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TOTAL PRODUCTIVE MAINTENANCE MODELS AND TOOLS IN FLOW LINE MANUFACTURING SYSTEMS

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Total Productive Maintenance
Models and Tools
in Flow Line Manufacturing Systems

by

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SOMMARIO

La *Manutenzione* degli Impianti Produttivi è una funzione strategica delle realtà industriali che ha l'obiettivo di assicurare il funzionamento regolare ed il buono stato di conservazione di questi sistemi (OSCE, 1993); in particolare, secondo la definizione UNI9910, essa comprende tutte le azioni tecniche ed amministrative, incluse le azioni di supervisione, volte a mantenere o a riportare un'entità in uno stato in cui possa eseguire la funzione richiesta. Se inizialmente un'azienda decide di investire una parte del proprio capitale nella costruzione ed avviamento di un nuovo impianto produttivo, successivamente è necessario investire tempo e risorse per il suo mantenimento, al fine di mantenere i requisiti richiesti e soddisfare le aspettative (*Pay Back*).

Il TPM (*Total Productive Maintenance*) consiste in un insieme di tecniche e strumenti che hanno la funzione di ottimizzare il mantenimento degli impianti produttivi, aumentandone l'affidabilità e riducendo fermi e guasti. Il TPM mira ad aumentare la produttività degli impianti (*Productive*), coinvolgendo tutto il personale (*Total*), attraverso la manutenzione (M*aintenance*). I benefici del TPM sono ormai ben noti nelle industrie: le aziende che hanno implementato tale paradigma hanno registrato una riduzione dei guasti del 50%, del 70% di produzione persa, del 60 % dei costi di manutenzione e tra il 50-90% dei tempi di set-up.

Tuttavia la sua implementazione non è sempre facile e diretta: è necessario porre attenzione ad alcuni fattori che possono pesantemente incidere sul successo del progetto. Per quanto riguarda il mondo degli impianti automatizzati, dove il fattore umano è ridotto e spesso estraneo, coinvolgere il personale nel mantenimento delle macchine può risultare difficoltoso. L'obiettivo di allineare esigenze produttive e manutentive, nell'ottica di ottimizzare l'affidabilità degli impianti, implica concordare fermi produttivi rispettando tempi di consegna sempre più ristretti con previsioni della domanda estremamente variabili; pertanto risulta evidente come ottimizzare la produzione attraverso la manutenzione possa essere un obiettivo ambizioso nelle realtà industriali.

In tale contesto si inserisce la presente trattazione, che ha l'obiettivo di proporre un framework di applicazione di tecniche di manutenzione nel contesto degli impianti automatizzati, in particolare legato al mondo del Food & Beverage. Tale settore, oltre alle peculiarità legate al mondo automatizzato, è caratterizzato da fattori di sicurezza alimentare, elevata qualità e obiettivi a sfondo ecosostenibile. Da quanto emerso in letteratura, il processo di applicazione del TPM è lungo ed impegnativo, e spesso i suoi benefici richiedono lunghi periodi per diventare tangibili. Quanto proposto in questo lavoro si differenzia dall'attuale stato dell'arte in quanto ambisce a massimizzare ed evidenziare i benefici di tale paradigma in tempi più ristretti; il framework proposto, in particolare, mira a focalizzarsi sulle criticità degli impianti produttivi, proponendo varie tecniche risolutive al fine di massimizzare i risultati e aumentarne la visibilità. E' poi proposta l'applicazione di tale framework ad una vera realtà industriale, quale una linea di imbottigliamento.

Una seconda parte di tale lavoro è dedicata, invece, all'analisi delle micro fermate negli impianti automatizzati. Infatti, come emerso anche dal caso studio, esse rappresentano una rilevante fonte di inefficienza negli impianti automatizzati. Le microfermate possono essere di natura tecnica e/o di progetto oppure legate al normale funzionamento di più macchine con caratteristiche differenti che lavorano in sequenza. Tale inefficienza talvolta può essere risolta con soluzioni tecniche mirate e definitive, se opportunamente convenienti (recupero efficienza rispetto investimento proposto); talvolta invece è richiesta una rivalutazione del dimensionamento del Buffer tra le due stazioni di lavoro al fine di ridurre l'incisività delle micro fermate di una macchina sull'intera linea (fenomeni di *starving* and *blocking*). Nelle linee automatizzate è frequente che una macchina si trovi nelle condizioni di non poter operare per mancanza di input (starving) o per eccesso di output (blocking).

La tesi è suddivisa in quattro fasi:

1. Analisi dello stato dell'arte dei fattori che hanno influenzato l'implementazione della TPM nei sistemi automatizzati e delle peculiarità dell'industria alimentare al fine di identificare un modello di implementazione strutturato ed innovativo; la differenza dallo stato attuale è il focus su risultati accelerati e visibili.
2. Applicazione del modello ad un impianto di imbottigliamento; individuazione delle micro fermate come causa impattante di inefficienza produttiva.
3. Analisi dello stato dell'arte sui *Downtime* negli impianti automatizzati, focalizzandosi sull'impatto delle micro fermate sull'efficienza produttiva ed affidabilità del sistema. Proposte di miglioramento di tali inefficienze: Soluzione tecniche mirate con modello di recupero di efficienza produttiva (*CPI – Cost Performance Indicator*) o rivalutazione del dimensionamento dei buffer (*BAP – Buffer Allocation Problem*).
4. Analisi mirata delle micro fermate di una stazione di lavoro critica e relativa costruzione del modello simulativo per valutare il dimensionamento di un buffer. Tale modello risulta innovativo in

quanto è basato su distribuzioni di Weibull personalizzate per ogni tipologia di micro fermata.

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ABSTRACT

Productive Plants Maintenance is a strategic function of industrial realities that aims to ensure the regular functioning and good conservation of productive equipment. (OSCE, 1993); in particular, it comprehends all technical and administrative techniques, including controlling activities, that aim to restore to and/or maintain an item in a condition in which it can performed the required function (UNI9910). A company, at in a first moment, decides to invest a part of its capital in new equipment for production, to reach its core business goals and gains success; in a second moment, anyway, it is necessary to invest resources and time to guarantee its correct functioning and conservation, to satisfy the productive expectation (*Pay Back*).

