POLITECNICO DI TORINO

Master Degree in Engineering and Management

Analysis, data collection and impact on OEE of a wine bottling line

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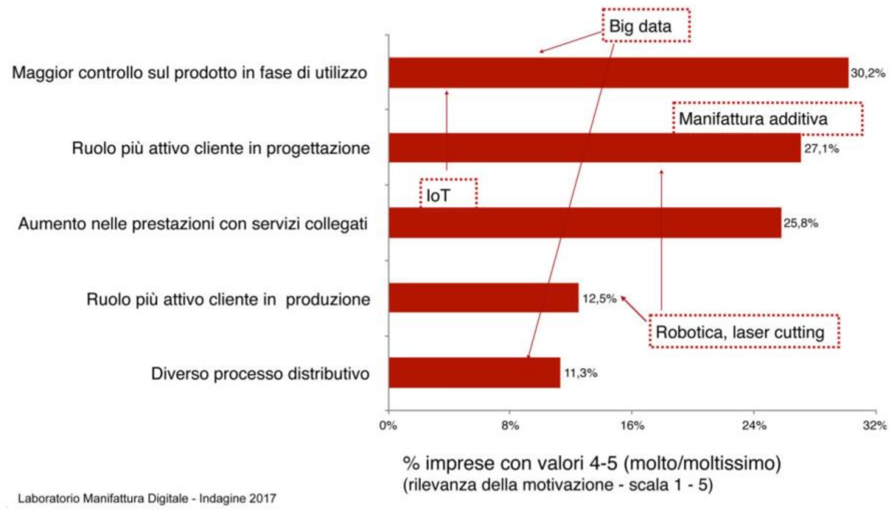
Summary

1 Introduction

PMI for Piccole Medie Imprese (SME in English) are considered the base on which Italy's economic texture is based on. Only in 2017 people occupied in them were 15 million for total revenues of 2000 billions. For the European Union, firms are classified on the base of the number of employees and revenues, an enterprise would be: medium with less than 50 million of revenues and 250 employees, small with 10 million and 50 workers and micro with 2 million and 10 employees.
Despite the great importance of these enterprises for the Italian economy, the level of innovation is very low.
For the "Secondo Rapporto Industria 4.0 nelle PMI italiane" wrote by the Laboratorio Manifattura Digitale dell'Università degli Studi di Padova" highlights how in a sample of 1020 industries located in the north of Italy deal with the introduction on "Industry 4.0" concepts.



The first important take away is the percentage adoption of at least one of the possible technologies in the Industry 4.0 (robotics, additive manufacturing, laser cutting, big data, cloud, IoT, scanner 3D and augmented reality) that states at 18,6%
In the first graph are shown perceived improvements given by these technologies by firms. The first one at 30,2% is the greater control on production phase, followed

by proactive role in design, performance improve, more client oriented and different distributive process.

On the graph below is shown difficulties that are perceived in the implementation process.

Difficult to hire professional personnel, shortage of adequate internet connection, limited financial resources, long time to implement, lack of internal capabilities is the major concern about these types of innovation.

A firm with the goal of a more flexible and proactive innovation in processes must first analyse its current situation to build a base to make improvements.

In the production process one of the most important and recognized indicator is the OEE.

This thesis, thanks to this KPI, has the mission to set the current situation in a wine bottling line of an ancient wine cellar, to show how small improvements can lead to a great impact especially on these types of small and medium enterprises.

The Overall Equipment Effectiveness is considered the main performance indicator for a productive plant because it's influenced by the inefficiencies as failures, setup, warmup, defectives, all the elements that slow down the process.

Monitoring the OEE does not lead to an immediate increase of productivity but if it is paired with improvements and a deep analysis on the causes of it, it can be very impactful.

2 Fontanafredda and the market

The name of Fontanafredda comes from the presence of a water source very cold, near the cellar, very useful to control temperature of wine oak.
In 1858 the estates are bought from the king Vittorio Emanuele II, as a present to Bela Rosin (Rosa Vercellana) his future wife. In 1931 the bank "Monte Paschi di Siena" acquire the wine cellar and keep it until the 2009, year that which the property returns in private hands.
In 2017 Fontanafredda is awarded from Wine Enthusiast Magazine, one of the most important publication in wine category, to be Best European Winery of the year.
In the same year consolidated revenues were approximately of 60 million, with 8 millions of sold bottles.
Handmade processes of this ancient work have to deal with new innovation useful to improve the quality and the production flow, since all processes are held in house, from cultivation to packaging and stoking.

In last years the global market of wine had several changes from the producers view point. Thanks to a more and more expansion to new countries the need to adequate the product the different request for every country (mainly differences in packaging) led to a personalization in production, this had the result to shift from a semi-mass production to a smaller batches production, with evident differences in the management of the line.
This condition led to the need to rationalize the production process to gain in flexibility and greater control.
As well as some of product presenting the food and beverage industry, wine bottling is forced to comply with the natural age process of wine, this implies the need to respect the role of time, and when the product is ready, to be very agile and efficient to bottle it in the best way possible.

3 The production layout

In the part of the plant dedicated to bottling there are two lines: one is dedicated to sparkling and the other to still wine. The distinction comes from few differences: first of all, the former has the cage for the plug (and consequentially the correlated machine), necessary given by the presence of much higher internal pressures. Secondly sparkling wine with low levels of alcohol needs a biological stabilization (anti-fermentative treatment) given by a pasteurizer. This machine has huge dimensions, since uses hot water to heat up bottles, and creates a big buffer: it essentially divides the line in two different part since the capacity is of 5000 bottles. This led to have a difficult and not coherent analysis. Recently the pasteurizer is replaced by filters that can stabilized the wine without using the heat (obviously increasing easily the quality of the final product and production), but since it's important to not have condensation due to the low temperature of the sparkling wine, the pasteurizer is used as heater.

An example of a pasteurizer. Photo from https://www.padovan.com

In this analysis, we will focus on the line dedicated to still wine also because it's the one most used and it has to manage more formats of bottles, wine and packaging, leading to frequent changes in set-ups.

3.1 The bottling line for still wine

Every machine is connected to others thanks to conveyor belt, that is capable to slow down, stop and restart in case of bottle accumulation in valley thanks the presence of photocells. This method helps to manage the downtime of the machine and avoid broken bottles, due to the collision between them in case of differences in speed.
The line has no inter-operational buffer, since it has a very limited space between the machines and no places where bottles can be accumulated.

The bottling line is composed by:

1. De-palletizer
2. Bottle washer
3. Bottle filling and corking machine
4. External bottle washer and dryer
5. Capper
6. Labeller
7. Packing machine and boxes forming
8. Hive and boxes printer
9. Palletizer

Start of the line

De-palletizer

The pallet full of bottles is inserted in the machine through a system of chains and rails, protective films are removed and every floor of bottles is positioned in the accumulation area before the washer machine.

Bottle washer

Consisting of a rotary carousel with one inlet and an outlet that allows internal and external washing of the bottles, compulsory to eliminate the dust or other substances before the bottling machine, after the machine the section that connects them to the belt is closed by Plexiglas barriers.

Centre of the line

Bottle filling and corking machine

Machine used for filling and capping bottles. Thanks to an auger, the bottles are ordered and a star transfers the bottles to the central carousel, using small plates. These are raised, thanks to the pistons, to adhere to the gasket of the faucet centring bell. The bottle is put under internal pressure, thanks to a command that opens the valve, when the bottle reaches the same pressure as the tank, the isobaric filling begins. To get the right level, the machine reabsorbs the excess quantity through the same tube. Then the bottle is taken from the outgoing star and returned to the convoy, which immediately reaches the corking machine after a level test.

External bottle washer and dryer

Immediately after the corking machine, the bottle is washed and dried externally to guarantee the perfect adherence of the label and the absence of residual materials.

Capper

Here the bottle enters and a cup using compressed air to catch and release the capsule on the neck of the bottle. Than a satellite rotating machine rolls the neck to let the capsule adhere perfectly.

Labeller

Here the bottle entering through an input auger is placed in a rotary carousel with rotating plates and jacks that hold the bottle in place by pressing on the cap. The reel is loaded on a rotating support and by rollers. it is turned, catted and glued thanks to the passage on a hot glue roller. In total to be applied there is a back and front label and a small “collar label” (a band to cover the space between the capsule put on the top and the glass of the neck of the bottle).

The state seal with the unilateral product code and the lot number is printed on the production seal, positioned on the neck of the bottle. When the bottles are carried on the belt, exiting the machine, an output auger helps them slip into a short duct with brushes to make the labels stick better.

