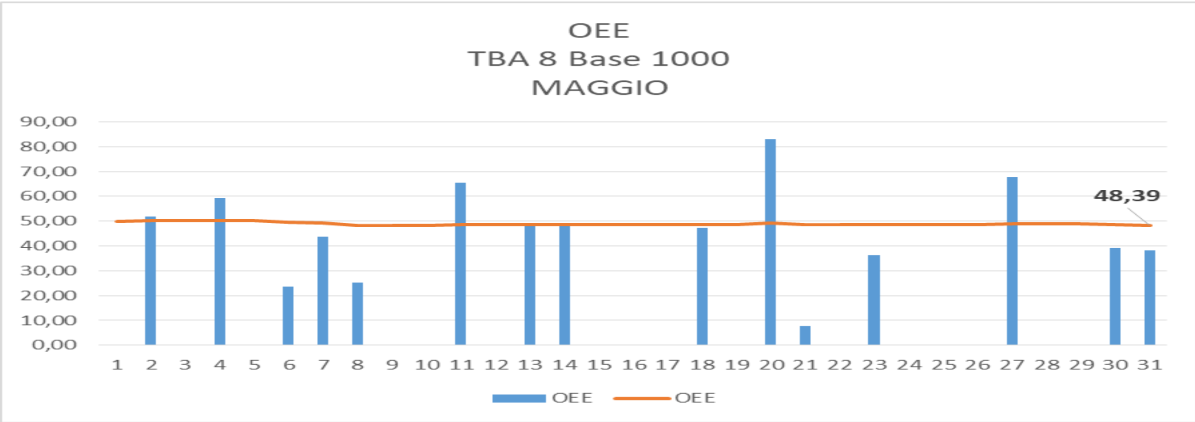

Figure 136-OEE May (6)

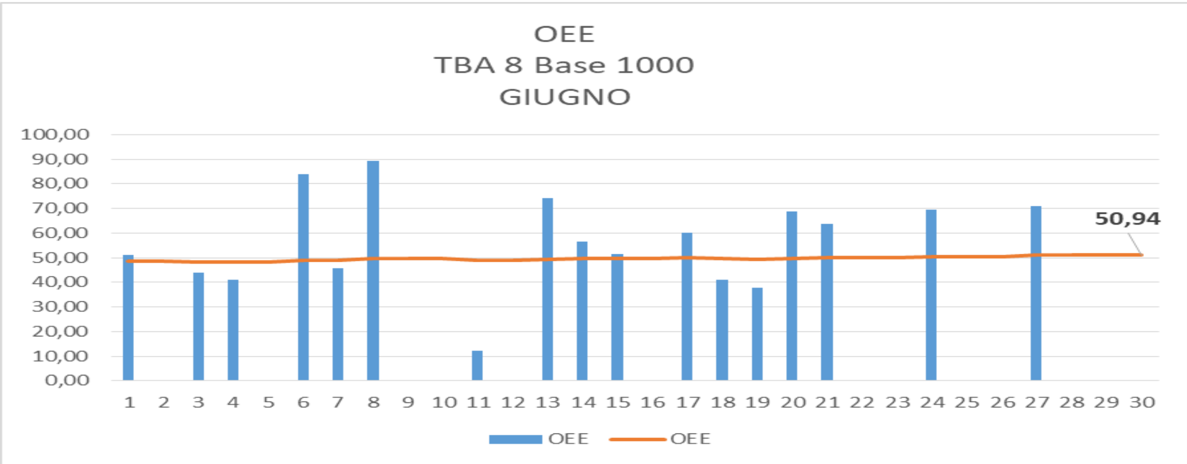

Figure 137- OEE June (6)