TPM (*Total Productive Maintenance*) is an industrial tool that comprehends all techniques and methods that aim to optimize industrial plants effectiveness, through equipment availability improvement and making downtime and failure decrease. TPM paradigm aims to increase productivity (*Productive*), involving all the staff (*Total*), through maintenance (*Maintenance*). TPM benefits are well known in our industries: companies that applied these techniques registered a reduction of failures of about 50%, a reduction of production loss of about 70%, the 60% of reduction of maintenance costs and, finally, 50-90% of reduction in set-up time.

However its implementation in industrial realities it is not always so easy: it is necessary to take care to some critical factors that might influence the success of the project. In the world of automatic production systems, where the human factor is reduced and often useless, to involve people in equipment maintenance might be hard. Moreover, to align production and maintenance requirements, in order to optimize equipment availability, means to plan together production downtime, looking to satisfy the demand that is becoming more and more variable and uncertain, with shortest lead time.

In this context, this work aims to carry out a useful framework to apply TPM in automatic production systems, in particular in Food & Beverage sector, focusing on the drivers that might influence its implementation. Food Industry, in addition to peculiarities related to the automation world, is characterized by factors related to security, safety, quality and sustainability. From literature review about many case studies of TPM Implementation it arises that the application of this paradigm on industrial realities requires a very long time and a lot of resources, and its benefits are slowly to arise. What is proposed in this work is different in the way it aims to maximize and to highlight TPM benefits in a faster way; the framework, in particular, is focused on carrying out productive equipment criticalities, through the use of various tools and techniques, to optimize and arise results. Therefore, it is propose the application of the framework to a real industrial case.

Then, a second part of this work is dedicated to micro downtime analysis in automatic production flow lines. In fact, as it arises from the case study, micro downtime is the greatest cause of inefficiency in these production systems. Micro downtime can be related to technical and/or design causes, or to the normal functioning of more machines working in series with different characteristics. Sometime micro downtime inefficiency could be solved with technical solutions, if they result convenient (efficiency improvement compared to the investment proposed); in other cases it is required to evaluate the buffer size and allocation. In fact, in this sector, machines downtime might be related to lack of product in ingress (the upstream machine is down – starving) or the excess of product in exit (the downstream machine is down – blocked).

The Ph.D. thesis structure is the follow:

1. State of the art analysis about factors that influence TPM implementation in automatic production systems and about food and beverage sector peculiarities; the core objective is to identify an innovative and structured framework for TPM implementation; what is new in the proposed framework is the focus on accelerated and visible benefits.
2. TPM framework application to a real industrial case, in particular a bottling line. During the framework implementation, micro downtime arise as the core inefficiency.
3. State of the art analysis about Downtime in automatic production systems, focusing on micro downtime impact on production efficiency and machines availability. Improvement for these inefficiencies are proposed as: technical solutions related to the improvement of equipment effectiveness (CPI – Cost Performance Indicator) or evaluation of buffer sizing and location through a simulative model (BAP – Buffer Allocation Problem);
4. Micro downtime analysis applied to a real case study; construction of the CPI, when possible, and of a new simulative model to evaluate buffer sizing and allocation. It is proposed a new simulative model based on ad hoc micro downtime probability distribution (Weibull Distribution for each micro downtime).

This Ph.D. Thesis has been carries out in strong collaboration with Acqua Minerale San Benedetto S.p.A., that made possible the framework implementation and data collection.

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To My Mum and My Dad

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1

Introduction

"Total Productive Maintenance (TPM) is increasingly conceded out by numerous organizations to get better their equipment competence and to attain the competitive benefit in the worldwide market concerning cost and quality. But, creating TPM is not a trouble-free task. There are specific enablers, which assist in the performing TPM. The uppermost need is to analyses the behavior of these enablers for their successful utilization in the performing of TPM."

[Masoomeh, 2014]

1.1
Maintenance in Automatic Systems

Companies, of every size, aim to enter, stabilize and gain success in the interest market through reaching their business goals, defined year by year, that could be of various nature (economic, qualitative, sustainable, etc.). Business goals are defined by the top management that are those company's groups which gain the highest decisional-making level. Each business goal is then expressed in *functional goals* from each sector of the company.

In this context, *Maintenance* is a strategic factory function that aims to maintain production systems in order to guarantee the needed output, or more in general to preserve these systems in a state where they could satisfy their given function.

Maintenance, in the past, worked as a secondary function; it was like a sort of fire station, which principal aim was to react to failures as efficient and fast as possible. Failures represented the reason of maintenance function, and the core aim was to repair machinery as soon as possible in order to produce. Time to repair and time to restore the equipment was as long as it was necessary to find the failure origin and to recover spare parts; spare parts warehouse costs, in this context, were high and often materials were bad organized.

Nowadays the importance of guarantee a more and more machinery efficiency, of prevent failures before they occurs, of plan production downtime instead of "waiting" for failures, makes maintenance a primary and strategic function that aims to preserve and to improve production systems.

The literature has revealed that the manufacturing organizations worldwide are facing many challenges to achieve successful operation in today's competitive environment. Modern manufacturing requires that to be successful, organizations must be supported by both effective and efficient maintenance practices and procedures [Ahuja, 2008].

Basic maintenance action are focused on preventive activities, predictive activities and improvement activities. During last years numerous methods, techniques and instruments had been implemented in order to prevent production downtime; one of the most popular is Total Productive Maintenance (TPM), born in Japan around 1950. TPM is a paradigm that involves many techniques and frameworks in order to maximize production; it could be applied to all production systems in all sectors.

This work is centered on TPM applied to automatic production systems in food and beverage sector.

Automatic production systems are characterized by several machines working in series related by transport systems; the main characteristics is that the human requirement is minimal, as machines could operate by themselves. In food and beverage sector, these production systems are very common, as products are characterized by big quantity and repetitive processes. Food production is characterized by several rules, related to hygienic and safety parameters; moreover food market is influenced by quality and sustainability characteristics that, even if they could not be mandatory rules, are fundamental for the company to exist in the market. Applying TPM to food and beverage companies means consider these aspects as drivers for the project success, as they could deeply influence TPM tools and methods.