Final part

Packaging machine and boxes forming

Here thanks to dividers the bottles are divided according to the necessary rows to be inserted in the box. The forming machine prepares the box which, in groups of 3, enter in the machine to be filled from the top by a bottle dispenser which, thanks to mechanical arms and pressure suction cups, pick up the bottles from the top of the neck and place them in the cartons.

Hive, box closer and printer

At this point the hive is inserted, thanks to an arm that picks it up and by means of two small suction cups it makes it slide between the bottles, after which the box enters in the tunnel that allows to close the cardboard with glue, to print on the box the lot number and others useful information. Then a check is carried out on the weight so as to avoid boxes with missing bottles.

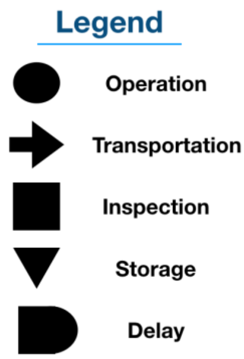
Palletizer

The machine composes the pallet layer by layer according to the directives that are present, wraps it thanks to a film and places it in the loading bay of the automatic shuttle that will pick up the pallet and take it to the automatic warehouse.

3.2 ASME chart

The ASME chart is a symbolic tool implemented in 1947 to represent all activities that compose a production line.
The analysis comprehends also the inspection areas where the product is analysed and reject if not conform and the storage areas where the product can be stored.
The following table it is for the representation of the line, according this method.

ASME chart symbol	Function
●	De-palletizer
➔	
●	Bottle washer
➔	
●	Bottle filling
➔	
●	Corking machine
➔	
■	Level control and cork presence
➔	
●	External washer and dryer
➔	
●	Capper
➔	
●	Capper presence control
➔	
●	Labeller
➔	
●	Date and lot number printer
➔	
●	Box former
➔	
●	Packaging machine
➔	
●	Hive, box closer and printer
➔	
■	Weight control
➔	
●	Palletizer
➔	
▼	Finished products warehouse



4 Line personnel

As the majority of a firm, in the production area, there are: maintainers and line personnel.

The first category is for people that have the role to manage failures and doing improvements in the machineries. In some cases, they are useful also to replace if needed the line personnel or to help them with the set-up of machines, making it faster. It's necessary to formalize shifts to be sure that at least one is present in the building.
The level of specialization depends on cases but it's fundamental to have all the possibly area of knowledge covered, since failures can happen and block for hours production, creating a very big delay.

The line personnel are composed by workers that directly follow the working station, make changes of format and set-ups. In case of failures are the first to intervene and try to repair the problem in the shortest amount of time. In some cases, as for the labeller, there is also the need to replace the coil or reload the glue. Every station has his own crew, the line is virtually divided into: start of the line, bottle filling and finish of the line.
Every team manage shifts to have a better fit with the daily program of production, to reach a great flexibility in case of mid-day set-ups for example.

5 TPM

TPM stand for Total Productive Maintenance is one of the most used maintenance policies since its theorization in the late 1980s by Nakajima, at that time a Toyota technician.

The TPM methodology represents the evolution of the so-called Preventive Maintenance, introduced in the 1950s by the Japanese and subsequently adopted by Western companies.

It was created to guarantee maximum efficiency and to minimize losses by taking into consideration the faults and the downtimes that can be eliminated through preventive and proactive maintenance.

The main goals of the TPM are to reduce plant downtimes and their impact on the cycle as much as possible, increase efficiency, eliminate losses due to breakdowns and increase the useful life of the equipment.

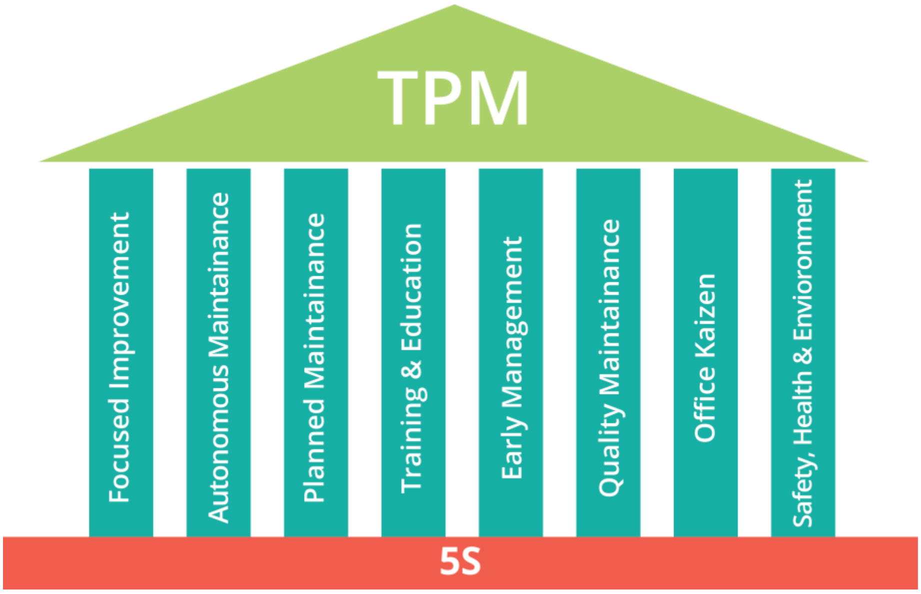
TQM's main characteristics are:

- Great focus on client
- Long term involvement and mission
- Strong commitment of the leadership and top management
- Continuous improvements

In fact, the ultimate goals are "zero defects, zero stops, zero failures" in an environment that link maintenance people and line personnel with the same goal of get better and better in efficiency.

As a means to achieve these goals there are eight fundamental pillars:

Focused Improvement, Autonomous Maintenance, Planned Maintenance, Training and education, Quality Maintenance, Office Kaizen and safety, health and environment.



TPM and 5s diagram from www.medium.com

These pillars are based on the "5s" five actions to be included in the company routine:

• Sort (Seiri), eliminate all the superfluous;

• Set in order (Seiton), set up the equipment in a convenient way;

• Shine (Seison), taking care of order and cleaning;

• Standardize (Seiketsu), making it easy to repeat;

• Sustain (Shitsuke), continuing over time to improve;

In every company, the implementation of the 5S is the starting point for the improvement of production activities and future development.

The implementation of 5S in the company must start in a controlled and limited way, it does not make sense to start with a project that covers the entire company, but it is much more feasible to start with a small or closed area and experiment and gain knowledge about it, to then adapt to the rest of the company.

6 Six big Losses

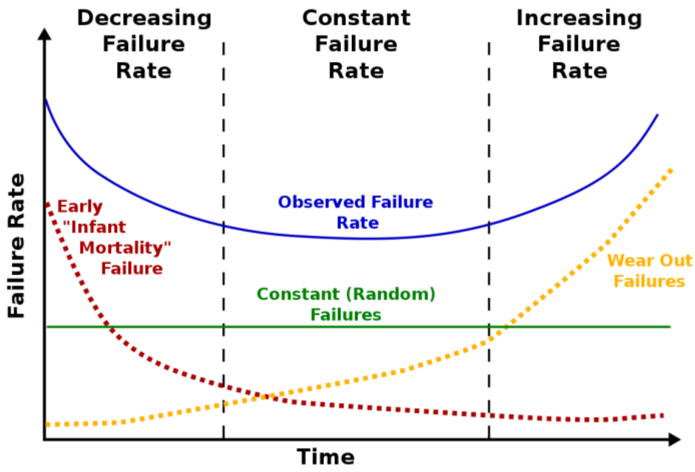
In a production process, everything that prevents the normal operation of the lines is considered a waste, these inefficiencies can be chronic or sporadic.
Chronic phenomena are generally small, hidden and difficult to detect because they are the result of several competing causes.
Sporadic inefficiencies, on the other hand, are easier to detect since they occur with high speed and with a large deviation from the normal working state of the plant. The latter also occur irregularly and at rather long intervals and their effect generally leads to serious problems.
In a plant, however, the most significant lost times are usually chronic ones because, although of lesser magnitude as the duration of the individual disturbance, their frequency leads to a low rate of equipment utilization and high costs due to losses. Moreover, chronic disturbances are subtler and more difficult to detect and are often considered as part of the normal functioning of the production process, ending to be underestimated or not considered at all.
These two types of disturbances lead to a less efficient process, in terms of resources consumed and since they generate waste and do not bring real value to the final product.

Nakajima focuses its study on six major causes of loss of efficiency in a production plant, called "Six Big Losses".

The Six Big Losses are divided into:

1. Downtime losses directly affect machine availability.

    - Machine failures that result in lost time or, a reduction in productivity and a quantity of product lost for defective products due to the failure. This leads to production-loss costs and reduced efficiency. This type of stoppage is extremely difficult to eliminate completely because some of the failures can be considered physiological.