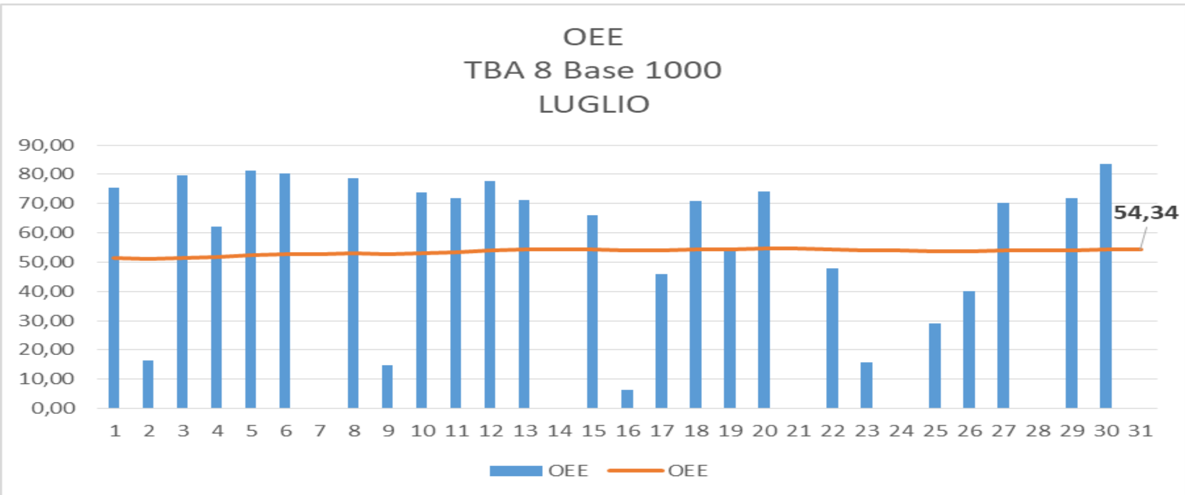

Figure 138- OEE July (6)

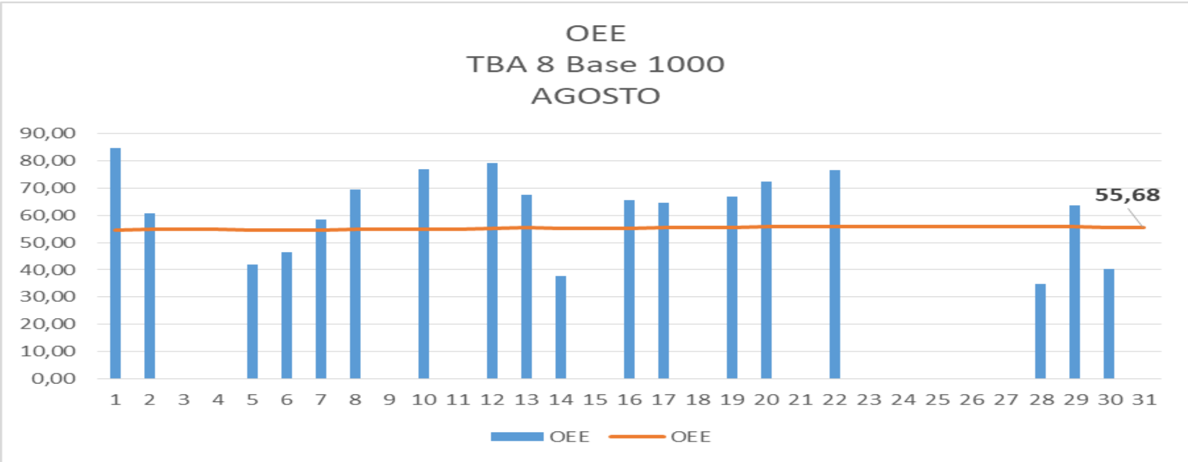

Figure 139- OEE August (6)

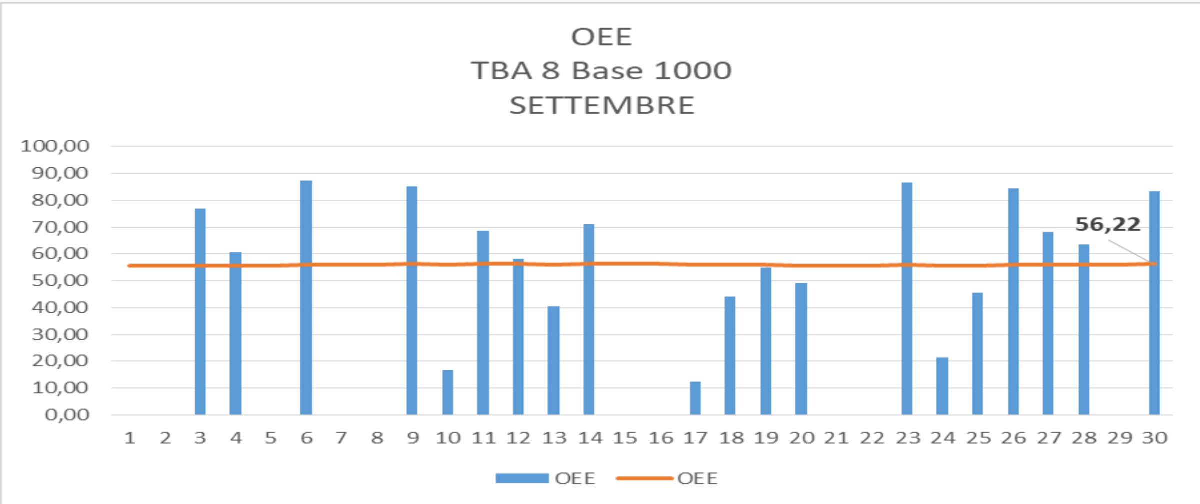

Figure 140-OEE September (6)