In this work, a large part of the analysis is dedicated to Micro Downtime study, as it emerges as the core inefficiency cause. Micro downtime are physiological stops of automatic machines, often related to starved and blocked states, jamming products, defects, etc.

Reduce micro downtime is needed to increment line efficiency as first, but it is not always so easy. If downtime is originated by a technical failure and could be solved with an active maintenance action, micro downtime could be

eliminate; if not, buffer capacity size is a solution to guarantee a continuous production, even if it represents a cost in terms of spaces and materials stock.
This work aims to presents criticalities and drivers in applying TPM in food and beverage sector, the collection data and analysis of inefficiency of these production systems, and the simulation approach proposed to improve OEE of production.

1.1.1 *Maintenance Overview*

Maintenance is traditionally associated to failures, as its primary goal is to fix items; in this context, maintenance activities are reactive, as they occurs when the item is just broken. In other words maintenance is a reaction to a failure.
Nowadays maintenance is a complex function, that can be defined as "All activities aimed at keeping an item in, or restoring it to, the physical state considered necessary for the fulfillment of its production functions" [Gits, 1992].
To support production, maintenance must ensure equipment availability in order to produce products at the required quantity and respecting quality levels. This support must also be performed in a safe and cost-effective manner [Pintelon and Gelders, 1992]. It is evident that to react to failures is not enough to reach the previews goals; for these reasons maintenance function has developed various techniques and tolls, explained in the following session.

Corrective Maintenance - CM

Corrective maintenance is a strategy that includes those activities carried out after a failure occurs. It is the first strategy adopted by industries, before

1950s. Machines restorations are carried out when they are strongly needed, as the item is broken and need to be repaired. The disadvantages are evident as the production downtime is unplanned, spare parts could not be available (or there are high warehouse costs), time to repair is high, machines are deeply damaged, there could be dangerous for personnel, and so on.
CM is in general an uncommon strategy, for all these reasons, but it is still used sometimes, when it is convenient/necessary. For example it can be used when failures do not caused production downtime, or when there are no safety risks for personnel or when spare parts are available and they are easy to replace.

However, companies are reluctant in applying this king of methodology as it is synonymous of uncertainty and lack in production equipment control; moreover it represents often a relevant cost when occurs.

Preventive maintenance - PM

Preventive Maintenance is the second strategy that was developed during last years; better said that it is the first proper maintenance strategy. It could be seen as a response to corrective one, as it is a strategy that aims to prevent failures by replacements and actions undertaken before failure occurs. Activities are carried out base on time factor, as the number of works hours or, if not possible, based on specified periods (*TBM – Time Based Maintenance*); preventive maintenance comprises those maintenance activities that are undertaken after a specified period of time or amount of machine use [Herbaty,1990]. This strategy provides that downtime can be planned, spare parts are available, and damages are avoided. The biggest disadvantage is the risk of not necessary activities, as machines spare parts might still be in a good state. Anyway it is widely used by companies, as it allows to plan uptime and downtime and to better control production equipment.

Predictive Maintenance – PdM

Predictive strategy provides maintenance actions based on a specific condition (*CBM – Condition Based Maintenance*); it aims to carry out replacements when they are strongly needed, due to predefine parameters, when it is possible. It often requires the use of specific tools as the thermal imager, the vibration analysis, the oil analysis and so on.

Production systems are taken under control and checked through the utilization of specified key factors as temperature, fatigue, stress, vibration, etc. The diagnostic techniques are deployed to measure the physical condition of the equipment such as temperature, noise, vibration, lubrication and corrosion (Brook, 1998).

This strategy presents a good match between machine availabilities and maintenance costs; by the way sometimes it is not suitable to all production systems, as it requires specific set conditions, specialized personnel and data collection storages.

Reliability Centered maintenance - RCM

RCM can be defined as an instrument used to develop and improve a maintenance planning model of a production systems. It was founded in airplanes industry in 1960s, and then extended to all productive realities. Ahuja define RCM as a structured, logical process for developing or optimizing the maintenance requirements of a physical resource in its operating context to realize its "inherent reliability", where "inherent reliability" is the level of reliability which can be achieved with an effective maintenance program.

It provides schemes and tools to individuate production systems criticalities, to prevent failures, to avoid their effects and to carried out technical or maintenance solutions; some of these instruments are: Failure Mode Effects and Criticality Analysis (FMECA), Fault Three Analysis (FTA), Plan Do Control Act (PDCA), Hazard and Operability Analysis (HAZOP), and so on.

Productive Maintenance

Productive maintenance is focused on maximization of production systems reliability through maintenance costs minimization. It involves not only maintenance activities, but also equipment design and construction, production operations and set-up, and all aspects that affected machinery reliability. Its purpose involves all the items lifecycle, aiming to raise equipment productivity.

In this context, TPM involves all these concepts in a complex paradigm that is presented below.

1.1.2 *Total Productive Maintenance*

TPM (Total Productive Maintenance) is a useful industrial tool, designed primarily to maximize effectiveness of equipment throughout its entire life by the participation and motivation of the entire workforce [Nakajima, 1988]. TPM strategy is much diffused in manufacturing industries world, as it focuses on an effective and efficient maintenance function to support organizations success. The emergence of TPM is intended to bring both production and maintenance functions together by a combination of good working practices, team-working and continuous improvement (Cooke, 2000).

TPM provides a comprehensive, life cycle approach, to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers. The objective is to continuously improve the availability and prevent the degradation of equipment to achieve maximum effectiveness (Ravishankar et al., 1992).

Nakajima identified three main meanings for the word total, as:

1. ***Total Effectiveness***, that indicates the TPM aim of maximize the economic efficiency or profitability.
2. ***Total Maintenance System*** that indicates the total involvement of failure prevention, maintainability improvement and preventive maintenance.
3. ***Total Participation*** that indicates the importance of the involvement of all staff in TPM philosophy, especially a deep collaboration between maintenance and production, through autonomous maintenance.