Bathtube graph taken from www.Wikipedia.com

The Bathtube curve shows how in the beginning and end of cycle phases of a machine there is an increase in the probability of failure, this result is evident precisely in the loss of efficiency that many companies are detecting, especially in comparison with new plants built by the newly born companies.

- Machine setups and adjustments, i.e. lost time and non-conforming products, given the need at this stage to make various adjustments to adapt machinery to the characteristics. depending on the type of goods made by an industry these times may be more or less significant.

2. Speed losses, i.e. inefficiencies that affect the plant's efficiency performance.

- Waiting times and micro-stops occur when production is interrupted or slowed down by a temporary malfunction of a machine or when equipment is waiting for a product. These types of lost time are often overlooked when in reality they have a great impact on the performance of a plant, given their very high frequency and short duration are difficult to consider and their overall influence can be very significant.

- Speed reductions resulting from the difference between the theoretical speed for which the machine was designed and the actual speed, these lost times do not cause a plant stop but a slowdown in production and therefore a lower production due to speed reductions can be caused by mechanical or quality problems;

3. Quality losses, identified as quality losses and reduce the quality index of the machinery.

    - Defect rejects and rework are quality losses caused by malfunctioning equipment that result in products not conforming to company specifications or standards. To remedy these defects, they must be reworked with obvious waste of time and resources.

    - Waste for start-up, i.e. losses that occur during the first phase of production. These are wastes that affect quality from the start-up of the machine to its stabilization at full capacity.

7 Measuring performances

But the most important things to start is the question: why measuring performance is so important?
In a small to medium sized company many times you do not give the right weight to the measurement process, just because you have the impression of over engineering processes or you are taken from the daily to daily routine and you try to solve the problems that arise more than go to the root.
It is therefore necessary to develop appropriate indicators that are meaningful for assessing performance.
Referring to a system for measuring the performance of production plants, it must be easy to use by top management and production personnel for the continuous improvement in the line.
It must also be comprehensive and cover all the dimensions that are considered critical to the success of the company; in particular, it must be a dynamic system, able to adapt to the needs and to link the various company functions.
It must be simple and give quick feedback on performance and link operations with the company's strategic objectives.
An effective system of indicators must allow the evaluation and comparison of performance in different periods or to compare them with benchmark values that can be internal, based on industrial sector level or best practice.

When designing a measurement system, it is essential to ask yourself two questions: what to measure and how to do it.
As pointed out by Jonsson and Lesshammar (1999), in order to decide "what to measure", it is necessary to evaluate:
Strategy: The first goal is that the measures have to be closely linked to the company's strategy, in this way they can emphasizes aspects that are more relevant to the company.
The strategy vision has to have a long-term commitment to guarantee flexibility in case of changes in direction.

- Flow orientation: another important aspect is to have an effective and efficient production flow of materials and the process. It is therefore necessary to use indicators that focus on the business process rather than on the individual business functions, in order to have a vision that is based on the concept of the supply chain.

- Internal efficiency: The objective of this dimension is to identify and evaluate the performance of an internal function, for example it is possible to use financial indicators to effectively compare the various departments and make trade-off analyses between costs and benefits.

- External effectiveness: unlike the one above, this dimension is linked to customer satisfaction, so its oriented to the external of the firm, therefore it requires measures of the level of service offered by the company and of quality at both strategic and operational level.
  But these indices are not exhaustive in the determination of the real satisfaction, because it is anyway an analysis carried out with internal indices.

To understand instead "how to measure" it is necessary to consider indexes easy to implement and improve, simplicity and flexibility of the measures.
For the former its essential that the indicators chosen must be a basis for undertaking and developing improvement processes. The indices depend closely on the data that is collected and on how the analyses are then conducted so the measurement system must cover all aspects relevant to indicating potential future improvements, they should identify and generate continuous improvement and to be taken over a continuous period.
For what is concerning simplicity and flexibility, the index should be simple and easy to understand and should not necessarily follow a fixed format, but should be adaptable to the specific needs of the moment and it must suit very well the firm.
If indicators are too complex, or too many, can lead the system to be overly reactive and not proactive, focusing only on performance monitoring and not on improvement.

What Beamon (1999) say in his essay each measure must have four characteristics to be useful and effective:

1. Inclusiveness: the ability to consider all relevant aspects.

2. Universality: the ability to be used and compared under various operating conditions.

3. Measurability: the ability to measure data analytically.

4. A complete measurement system cannot be made up of a single indicator because it is impossible for it to cover all the essential aspects, but it must be structured in a set of indicators linked together and respecting the dimensions indicated above.

8 Downtimes and stops

In the study of the performances of a production system a fundamental role is occupied by the times lost on a plant. They can be divided into two basic categories: downtime and short stops. Downtimes are periods of time when a system cannot perform its function, so the equipment is stopped for some reason. The reasons why an equipment is not operational can be varied, such as planned stops in the production schedule, planned maintenance, precautionary stops, lack of production orders, failures, lack of power, etc.;

Typical downtimes are:

- Planned stops: including preventive maintenance, cyclical maintenance, cleaning, self-maintenance, etc.;
- Faults: downtimes due to internal causes and typically of considerable duration that require the intervention of specialized personnel to restart the plant (the first of the Six Big Losses);
- Setup: retooling times of the machines for the processing of a subsequent product different from the previous one (included in the second of the Six Big Losses).

These lost times, reduce the possibility for a plant to produce during the total time it has available.

Short stops and slowdowns, on the other hand, are periods of time in which the system is underperforming due to small stops or reductions in machine speed.

This downtime does not necessarily cause downtime, especially in the presence of inter-operational buffers.

These inefficiencies are divided into:

- Micro downtime and waiting times: short stops or slowdowns due to temporary malfunctions of a machine or waiting for products, typically starvation and blocking phenomena, represented by the third of the Six Big Losses.

- Speed reductions: production slowdowns due to a difference between the theoretical speed and the current speed of the machine, loss belonging to the fourth of the Six Big Losses.

In a production plant, in addition to stops of a certain amount of time (failures, setups, maintenance), there are also lost times that are very difficult to detect because of their short duration, micro breakdown.
The problem on this type of stops is that are often are considered to belong to the normal functioning of a line. The duration of these stops can range from a few seconds to a few minutes, but they are all due to temporary malfunctions of the equipment, which can generally be restored to normal operation by the operators of the machines in a short time.
If the number and duration of micro downtime is consistent, they can significantly reduce the productivity of a system, leading to delays, lack of production, the need for a reschedule of production orders, longer cycle times, lead times and so on, all of which can be achieved through the use of a single system.
The elimination of micro-breakdowns can be possible through preventive maintenance plans that are able to anticipate critical issues.
In the analysis of this type of plant the distinction between micro stops and downtimes were not made. This decision is strategical coherent with the difficult for a low innovative line to collect detailed data but more importantly to use it in a useful manner.

9 OEE

The following quote of Nakajima clarifies the right approach to use: "Considering OEE as "a bottom-up approach where an integrated workforce strives to achieve total effectiveness and efficiency of equipment by eliminating the six big losses".

A machine belonging to a line is not isolated but it must dialogue with those that are downstream and upstream. For this reason, machines cannot work continuously or at maximum speeds, as they undergo various stops and produce defective parts. These problems are the cause of reduced machine efficiency. The conditions that cause these problems are called "equipment-related losses", and are divided in:

- Availability: it is based on the actual "scheduled production time".
- Performance: reduced speed and minor stops.
- Quality: its reps scheduled break times, scheduled clean up at the end of the shift and scheduled preventive maintenance.

These losses are included in the OEE calculation, the indicator introduced by Nakajima in the 1980s. It is an effective means of assessing the effectiveness of TPM and possible line improvements projects. The index is very synthetic and must be analyses in relation to its various component parts.

OEE measures how effectively time is used and is the perfect index to use in a context of TQM.

Before starting the calculation, we have to define these indicators:

$$\text{Scheduled Production Time or Planned Production Time}$$

$$\text{Planned Down Time} = \text{ Scheduled down time events}$$

$$\text{Unplanned Down Time} = \text{ Unscheduled down time events}$$

Net Available Time

$$NAT = Scheduled\ production\ time - Planned\ down\ time$$

Net Operating Time

$$NOT = Net\ avaible\ time - Unplanned\ down\ time$$

Ideal Operating Time

$$IOT = Time\ to\ produce\ all\ parts\ at\ rate$$

Lost Operating Time

$$LOT = \text{Lost Operating Time Due to Production of Scrap}$$

To constitute the OEE we need to calculate:

Availability (A) indicates the ratio between the time actually available for production and the total time the plant is potentially in operation and can be calculated as:

$$Avaiability\ \% = \frac{NOT}{NAT} \times 100$$

Performance efficiency is the ratio between the time actually allocated to production and the time actually available for production and it is possible to calculate it in terms of lost time. A different point of view is to consider performance as percentage of parts produced compared to the theoretical capacity, when the system is active, in other words it corresponds to the actual speed compared to the nominal speed:

$$\text{Performance \%} = \frac{IOT}{NOT} \times 100$$

Quality measures the ratio between the conforming products and the total products produced by a plant.
Since in this specific case there not real scraps, in the calculation this index will be used as 99.9% of result. This assumption is possible thanks the low number of products that needs to be re-processed compared to the output, for example in

case of wrong level in the bottle, this latter is individuated by a sensor, bottles and wine are reused, generating no waste and nearly zero-time consumption.