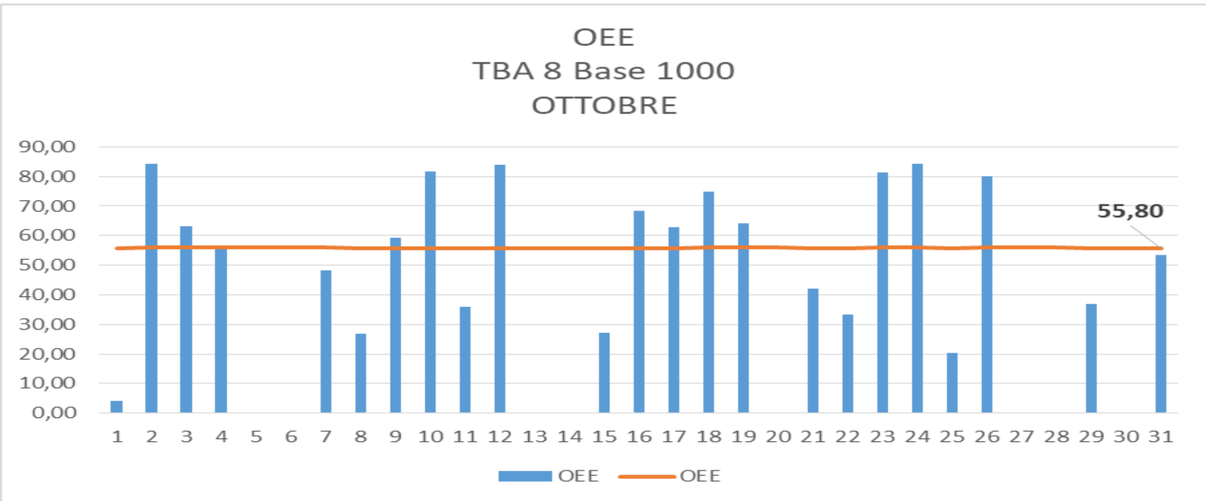

Figure 141 - OEE October (6)

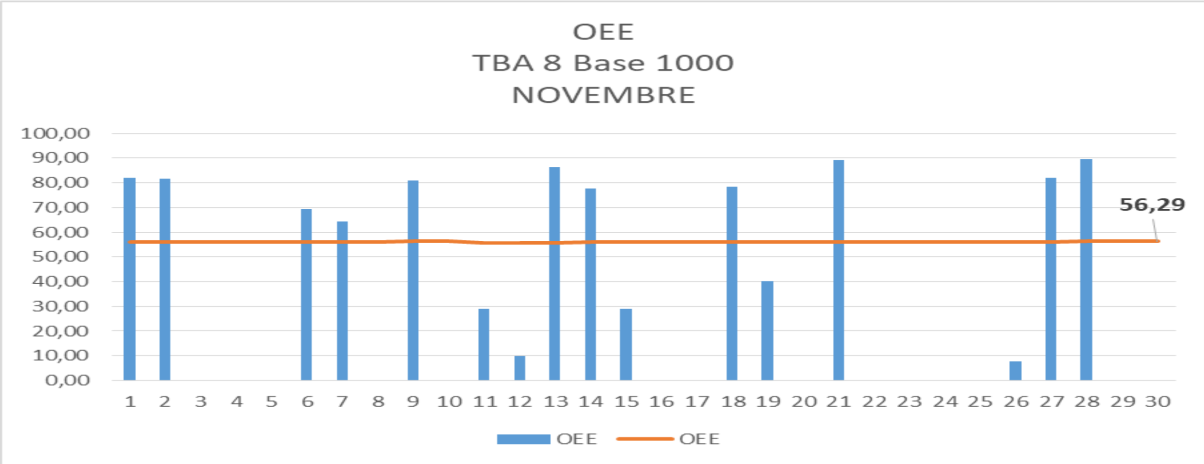

Figure 142 - OEE November (6)