TPM paradigm involves several objectives, which can be summarized in:

- Maximize equipment effectiveness.
- Establish a Total Preventive Maintenance (PM) system for all the machinery, through prevention, preventive actions and improvements.
- It requires the participation of all staff, especially of equipment designers, equipment operators and maintenance workers.
- It involves every single employee, from the production staff till the top management.
- It is based on the promotion of autonomous small group activities and team work.

The basis of this paradigm are called "the eight pillars of TPM", and each tool or method is classified into these eight macro subjects; pillars represent TPM building and model the core methodology to increase productivity, reduce costs and downtime. In particular they are known as: Autonomous Maintenance, Focused Maintenance, Quality Maintenance, Education and Training, Office TPM, Development Management and Safety, Health and Environment. Figure 1.1.

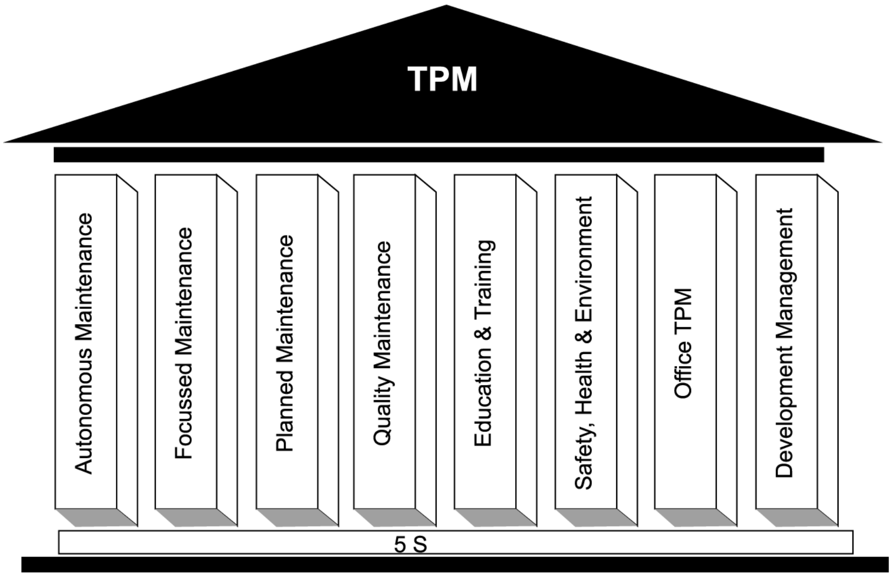

Figure 1.1 TPM 8 Pillars

TPM is considered as a tool that allows companies to make criticalities arise and consequently to improve systems efficiency. As all tools, its effects are measured by an *ad hoc* index, the OEE (Overall Equipment Effectiveness); OEE is the combination of three parameters as Availability, Performance and Quality and is the most common efficiency index used in all industries.

Companies that adopt TPM are seeing 50% reduction in breakdown labor rates, 70% in lost production, 50% - 90% reduction in setup, and 60% reduction in costs per maintenance unit (Koelsch, 1993). Organizations implement TPM primary to reduce equipment downtime; it is complementary to other paradigms as Total Quality Management (TQM), Just in Time Manufacturing (JIT), Total Employee Involvement (TEI) and other operations strategies.

Anyway, applying TPM is a long and complicate process, as it involves many functions, it requires deep changes and results are not immediate.

This Ph.D thesis is centered on its application in automatic production systems reality, focusing on criticalities of this industry, by presenting a realistic industrial case study.

1.1.3

Automatic Production Systems

Automation aims to reduce human presence in production systems, through the utilization of complex machines or workstation that replace human performances. Most products have always been made by human resources, through the utilization of materials and tools, following the development of knowledge. With the time passing, techniques were developed to support production, increase the quantity and standardize the throughput; nowadays machines have almost replace the human being in production industries.

An automatic production line is composed by several machines, or workstation, working in series and linked by handling systems that take items from a station to another one. In general there are buffer storage zones into the flow line, in a single location or between machines (transport); they allow a workstation to produce in continuous even if the downstream or upstream machine is down. Moreover, there are stations dedicate to inspections and controls of products, to guarantee a higher quality production on real time. When automation is not possible, manual station are located along the line, to perform the required action; in this case they are called "semi-automatic production lines".

The advantages of these systems are numerous, as the maximization of production rates, the labor costs reduction, the work-in-process decrease, the minimization of working spaces, the specialization and integration of operations.

Automation cannot be applied to all production systems, or it cannot be convenient; in general, it is used when processes are easy and repetitive, if there are high quantities, and products requires precision in manufacturing or do not need high personalization. As these machines do not need human presence, they are characterized by high complexity and sophistication.

In general principal disadvantages of automation are:

- High technology costs
- High skilled maintenance department
- Technology limits

Advantages, instead, can be summarized as:

- Standardization of processes and products
- Support and facilitate human work
- Faster production
- Decrease of labor costs

To guarantee continuity in production, maintenance action are needed; maintenance plans comprehend preventive, predictive and corrective actions, which aim to guarantee machinery availability. Maintenance activities in this industrial world are characterized by focused plans that requires the downtime of the complete production system. Moreover, activities cover numerous aspects, from cleaning to specific replacements that require specialized personnel. The complexity of these systems is so high in production functioning as in maintainability.
Food and beverage sector is highly characterized by automatic systems, justified by repetitive operations and big quantities. Since this work is centered on a case study in food industry, a dedicated analysis of its influential key factors is carried out.

1.1.4

Food & Beverage Sector

Food and beverage industry can be defined as "all companies that involved in processing raw food materials, packaging, and distributing them". This

includes fresh, prepared foods as well as packaged foods, and alcoholic and nonalcoholic beverages. Any product meant for human consumption, aside from pharmaceuticals, passes through this sector. Products of food industry are characterized by short lifetime, strict hygienic rules, high quantities and standard processes. Food processing provides the transformation of raw ingredients in the final product, including pasteurization, if needed, packaging application, preservation and transportation till the retailed stores. Food products are essential and critical elements in overall economy and consumer’s daily lify; the food industry is among the most competitive business one. Thues, efficient manufacturing of food products is of substantial importance (Xie et al., 2012).
This sector is deeply characterized by automatic production systems, as food processes are simple and repetitive, justified by high amounts. Automation in this sector is very common and useful, and human presence is needed to control and check machines and products. In this context, labor can be focused on maintaining machines available and efficient, through maximization of production, minimization of downtime and reduction of waste.