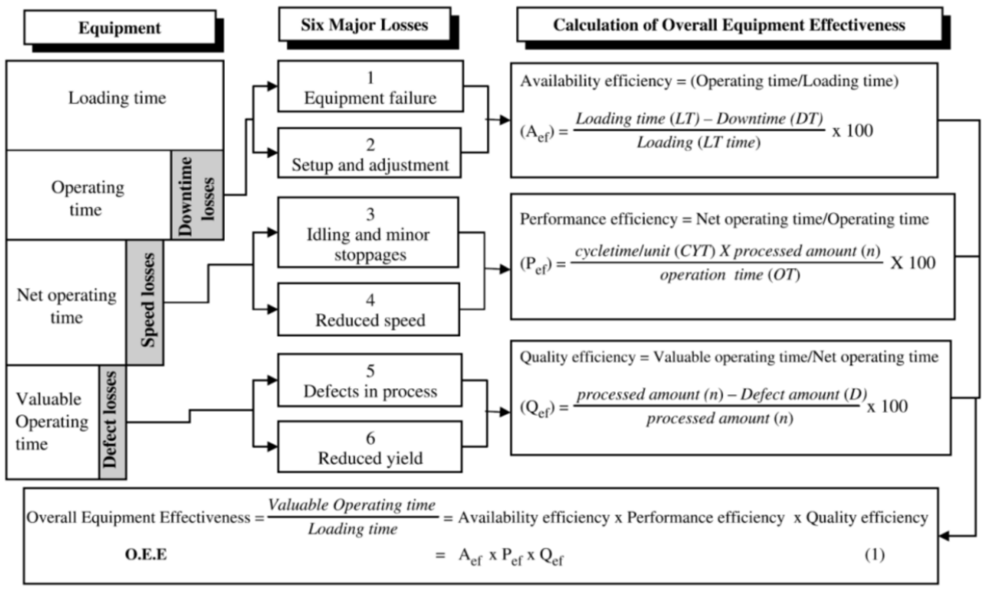
$$\text{Quality} = \frac{(IOT - LOT)}{IOT} \times 100$$

$$OEE = Avaiability \times Performance \times Quality$$

Overall Equipment Effectiveness	Recommended Six Big Losses	Traditional Six Big Losses
Availability Loss	Unplanned Stops	Equipment Failure
	Planned Stops	Setup and Adjustments
Performance Loss	Small Stops	Idling and Minor Stops
	Slow Cycles	Reduced Speed
Quality Loss	Production Rejects	Process Defects
	Startup Rejects	Reduced Yield
OEE	Fully Productive Time	Valuable Operating Time

OEE calculation method from www.oee.com

Once obtained the OEE, it is necessary to proceed with the analysis, comparing the data with a best practice benchmark. In 1988 Nakajima claimed that under ideal conditions the OEE should be greater than 0.85 for a world class company, with 90% availability, 95% performance and 99% quality. For Kotze the realistic values should be around 50%, Ericsson between 30% and 80% and instead for Ljungberg between 60% and 75%. This makes it very difficult to understand what the reference values to use may be, clearly depending on the sector in which one operates and the type of company.



OEE tree from Nachiappan and Anathram 1

10 The project and the data collection

The initial phase of the project was to select the line that most needed this type of analysis.
The main concern about this implementation was about the replicability of the project, since the enterprise context still a small medium firm.
Given the absence of sensors that can evaluate the stops, the data was collected by hand. Among the advantages of this method is the low cost and the possibility of going into great detail: given the small size of the line it was easy to have a great physical vision point, in a strategic place, to be able to see all the stops and their causes.
Manual collection by line personnel wasn’t an option because its limitation of not being so accurate due to poor motivation and loss of training of the worker.
Moreover, the difficulty to understand the forms to fill, the perceived lost time of the operator, the forgetfulness and the variations between the various operators are just some of the reasons that in the absence of a person assigned to the manual collection.
This operation should lead the company to invest first in a software that manages the downtimes and take note of the performances in an automated way.

The form in the next page is the one used for manual data collection, created specifically for that purpose, to be easy to read and understand from all new people could approach to this project.

FONTANAFREDDA

OEE DATA SHEET

Day:	Type of product:	Number of bottles:	Time of start of the line:	Time of finish of the line:	Note:
Machine name	**Start**	**End**	**Reason**	**Operator**	**Note**

The collection was therefore directed to a specific line and a specific product line with specified and same characteristics.

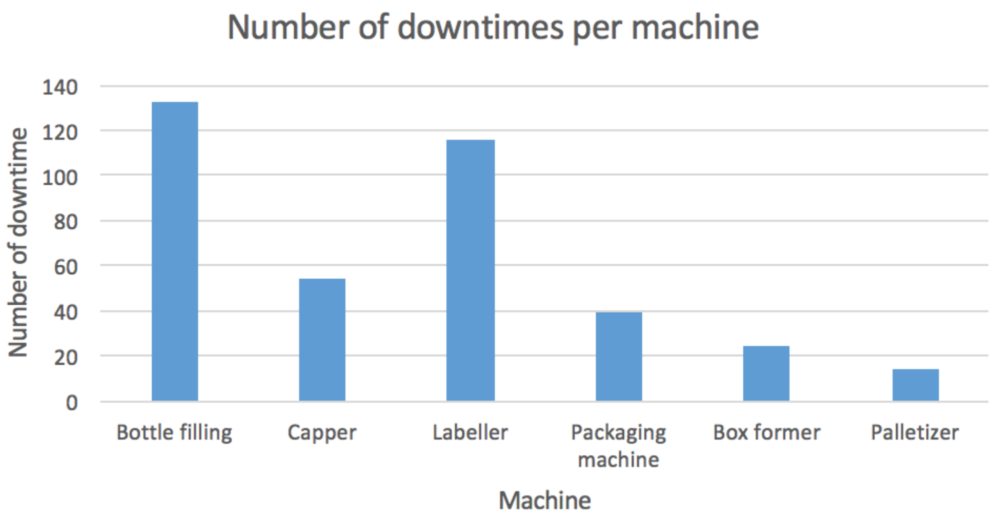
The variability in production could be in:

- Bottle format (0.375 / 0.5 / 0.75 / 1 l)
- Screw or cork stopper
- Shrinkable or rolling cap
- Presence of retro label
- Presence of collar label
- Box of 6 or 12 bottles
- Pallet 800x1200 mm or 1000x1200 mm

To standardize data collection, the 0.75 litres format with cork cap, rolling cap, rear and collar label, box of 6 in 800x1200 pallets was chosen.

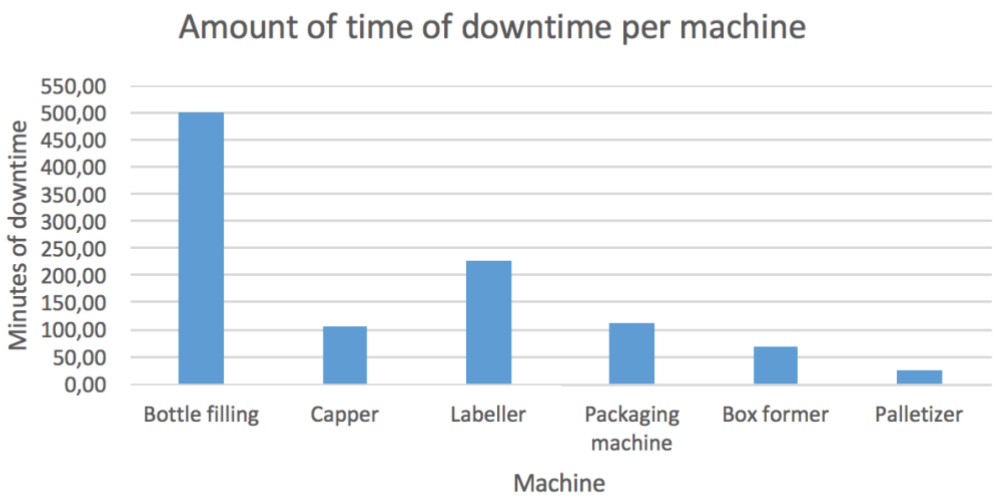
Then a careful analysis on the field of the times that involved stops and subsequent reprocessing followed, until the results converged to average and obvious data.

In the graph below are represented downtimes for each machine present in the line:



As is evident from the graph the most impact on downtimes is given by the filling machine with a total number of 133 downtime for a total of 502 minutes of stops.

To also be aware of the duration of the stop we must calculate the total number of minutes per machine.



Very useful to use are the TTR and the MTTR, as indexes to understand the real impact of each stops.

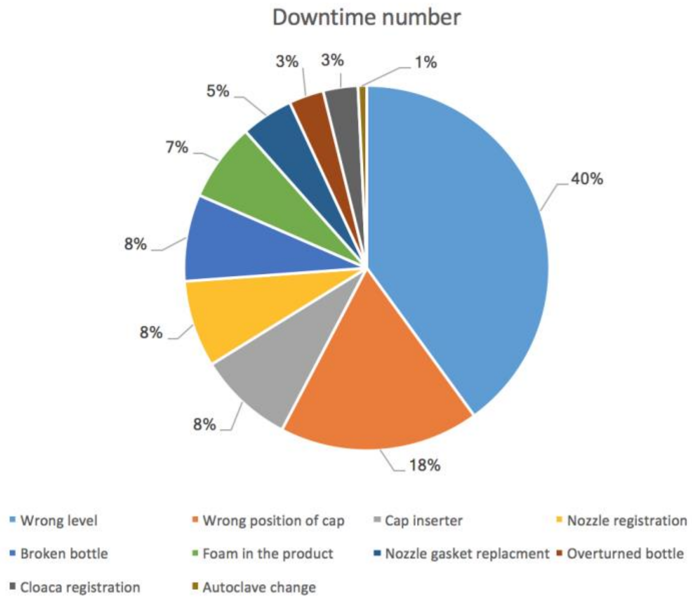
The MTTR parameter represents the average value of the duration of the repair operations that allow a stationary or faulty component to resume its function and is calculated as the ratio between the total time in which the component is stationary and the number of stops it makes, again with reference to the duration of the period being considered.

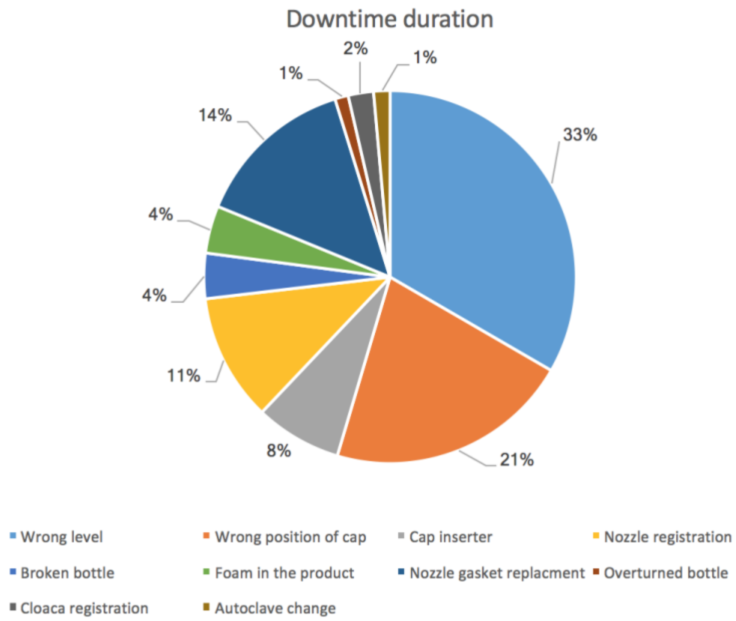
$$MTTR = \frac{Total\ amount\ of\ minutes\ of\ downtimes}{Total\ number\ of\ downtimes}$$

Machine	Number of downtime	Duration of downtime (hours)	% on total minutes of downtimes	MTTR (hours)	MTTR (min)	Duration of downtimes (min)
Bottle filling	133	08:22:08	48%	00:03:47	3,78	502
Capper	54	01:46:55	10%	00:01:59	1,98	107
Labeller	116	03:47:26	22%	00:01:58	1,96	227
Packaging machine	39	01:51:44	11%	00:02:52	2,86	112
Box former	24	01:08:57	7%	00:02:52	2,87	69
Palletizer	14	00:26:40	3%	00:01:54	1,90	27

11 The filling machine

After collecting and creating a database, the analysis focused on the bottling machine, that is the machine that most impacts the line in number and duration of downtimes.



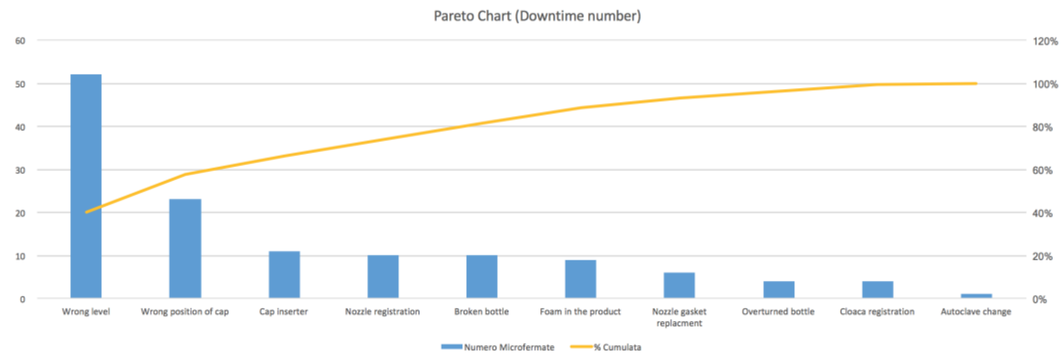


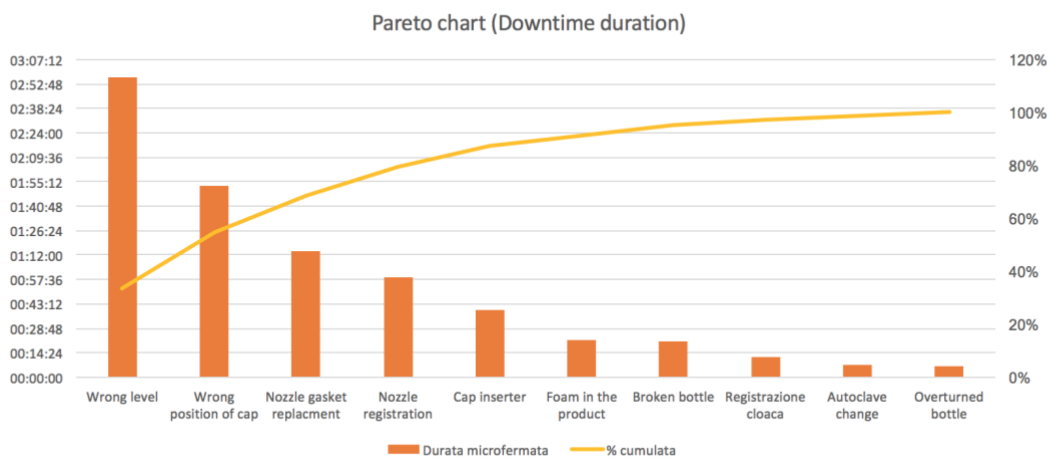
11.1 Pareto chart and MTTR table

The basic principle of Pareto analysis is based on the 80-20 rule, that is 80% of the effects are caused by 20% of the causes, an idea considered acceptable in almost all cases.

It is represented by a histogram based on the durations ordered in descending order with a line that represents the cumulative percentage.

Thanks to the Pareto analysis, it can be seen that there are only some causes that have an impact for the most part. From here therefore the decision to analyse in more specific the stops that represent 80% of the total amount.





Below the graph shows MTTR for every single failure:

MTTR	Downtimes numeber	Duration downtimes	MTTR
Wrong level	52	02:56:56	00:02:48
Wrong position of cap	23	01:52:37	00:04:54
Cap inserter	11	00:39:50	00:03:37
Nozzle registration	10	00:58:35	00:05:51
Broken bottle	10	00:20:54	00:02:05
Foam in the product	9	00:21:50	00:02:26
Nozzle gasket replacment	6	01:14:25	00:12:24
Overturned bottle	4	00:06:09	00:01:14
Cloaca registration	4	00:11:40	00:02:55
Autoclave change	1	00:07:33	00:07:33

As we can see thanks to the MTTR we can easily get the idea about the importance of each downtime present in the filling machine, the great variance between them is the explanation of the different manual processes that are needed to start again the machine. Many times, the line personnel are enough competent to repair the machine without calling the maintenance workers.