Food sector is characterized by specific rules and regulations, in addition to automation sector peculiarities; in particular aspects like safety, hygienic, quality and sustainability deeply influence production processes.
Moreover, *Roth et al.* developed a framework called the "*Six Ts*" that aims to identified and control criticalities in food industries, as Traceability, Transparency, Testability, Time, Trust and Training.

1. *Traceability*: it is the ability to track a product's flow. Behind traceability there are security, safety and quality reasons, regarding both the company and the customer’s interest. Traceability is regulated from legislations and governments, and it is a great source of information.

2. *Transparency*: it regards the product and process information, like ingredients, treatments and packaging. This aspect is regulated by specific safety rules and regulations, and it requires a deep information sharing among the supply chain.
3. *Testability*: that is the possibility to verify a characteristic of the product, like freshness, contamination test, quality; often this tests are destructive. When a problem is checked it could be related to maintenance activities, like cleaning, regulations or little failures, not relevant for the machinery life but for the quality product.
4. *Time*: that is the duration of a process (production, delivery, etc.). It is often very critical, due to the short product life time.
5. *Trust*: that is the relationship between partners in the supply chain, the expected information flow; this aspect is important for the efficiency and quality of the supply chain.
6. *Training*: that is the continuous developing of skills, knowledge and attitudes regarding international standards of quality and food safety.

In the food industry, the production process requires non-stop operations of automatic production line equipment. A stoppage in a production line, due to failure, causes a drop in the production rate as well as quality problems on the products. The most important type of quality deterioration in such products is the rise of the dough in the stages before baking. [Tsarouhas P., 2014].

Organizations of food industries which implement TPM paradigm, have to consider these factors as drivers in its application. Even if they are not directly related to maintenance activities, they could influence their execution and effects. For example, hygienic regulations often provide the use of strong disinfectant products, which influences normally lifetime of items.

Considering these reflections, chapter 2 of this thesis presents the state of art of the previous concepts, focusing on carried out drivers and tools of TPM implementation in food industry.

1.2 Buffer Allocation Problem - BAP

The second part of this research project is dedicated to Buffer allocation problem, related to automatic production flow lines and machinery efficiency improvement. High availability in productions systems brings to high productivity and quick response to market changes. Machine breakdowns are important causes of variability increase in process times and flows of production systems, leading to reduced manufacturing performance [Hopp and Spearman, 2000]. Automatic Flow Production Lines are often affected by the presence of micro breakdown which can penalize the productivity of the system and increase losses in availability for the whole plant. Moreover, micro downtime cause inability of the system not to respond to sudden changes in demand due to capacity restrictions [Battini et al., 2009].

In fact, applying TPM principles, downtime arise as a big source of waste for automatic production; moreover, while big failures can be managed with preventive and predictive maintenance, micro stops of few seconds but high frequency need different solutions to be reduced. If the nature of these so called micro downtime is technical, an ad hoc solution can be carried out; otherwise, if their nature is intrinsic in the process, buffer might be considered as a solution. In particular in the reality of automation, where high throughput is required and so production speed is relevant, buffers allocation and size can be a valid solution to increase equipment availability, especially in case of short downtime presence.

Buffers located between the various working stations in flow line productions, might increase the reliability of machines and so of the whole system, by limiting micro downtime inefficiency and save companies from making inadequate purchases of oversized equipment.

The following session presents an overview of Buffer Allocation Problem, from a downtime reduction viewpoint.

1.2.1

Buffer in Automatic Production Lines

Automatic production lines often includes strategic storage zones for collecting pieces between workstations and basic transfer mechanism: these zones are called "buffer". Buffers have many functions, and their size and position are strategic for the production effectiveness. Buffer size deeply influences production performances: to minimize their size and number looking to guarantee the required output is the core objective of BAP problem.
In automation, buffers are often represented by transport systems that have the double function of:

- To get products from a machine to another (material handling)
- To guarantee a constant production flow (material storage)

Each workstation has its own operation, and also its own time variation: to make different machines with different time variation working in sequence means to consider adequate buffer to permit a continuous material flow; in other words, even if machines are related one each other, their independence must be guarantee. Moreover random failures, uncertain time to repair and speed loss are no predictable factors that influence production line

performance. If independency of work stations is not guaranteed, machines blocking and starving states might occur and decrease production efficiency.
In automatic production systems, the size of intermediate buffers significantly affects the success of the production system, especially when their functions is to protect the system from the inevitable processing time fluctuations caused by machine disruptions [Battini et al. 2009].

Buffer size and location aims to ensure this independence. Weiss (2005) individuated three main focuses of BAP:

1. minimization of the total buffer capacities with the respect of a given goal throughput
2. throughput maximization respecting a given number and size of buffers
3. profit maximization

Allocate a buffer inventory, or in this case built a transport system, between two machines working in sequence, is necessary to satisfy production demand during machinery downtime and to avoid investment in new machines technologies. BAP in automatic production lines is a well-known problem and deeply discussed in literature (as in Chiadamrong and Limpasontiong, 2003; Papadopoulos and Vidalis, 2001; Vidalis et. al, 2005; Jeong and Kim, 2000; Aksoy and Gupta, 2005).

1.2.2

Methods Overview

In literature, many authors proposed methods and frameworks to optimize buffer size and location. Buffer Allocation Problem fundamentally addresses two different problems: the optimal buffer location definition and the optimal buffer size computation. In other words, where to place a buffer in the line and how much storage capacity to allow [Battini et al., 2009].