12 TTF and MTTF

To complete the analysis, we can use the TTF: it represents the time between one downtime and another one of the same typology of failure, without considering the TTR in between.

The MTTF parameter represents the average time between two successive stops, if a system can be considered repairable. Its value is calculated considering the initial instant, after each repair, as if it were the first instant of operation.

A stop with high TTR but low TTF can affect much less than the opposite, this analysis serves to weight these two indexes and have a big picture view of the singles type of stops in the machine.

Machine	Filling machine								
Failure	Wrong level								
MTTF	01:16:59								
Data	10/04/19	11/04/19	15/04/19	16/04/19	17/04/19	08/05/19	13/05/19	15/05/19	16/05/19
		00:45:32	00:00:42	01:23:49	00:59:55	00:18:22	00:04:21	00:06:16	01:24:02
		00:10:12	00:27:51	01:33:47	04:36:09	01:08:57	01:11:56	01:18:51	02:46:26
		02:30:12	01:53:59	00:15:18	00:46:12	00:11:37	00:44:56	01:29:49	00:43:30
		00:01:57	00:20:38	02:04:11	02:01:04	00:32:31	02:24:42	04:31:57	00:11:28
		01:15:09	06:16:23	00:05:30	00:26:00		02:52:58		02:55:52
		00:08:11			00:20:10		00:19:14		
							00:55:29		
							00:34:31		

Machine	Filling machine								
Failure	Nozzle registration								
MTTF	02:00:49								
Data	10/04/19	11/04/19	15/04/19	16/04/19	17/04/19	08/05/19	13/05/19	15/05/19	16/05/19
				03:19:51	02:56:42	00:08:05			
					01:38:40				

Machine	Filling machine								
Failure	Cap inserter								
MTTF	01:34:43								
Data	10/04/19	11/04/19	15/04/19	16/04/19	17/04/19	08/05/19	13/05/19	15/05/19	16/05/19
			05:35:12			00:05:59		00:06:12	
								00:31:30	

Machine	Filling machine								
Failure	Wrong position of cap								
MTTF	01:23:10								
Data	10/04/19	11/04/19	15/04/19	16/04/19	17/04/19	08/05/19	13/05/19	15/05/19	16/05/19
	03:14:10		02:59:11		03:16:05		00:10:41	00:06:50	02:45:33
	01:03:24				01:37:14		03:20:42	00:09:41	
					00:40:57			00:29:44	
					00:37:10				
					00:19:01				
					00:10:23				
					01:09:58				

Once calculated TTF and TTR, the relationship of the two has to be analysed to understand whether a type of micro-stop is characterized by high or low TTFs and high or low TTRs, in order to identify the most appropriate strategy with which to act to improve.

The combination of these two elements allows to make considerations:

- Stops with low TTR and TTF: they are characterized by a high frequency and a short duration of machine downtime; this high frequency indicates that they are most likely chronic stops that can be solved or in any case strongly limited by targeted improvement interventions.

- Stops with low TTR and high TTF: they have a low frequency of occurrence and short durations; therefore, they do not affect almost nothing in the performance of the line since their impact is minimal and probably are absorbed by the buffers if present.

- Stops with high TTR and high TTF: the duration of the stop is high but the time interval between one and the other is quite long. Considered in a precise temporal moment (for example in a period of three hours) but on a daily level they can have little effect, if the stop is not excessively long.

- Stops with high TTR and low TTF: are stops that require a very careful and timely analysis because it means that their duration is high but also the frequency of occurrence is very high, this type can indicate that the type of intervention that must be performed by the operator is not simple or perhaps also requires the intervention of specialized technical staff, also means that the necessary specific measures have not been taken to avoid these stops highly impacting, so you must investigate whether the maintenance plan is adequate and whether it is possible to introduce improvements that can prevent the stop or reduce the difficulty of restoring the machine, so that the operator's intervention can be faster.

These stops have a considerable weight on the performance of the line and are difficult to classify in a single category like the previous cases because they can range from frequent failures to machine stops that require a high recovery time due to various operations necessary to solve the problem and restart the equipment; in any case, they must require immediate attention from the managers and technical staff of the line.

Filling machine	Type of downtime			
	Nozzle registration	Cap inserter	Wrong position of cap	Wrong level
MTTF	02:00:49	01:34:43	01:23:10	01:16:59
MTTR	00:05:51	00:03:37	00:04:54	00:02:48

In the table above we can compare the two indexes concerning the most important downtimes (the ones that represent the 80% of the total).

The most common is the “Wrong level” problem, that arises every 1 hour and 16 minutes on average with a repair time of 2 minutes. This problem can fall in the first category that we analysed, low TTF and TTR, a stop that can be limited by finding improvements.

The “Wrong position of cap” is the second problem to analyse in order of TTF because of the similar but less impacting characteristics of indexes. It has a TTR of nearly 5 minutes, so it’s very important to find strategies to be faster in solving the problem and restart the line.

The “Cap inserter” has similar influence to the “Wrong level” problem, so it can be analysed to find a way to improve the performance of the machine.

The “Nozzle registration” problem is different from the other because of its MTTF very high. This indicates a stop that has not great priority of improvements since has low TTR and TTF.

Therefore, before making investments in new technologies, it is a good idea to ask oneself if one does not already have adequate equipment and what needs to be reviewed and better managed. This latter option can be applied, moving on to carrying out certain maintenance activities from a logic of failure to a predictive or preventive logic.

13 OEE Calculation

Since the OEE is a ductile coefficient, customizable for each company and need, in this case it was decided to procedures with the calculation of operating time as the loading time minus set up times. For the original definition, this assumption contrasts with what Nakajima claimed that set-ups were part of the production process. Given the high variability of the set-up times, it is advisable to include them in the index account in order to have a better view of any waste.

As for the performance index, it was calculated considering the bottles produced and the ideal bottles produced. In this way, it is evident that there is a very significant term for bottles "lost" because of the stops, whether they are micro or downtime more substantial.

Date	Avaiability	Performance	Quality	OEE
10/04/2019	55.3%	63.0%	99.9%	34.8%
11/04/2019	67.0%	77.0%	99.9%	51.6%
15/04/2019	72.5%	91.0%	99.9%	66.0%
16/04/2019	79.0%	86.8%	99.9%	68.5%
17/04/2019	67.1%	61.2%	99.9%	41.0%
08/05/2019	68.8%	74.3%	99.9%	51.1%
13/05/2019	68.6%	73.0%	99.9%	50.1%
15/05/2019	74.0%	80.6%	99.9%	59.7%
16/05/2019	75.6%	80.6%	99.9%	59.6%
Average	69.8%	78.9%	99.9%	53.6%

Typically, in a production system that has never faced a project to improve efficiency is at OEE values not exceeding 50-60%.
The best producers, on the other hand, achieve and maintain over time an OEE of 85%, considered a "world class" target.

As we can see, there is a great variance in daily calculations, this phenomenon is the result of a great impact of the line personnel in the downtime recovery and in the manage of failures.
Looking at averages indexes we can see that the bigger problem is the availability, that we calculated keeping in consideration set-ups and cleaning.
This is important to focus the attention in a non-standardized procedure, that leads to inefficiency in the managing the set ups.
The performance index is calculated on the lost production potential: based on downtimes and speed of the line it's easy to understand how many bottles are "lost" due stops.

In the graph below are summarized the calculation for Performance index:

Data	Net operating time	Nominal bottle rate (per hour)	Downtime [min]	Lost production in bottles per day	Ideal production	Real production rate per day
10/04/19	05:31:41	5500	195	17857	48261	30404
11/04/19	05:21:49	5500	96	8797	38297	29500
15/04/19	09:20:28	5500	55	5048	56424	51376
16/04/19	06:42:56	5500	61	5598	42533	36936
17/04/19	06:49:38	5500	260	23813	61363	37550
08/05/19	06:53:05	5500	143	13069	50935	37866
13/05/19	06:45:50	5500	150	13730	50932	37201
15/05/19	07:24:18	5500	107	9766	50493	40728
16/05/19	08:18:58	5500	133	12173	57912	45739

The rate of production used is of 5500 bottles per hour, this rate was taken as base to construct the index. This rate reflects the reality thanks to the greater capacity of the machine present in line, but is also the target rate at with the line can produce without any big problem on quality.
Ultimately the rate per minute is 4193 bottles on average per hour and given the downtime period in a day it's easy to find the real average production amount of 38589 bottles per day.
This find it's an important number since it explains, in a very direct way, how the downtimes affect daily production. With a resulting average production of 12206 lost bottles per day from the nominal 50794 bottles on average.