In general, the main objectives are:

1. **Production Maximization**: Size is calculated steering to guarantee the highest independence between machines, looking to a continuous flow of products, through the elimination of process downtime.
2. **Buffer size Minimization**: Once individuate the store size, the cost of the space location might be consider in order to balance the benefits and disadvantages of buffer location.
3. **Average work-in-progress minimization**: Finally, buffer represents also a cost in terms of material stock that should be minimize.

A lot of methods are centered on performance measurement of production flow, looking to the throughput or the average work-in-progress. In general, these methods are focused on the minimization of buffer space looking to satisfy the desired production request. This can be considered as the "primal problem"; then methods are in general focused on the "dual problem" that is to maximize the throughput with a given number of buffer located.

Depending on the production type and the business of the company, the BAP could be about the size and/or the location; the main objective are expressed in business goals as:

- Maximization of net present value
- Minimization of total operation costs
- Minimization of number of stations
- Maximization of throughput
- Minimization of the average idle times
- Minimization of the cycle time
- Minimization of the total buffer space

- Maximization of the service level

Approaches used till know are very different. There are mathematical approaches, simulation models, non-linear programming models, and so on. It depends from the production reality and from the business goals that are defined.

It is proposed Weiss et al. (2005) classification of buffer sizing methods, as:

- The exact approach
- The heuristic approach
- The rules of thumb approach.

Exact Approach

The exact approach provides methods that carries out well defined buffer solutions but requires numerous and specific data in input. It can be applied with success to small realities, because the combinatorial complexity of bigger lines and the lack of exact evaluation methods makes this approach complicated for larger realities. Considering small lines it is possible to apply methods that carry out more specific solutions; during last years, sample-based approaches have been applied to optimize buffer with limitations in size and in numbers. For sufficiently large sample size, these methods carry out exact solutions. In 2008, Matta proposed an exact mixed- integer programming (MIP) formulation that optimizes the number and the capacity of buffers using samples of the processing times in continuous time.

Heuristic Approach

Heuristic approach is based on samples studies and statistical analysis application. Many studies focused on this approach are carried out: Gurkan (2000) uses sample-based gradient estimates of performance to measure the optimal buffer size in production flow lines. Moreover Helber et al, (2011) proposed a discrete-time linear programming formulation for solving the BAP. The aim is to transform the stochastic processing times of different tasks of a given station into the corresponding realizations of production capacities in a defined period. In these case there might be simulation and discretization errors. Another work of Alfieri and Matta (2012) proposed the concept of time buffers, which can be used to define approximate buffers allocations. Other models about heuristic approach include Tabu Search and simulated annealing as generative methods, in addition to simulation or decomposition. Trying to improve these approaches to obtain more and more exact results, there is the risk to obtain local solutions or to make too much restrictive assumptions. Caramanis (1987) proposed Generalized Benders Decomposition with gradient estimates application for performance approximation; anyway optimal solution cannot be guarantee. Heuristic methods carried out fast strategic solution, but do not guarantee the optimal allocation, due to errors in allocation.

Rules of Thumb Approach

Based on extensive numerical studies, many models are proposed by Hillier et al. (1993), Powell and Pyke (1996), and others. Anyway each method is different from each other and required ad hoc assumptions; results cannot be generalized without a deep study to adapt them to other realities.

1.3 Research framework

The topic of this Ph.D. thesis is maintenance models and tools applied to automatic production systems in food and beverage industry. The focus of this research comes from the need of identify a general framework for applying TPM in automatic flow line systems considering food sector characteristics. In fact peculiarities of food industry deeply influence production equipment performance and maintenance activities. Since the increasing of the strategically relevance of maintenance function, a structured tool to implement TPM in this sector is required.

The idea is to carry out a systematic method to improve efficiency of production lines through maintenance activities and production optimization, considering the influential factors of the studied sector. Moreover the core of the framework proposed is centered on the identification and resolution of criticalities, to make results arise and involve people in trusting in TPM (from production till management). In fact, traditionally methods that follow the 8 pillars framework provide the application of TPM techniques on the whole production equipment, from autonomous maintenance till improvement activities; but in this way, results and benefits might be missing.

First of all, a deep literature analysis about the state of the art has been carried out, to construct a general framework about TPM application. Chapter 2 is centered on the following research questions:

RQ.1 ***Which factors should be taken into account in TPM Implementation?***

RQ.2 ***How is the current automation context in food and beverage sector? Which peculiarities of this sector might influence reliability of machines?***

The framework carried out considered peculiarities of food industry related to maintenance of automatic machinery. Moreover it aims to underline equipment criticalities in terms of production equipment inefficiency, focusing on the lower efficiency index. The objective is to individuate those activities that give remarkable results in order to highlight TPM Implementation benefits.
Chapter 3 presents the first part of the case study related to this Ph.D. thesis, where the framework had been applied. In fact this work is carried out with a straight collaboration with Acqua Minerale San Benedetto S.p.A., an Italian Company leader in its sector.
During the framework implementation, it emerges that downtime is the core inefficiency of automatic lines, in particular *micro downtime*, defined as short stops of few minutes but with high frequency. Micro downtime are physiological inefficiency of automation world as asynchronous machines are working in series; each workstation depends from the upstream one and also influences the downstream machine. A general study of them is proposed, focusing on technical solutions, based on investments in new technologies activities. Anyway, new technologies are not a solution always applicable for companies, as they need to remain competitive in the market at the lowest product cost.

A third research question arise as:

RQ.3 ***How micro downtime influences equipment reliability and how can be reduced?***

Chapter 4 is focused on this research question, mining the existing literature about downtime analysis; many models and studies are collected, and the main approaches are presented.
The lack of a focused micro downtime study, of a model that aims to individuate the nature of this phenomena and to propose a solution in order

to improve availability, is the reason of the second part of this Ph.D. thesis. Moreover it is carried out an analysis about buffer allocation and sizing as a solution to micro downtimes and speed reduction in automatic lines.

It is proposed a model to study micro downtime, to fit them probability distribution and to use a simulative model to evaluate the buffer size in order to reduce their downtime.

Chapter 5 presents the second part of the case study. In this chapter it is proposed a focused micro downtime analysis of the most critical work station and the line simulation to quantify the benefits.