14 Starvation, Blocking and Bottleneck

The OEE has been analysed considering the whole line as a single resource since, as has already been said, even very short stops generate stops throughout the production line.
The phenomenon of starving occurs when the activities of a phase have to be interrupted due to lack of work
Instead, the blocking event happens when the activities of a phase must be interrupted because there is no space to deposit the output.
For the Bottleneck, the analysis is more difficult since there are several methods to identify this process:

- Accumulation: the process of the production line that accumulates the longest tail is usually a bottleneck. This method of identifying bottlenecks is particularly useful in the production of individual items, such as a bottling line. In this case it is possible to easily check where the bottles accumulate and identify the machine that does not have enough capacity, frequently fails or has an operator who needs training. When there are queues at different stages of the process, the situation is more complex and, in such situations, additional methods need to be used to identify the most critical bottleneck.

- Throughput: it is directly linked to the output of the bottleneck machine. This feature identifies the main bottleneck in a production process. Increasing the output of a machine that is not a bottleneck and it has little effect on overall production, as the bottleneck limits throughput. If you change the throughput of each of the machines one at a time, the machine that has the greatest effect on the overall output is the bottleneck.

- Capacity: Most production lines track the percentage utilization of each production unit. A unit or machine has a fixed capacity and the production process uses each machine as a percentage of its full capacity. The machine that uses the highest percentage of its capacity is the bottleneck. Usually, this machine runs at full capacity while it functions as a bottleneck and limits other production units to a lower capacity utilisation rate. Similarly, if you increase the capacity of the bottleneck machine, the capacity of the entire production line increases.

- Waiting Time: sometimes, many of the units in a production line run at high capacities and a different method is required to find the bottleneck. Usually, the production process also keeps track of machine waiting times. When there is a bottleneck, the next machine along the line has high waiting times because the bottleneck is holding back production and the output processing machine does not receive enough material to work continuously. When you find a machine with long waiting times, the step before the waiting machine is a bottleneck.

Looking at the data of the line and especially based on the time spent to see the line running, it is easy to see that the line is almost a single machine because a stop, even minimal, generates queues and stop of previous machines.
The nominal speed of the machines is very varied, but thanks to the experience of the line staff, the speeds are manually adjusted to obtain a product that is in conformity and continuously outgoing, without stopping production. This manual setting can be effective but remains highly variable and therefore has little capacity to collect useful data and optimize processes as one automated line managing.
All the machines refer to the bottling machine rate of filling because it is the machine that sets the production rate, pushing the products downstream.

15 OEE improvements

The next step is to quantify the potential benefit of eliminating or reducing downtimes on the overall OEE of the line. This phase is, however, particularly complex: while time that can be recovered on a single machine is easily identifiable because they are those that determine a blockage of the equipment, understanding the recoveries on the entire line is certainly much more difficult, since the real times that can be recovered are those that block the entire production flow and not the single machine.

This analysis must be carried out with the utmost care, especially for the assumptions that have to be made.

Together with the staff of the line, we've analysed the stops that can be supposed to be eliminated, i.e. the stops under 3 minutes of duration fort the filling machine.

Data	NEW Avaiability	NEW Performance	NEW OEE	Old OEE
10/04/2019	56%	63%	36%	34%
11/04/2019	71%	81%	58%	51%
15/04/2019	75%	93%	70%	66%
16/04/2019	81%	89%	72%	68%
17/04/2019	69%	63%	43%	41%
08/05/2019	70%	76%	54%	51%
13/05/2019	72%	77%	56%	50%
15/05/2019	76%	83%	63%	59%
16/05/2019	79%	82%	65%	59%
Average	72%	79%	57%	53%

This assumption starts from the idea of creating a methodology that can be easily replicated in the company and in the production line with the practical indications that have be applied.

Only eliminating the "under 3 minutes stops", It's easy to see how the OEE can grow.

An increase of 4% seems not so much but we have to remember that in reality is an increase of the 7.5% of increment.

The production line in the as-is situation is a very connected line, given the absence of buffers between machines. This situation implies that even small downtimes can cause the entire line to stop, with a waterfall effect. For this reason, the filling machine stops have been analysed as determining on the line stops, as if it were that the line stopped immediately in its entirety. This methodology helps especially in highlighting the impact of stops more directly.

16 Economic reasoning and improvements

After finding the stops and determining the influence in the OEE it is essential to understand after you can implement the line for productivity to increase.
There are basically two possible ways forward: one based on investment and the other based on a simpler structure change.

16.1 First proposal

The replacement of the machine must be thought in the context of the possible improvements that the new bottling machines industry can offer today.
We have seen how the set-up times have an impact on availability, the times that operators need to get the machine ready for the type of product to be managed. New machines, unlike the one present in the company, can be regulated thanks of a PLC and therefore be able to change format and carry out the cleaning procedures in complete autonomy. That is, in line with the recent possibilities offered by automation, with obvious advantages in terms of time and accuracy in the result.
Many times, production stops are generated because of manual adjustment and the successive calibrations, it is obvious that if the machine were able to calibrate itself with precision, not only many stops would be eliminated, but set-up times would also be drastically reduced. A further advantage of the latest generation of machines is also the complete management of preventive maintenance, going to report if there are damaged seals or components to be replaced, avoiding to run for repairs due to an unexpected failure of the equipment.
This solution is obviously the most expensive as the machine has to be changed, and therefore it is difficult to give an estimate of the usefulness of the investment given the great variety of proposals on the market, but one can also consider the purchase. It is necessary to make a technical analysis but also economic solution, so as to evaluate the monetary outlay and the payback period, and the period of recovery of the investment. It should be noted that there is no better method than another, but it depends on the particular situation and the type of micro-stop considered.
Of course, all possible improvements are faced with obvious budget constraints, which is why it is essential to carefully evaluate which interventions to make and estimate the economic return.

Stops with low TTR and TTF are those that allow a more careful evaluation because they are generally chronic and, although of short duration, they impact a lot on the efficiency of the machines.
Given the budget constraints, it was decided to evaluate, together with company managers and technicians, a solution for the Downtimes that causes the greatest loss of OEE, concentrating the efforts on "Level issues" and "Nozzle" problems.
These types of stops are generated by the same component of the machine that each time a format change or a different setup is changed with the most suitable one.

16.2 Economic project valuation

Before making any investment involving the modification or replacement of a machine, it is essential to carry out a technical evaluation.

In fact, the change you are about to make must be consistent with the objectives you want to pursue, but above all it must also be feasible at the technical level, without affecting the operation of other equipment involved in the production process.

In this phase, the contribution of specialized technical personnel is fundamental, the new technology must be compatible with what is already present on the plant, some possible parameters to be evaluated are:

- The working speed of the new equipment must be adapted to that of the rest of the line.
- Interconnection with existing systems.
- Changes in personnel operating procedures, so as to assess whether specific training is necessary.
- Assess whether the materials used are compatible with the new technology.
- The benefits and complications in the operation of the machine and the entire plant resulting from the intervention.

Once the approval is obtained from the technical point of view, it is essential to evaluate the investment from the economic point of view, in fact, although it can bring benefits, it is not certain that the change can be sustainable and financially justifiable.

An investment is characterized by an initial cash outflow equal to the amount of the investment to be made, the annual cash flow is the result of cash inflows and outflows, this cash flow is partly to repay the investment until it begins to generate profits.

For this purpose, you can use the classic tools of investment analysis, namely the payback period, the NPV and the ROI.

The payback period method is used to determine how long an investment can generate profits for the company, i.e. when the net cash flows can repay the entire initial investment, to the point that the sum of the net cash flows is equal to the initial disbursement.

In order to determine the cash flows it is necessary to identify all the revenues and the differential costs in comparison to the actual situation (as-is). To calculate the total revenues, it is necessary to have the difference between the selling price and the unitary variable cost, i.e. the "unitary contribution margin of a product".
This index helps to understand how much more money the company is able to invoice as a result of the increase in derived production.
There are two types of contribution margin that can be used: the level one margin only considers variable costs and returns on valuation when revenues reward the initial investment and variable production costs, while the level two margin also includes fixed differential costs, so as to determine when these costs are also covered by revenues.

By multiplying the unitary contribution margin by the recoverable production volumes, it is possible to estimate the annual net cash flow. This flow can be considered constant for all periods or, in order to reflect the value of money over time in the currency of the investment, it can be discounted using a discount rate:

$$Discounted\ Net\ Cash\ Flow = \frac{Net\ cash\ flow_i}{(1+r)^i}$$

where r is the discount rate and i is the period in which the cash flow is evaluated compared to that in which the investment was made. In this way it is possible to see how the project is going on:

$$\sum Net\ Cash\ Flow_i - Initial\ Investment \geq 0$$

Once the result is obtained, it must be compared with the expectations of the firm and must be seen in the context of changes and time horizons.