Finally Chapter 6 presents the conclusion of this work, summarizing results of the case study and future extension of the model proposed.

Figure 1.2 presents the scheme of the structure of the thesis.

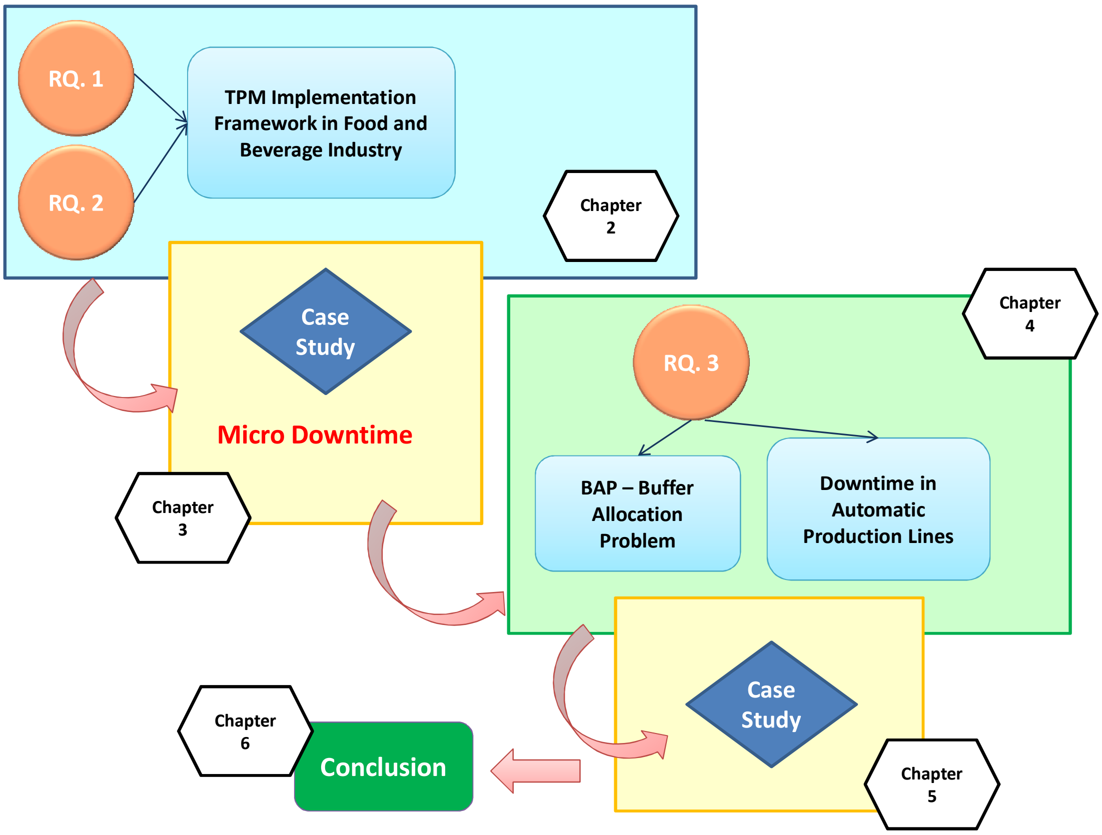

Figure 1.2 Thesis Structure

1.4
List of Publications

The research activity of my Ph.D. has lead to the writing of some papers concerning maintenance implemenation framework in Food & Beverage Industry and Micro downtime study in automatic Production Systems. They are both international conference papers and journal papers.

All of them have contributed to the composition of this thesis.

1.4.1
Paper for Chapter 2

- Battini D., Persona A., Sgarbossa F., Zennaro I., 2014,"***TPM Implementation in automated flow line manufacturing systems: criticalities and key factors to support a faster implementation"***, Summer School Francesco Turco, September 2014.

1.4.2
Paper for Chapter 3

- Battini D., Zennaro I., De Marchi R., "**When Micro Downtime Counts**" (2016), PCN Europe, March, pp. 12-13
- Battini D., Persona A., Sgarbossa F., Zennaro I., 2015, "**Downtime Analysis as a tool to improve efficiency in automated production lines: A bottle plant case study.**" , Summer School Francesco Turco September 2015**.**

1.4.3

Paper for Chapter 4

- Battini D., Persona A., Sgarbossa F., Zennaro I., 2016, " **Buffer Allocation Problem (BAP) related to Micro Downtime in Automatic Production Lines: A bottling plant case study**" , XXI Summer School "Francesco Turco, September 2016.

1.4.4

Paper for Chapter 5

- Battini D., Persona A., Sgarbossa F., Zennaro I., Celin A., 2016 “**Reliability Analysis based on field Microdowntime data: A bottle production plant case study** " . 22nd ISSAT International Conference on Reliability and Quality in Design (RQD 2016).

- Battini D., Sgarbossa F., Zennaro I., De Marchi R,., " **Micro Downtime: Data Collection, Analysis and Impact on OEE in Automated Production Lines: A Bottle Plant Case Study**" . Journal of Food Engineering, in progress.

1.5
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2

TPM in Food Industry

"Companies may be classified in three ways regarding to TPM: the ones that really have the structured and working methodology; the ones who say they have it, but they do not have even the structured basic principles; and the ones who had already established the pillars but let this structure to fall serving its fragments only to satisfy the audit... the impact of an inadequate and an inefficient maintenance can define the business profitability and the survival of the company."

[Rodrigues and Hatakeyama, 2006]

2.1 TPM Implementation

TPM began in Japan, in a factory of Toyota's group, in 1971. It is the answer to the rapid market evolution of last years, as the increase of products variety and differentiation, and the improvement of effectiveness of production to satisfy the demand. In practice, this is expressed in production goals as waste elimination, equipment effectiveness improvement, downtime reduction, product quality optimization and maximization of operations' efficiency.
TPM harnesses the participation of all the employees to improve production equipment's availability, performance, quality, reliability, and safety. TPM capitalizes on proactive and progressive maintenance methodologies and calls upon the knowledge and cooperation of operators, equipment vendors, engineering, and support personnel to optimize machine performance, thereby resulting in elimination of breakdowns, reduction of unscheduled and scheduled downtime, improved utilization, higher throughput, and better product quality [Ahuja and Khamba, 2008].