Another instrument often used is the "Net Present Value" of the investment (NPV), i.e. the present value of future cash flows. The NPV is very useful in the case of comparison between several alternatives because it allows you to make a choice between investments, going to select the one with the highest NPV. It will be the company to determine the number of years on which to calculate it taking into account its internal policies.

Cash flows can be discounted or not:

$$VAN = \sum \frac{Net\ cash\ flow}{(1+r)^i}$$

with i=1,…,N is the number of periods

The third indicator used for these forecasts is the Return on Investment (ROI), it allows to find the economic return on the initial investment, clearly the higher the ROI, the earlier the investment is recovered.

$$ROI = \frac{Net\ Period\ Cash\ Flow}{Investment}$$

To get an overview and not limited, these indices are often calculated together.

Given the difficulty in estimating realistic data about a possible new machine, in this analysis we will calculate the maximum OEE achievable with a machine that has no downtime.

Data	NEW Avaiability	NEW Performance	NEW OEE	Old OEE
10/04/2019	63%	72%	45%	34%
11/04/2019	78%	90%	70%	51%
15/04/2019	77%	95%	72%	66%
16/04/2019	83%	91%	75%	68%
17/04/2019	78%	87%	68%	41%
08/05/2019	77%	83%	64%	51%
13/05/2019	77%	83%	64%	50%
15/05/2019	80%	87%	70%	59%
16/05/2019	84%	88%	73%	59%
Average	77%	86%	67%	53%

It's possible to see how the OEE can grow up to a result that can be considered good for a firm. Only substituting the filling machine is clear that the line can have a big performance improvement.

16.3 The second proposal

The second possibility to work for the line improvements is the introduction of buffers between machines.

As it has already been pointed out, the line works almost like a single machine because of the absence of buffers that allow the absorption of even the smallest stops, such as those dictated by mandatory changes of reels for the labeller.

Although the ideal goal is to eliminate the micro-downtime, a more realistic hypothesis is to reduce them, since a proportion of them can be considered physiological and inherent in the production process.

Irrespective of the number and duration of micro-stops, inter-operational buffers play a crucial role in reducing their impact on the OEE and increasing the reliability of the system. The buffers are "accumulation lungs" placed between two machines in an automated production line, their task is to decouple the equipment in series and to absorb small machine downtime or machine delays upstream, so that the downstream one can continue its regular production function.

Another great improvement given by a buffer is that it allows to manage different machines speeds, so that they do not work with a fixed frequency line where the production rate is determined by the slowest machine and all have to be adapted to that speed.

The most important take away is that without the use of buffers, a machine stop would block the entire process.

So, the insertion of lungs prevents companies from improperly purchasing oversized equipment and allows a production system to be better balanced.

Ultimately, a buffer allows a workstation not to be affected by all the losses of the previous stations; in fact, in the case of a line without buffer, availability is the product of the availability of the various stations and the quantity of product required in input to obtain a certain output is affected by all type of inefficiencies of a station.

In the case of a line with inter-operational buffers, the availability of the entire line is determined by the station with the lowest availability

To give some indication on the possible dimension of a buffer between the filling machine and the external washer we need to calculate the bottles needed to stop machine in the valley in respect of the former.
The buffer must allow the uncoupling of the machines to allow both the labelling machine, for examples, to be able to recharge the coils (average of 00:00:58) to do not interrupt the line or have a mandatory stop but that impacts on the speed of the machines upstream.
The buffer must also allow the padding machine to be stopped without having to puncture to block the downstream line. The average of a stop considering the stops that represent 80% of the total downtime is 00:03:51.
Considering the average rate settled on 5500 bottles per hour, that yield per 92 bottles produced in one minute.
So, if we multiply the bottles by an average stop we know that if there was a buffer of 354 bottles the stops of the bottling machine would not imply the stop of the machines downstream.

17 Conclusion

In today's competitive environment, careful maintenance and ever-present optimization are essential for companies that want to remain competitive.
The global market offers new opportunities but also challenges especially for those companies that have a great history and therefore it is more difficult to re-imagine the structures. An ever-present target is the offering to customers products at low prices and ensuring a certain internal and external flexibility.
This function of control and improvement of production processes is carried out by the production area, which is therefore fundamental not only at an operational level, but also strategic for the entire company; to perform effectively and efficiently in this area brings great advantages for the entire business. In order to succeed in this objective, it is essential to measure the performance of the production plant, using indicators such as OEE, so as to assess the current condition of the equipment and understand where and how to improve. This also leads to the possibility of quantifying the extent of the improvement, so as to understand the real benefits and justify any interventions.
The study was brought forward having in mind the usability of the KPI that could then be used to begin a more structured and complete analysis.
This thesis has the task to being able to explain through the analysis carried out to show a methodology based on industry research and useful tools.

First of all, we've started with the choice and analysis of the designated line, after which the creation of an "as-is" situation, using the data collected manually online during the time spent during the internship in the plant.
In order to have a certain integrity of the data, we chose a unified product with certain characteristics so as not to add variables to the analysis.
When the machine with the most impact in terms of downtimes was selected, the calculation of the OEE was carried out.
Since the line is not equipped with inter-operational buffers, it was decided to calculate the KPI as if it were a single machine, precisely because of the total dependence of each machine has with others.
In finding the availability index it was decided to focus the attention on the setups, considering them as lost times given the great impact on the remaining time for

production. In the calculation of the Performance index, no distinction was made between Micro-downtime and Downtime, precisely because of the desire to create an index that is easy to replicate even with the few tools now available in the company. For this purpose, this index has been calculated using the real production and not the analysis of only the micro-stops and slowdowns, more difficult to catch and to analyse.
For the quality index, we wanted to keep it fixed at 99.9% given the reduced rejects generated, below 1%, and especially for the rate used in the calculation of 5500 bottles per hour, realistic rate and especially precautionary, so as to avoid increasing the number of possible rejects due to excessive speed.
The analysis of TTR and TTF was very important to show which type of downtime was chronic and which was only sporadic. The former category is much difficult to analyse due to almost invisible problem.

Here there is an important consideration on "lost" bottles: analysing the stops, a very effective way to have a complete view of the situation is to see the stops as bottles not produced and therefore as time that could be recovered in the case of downtime recovered. On average, it has been analysed that the production rate is 4193 bottles per hour, against the nominal rate set at 5500, a value also considered for any production plans. Obviously, this data is also used to get an idea of the real production and therefore in case of purchase of new machines to consider the real rate and not the nominal one.
The indices that make up the KPI under analysis were then calculated and the result for the average OEE found was 53.6% totally in line with the literature data for companies that have never measured their performance.
Once analysed, a proposal of recoverable OEE was made based on the elimination of the shortest stops that can be eliminated.
It was then assumed to eliminate the stops below 3 minutes of the bottling machine, completely in line with the observations made by the line technicians on the possible improvements that can be made to the machines and the better management of maintenance.
These considerations must be considered since it is impossible to know the machines better than those who are in contact with them every day, especially in view of future implementations.

Before proposing an action plan to improve the current situation, please explain the principles to be considered for the various implementations that can be implemented.
First of all, there must be a technical feasibility, therefore considering the synergy between the existing machines, the bottlenecks, the layout, the production rate and the technical capacity of the operators.
In a second step, for the choice of the machine or the investment to be made, the economic and financial aspect will have to be evaluated. The NPV, payback and NPV methods come to the aid of this phase, helping to understand the extent of the investment and the weight it could have on the company's cash flow.
Since there are a multitude of possible options, it has not been possible to take into consideration one given the enormous differences in price that can be had.
In order to evaluate the maximum impact that can be achieved by replacing the filling machine, however, we wanted to create a calculation of the maximum OEE that can be achieved. This index only by eliminating all the stops of the machine reach the value of 67%. This result would be very satisfactory on an evaluation of the company and above all shows how much impact the machine taken into analysis.
A second solution, much less invasive and expensive, could be the introduction of an inter-operational buffer. In this way it would be possible to untie the machines downstream of the bottling machine and therefore not generate stops at the line because of this machine.
In line with the average production rate of 5500 bottles per hour, it was calculated that the buffer size should be at least 354 bottles.

This project has given the opportunity to deepen how, by implementing a time control and a greater attention to KPIs, in this case OEE, it is possible to analyse the line in detail. This combined with the desire to improve can lead to a targeted and sustainable innovation, which can only benefit growing companies but struggling to manage the market and the modern economic contest.

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