The first question is: why a company should implement TPM? Which are the benefits achievable from this tool?
Recent studies highlights that many production systems in use are not performing as required, operating at less than full capacity, with high production costs and low productivity. In accord with Mobely (1990), an average of 28% (between 15% and 405) of total production costs is attributed to maintenance activities. As a maintenance function tool, TPM aims to support a continuous improvement process, through optimization of production effectiveness and minimization of equipment inefficiency in terms of downtime, set-up, scraps, and reworks, with a team-based methodology that involves the participation of all staff, across all levels of operational hierarchy.

In general, TPM goals can be summarized in:

1. Zero Defects
2. Zero Accidents
3. Zero Breakdowns

In order to reach these goals, they are converted in practice in six objective that this paradigm aims to improve as:

- Productivity
- Quality Cost
- Cost of Product
- Delivery and movements of products
- Safety of operations
- Morale of those involved

These objectives are called "PQCDSM" (Bamber et al., 1998).

The reason why a company decides to invest time and resources in a long project is that it aims to become world class in its market, to satisfy customers demand and to achieve organizational growth. The focus is to remain competitive in an industry reality that is in continuous evolution, aiming to carry out more and more flexibility in production operations. Objective regarding productivity and quality can be achieved through a "revolution" in organization work culture and mindset. Moreover, TPM aims to minimize investments in new technologies and at the same time to guarantee the request output at an adequate manufacturing quality. Others secondary benefits are related to inventory levels optimization, and production lead-time reduction, implementation of employee skills and the improvement of safety in job tasks. In particular, with the pillar of autonomous maintenance, operators should be involved in maintaining machines by themselves; this can be achieved with an adequate improvement of motivation in the workforce, the support of specified empowerment, focused training and the implementation of organizational goals that requires employee participation.

Success of a TPM program is closely connected to the way of managing people, because the focus of the proposed work in this methodology is the human being [Rodrigues and Hatakeyama, 2006].

TPM implementation traditionally models provides the application of maintenance tools to the whole equipment, without a specific focus on critical machines or parts; this might cause benefits missing and the loose of employee support. The goal of this work is to carried out a framework in Food Industry focused on criticalities resolutions and results highlight.

Session 1 of this chapter aims to answer to the following research question:

RQ.1 ***which factors should be taken into account in TPM Implementation?***

But before presenting an overview of factors and drivers that influence Total Productive Maintenance implementation, it is important to linger on how TPM is measured.

Next session is dedicated to Overall Equipment Effectiveness index (OEE) that is defined as the principal indicator of TPM implementation.

2.1.1

O.E.E.

The Overall Equipment Effectiveness (OEE) is the core index of TPM paradigm. Measurement is fundamental to highlight benefits or obstacles in the continuous improvement process. TPM is well represented by OEE index as it aims to maximize maintenance operations, equipment management and resource availability.

OEE is composed by three parameters as Availability (A), Performance (P) and Quality (Q); the combination of these three parameters carried out a complete index about production equipment effectiveness.

The OEE measure is central to the formulation and execution of a TPM improvement strategy [Ljungberg, 1998], it provides a systematic method for establishing production targets, and it incorporates practical management tools and techniques in order to achieve a balanced view of process availability, performance efficiency and rate of quality [Bulent et al., 2000].

Availability is defined as ratio between the effective production time and the planned production time, as:

$$\text{Availability (A)} = \frac{Loading\ Time - Downtime}{Loading\ Time} \qquad (1)$$

Where downtime comprehends time of no production due to failures, downtime, set-up, and other events that affect equipment availability and loading time is the planned hours for production.

The second factor is represented by Performance of equipment, defined as:

$$\text{Performance (P)} = \frac{Effective\ Production}{Theoretical\ Production} \qquad (2)$$

Where the effective production correspond to the real output realized in the effective production time and the theoretical production is the items that should be produced in the corresponding effective production time. In other words, this factor is the ratio between the running time of machines and the Production time: it is affected by speed loss, micro stops of few minutes and others wastes that affects equipment performance.

Finally, the third parameter is the Quality that is calculated as:

$$\text{Quality (Q)} = \frac{Effective\ Production - defects}{Effective\ production} \qquad (3)$$

Where defects represent those items that do not satisfied product specifications.

Each parameter represents the effects of production waste on equipment effectiveness. Production wastes are summarized by TPM paradigm into 6 big categories as:

1. *Failures*: downtime related to machine breakdowns, as mechanical or electrical damages, equipment malfunctioning, and all technical problem that cause the production stoppage.
2. *Set-up*: It is the downtime caused by the need to adapt production equipment to the product specifications; it comprehends regulations, format changes, etc.
3. *Idle time or micro downtime*: it comprehends short process stops due to lack of products or material, blocking states, jammed items and so on.
4. *Reduced speed*: this loss took place when machines could not perform their nominal speed due to some events; it does not caused production stops but it affects the final production.
5. *Defects:* Products that do not satisfied the standard requirements and have to be eliminated or need to be reworked.
6. *Reduced Yield*: that includes losses caused by the start-up phase during production processes.

Availability is influenced by failures and set-up, that represent long downtime, Performance is influenced by idle time or micro downtime and by reduced speed, that represent short downtime, and finally quality is influenced by defects and reduced yield, that represent the need of satisfy the required standards.

Finally, OEE can be calculated as the combination of this three parameters, as:

$$\textbf{OEE = A * P * Q} \quad (4)$$

Figure 2.1 well represents the previews concepts.

OEE is a complete and useful index: its study can reveal lack and inefficiency in production systems, through the analysis of its categories. It offers a measurement for evaluating production effectiveness, and it make possible to control TPM implementation evolution. In order to maximize its benefits, losses should be divided more detailed as possible to highlight inefficiency causes. In fact, factors influencing OEE are not equally important in all sectors or machines and different weights should be established.

In conclusion OEE is fundamental for OEE performance measurements; it requires a deep classification of losses and inefficiencies to better fit machines utilization and to maximize its effectiveness. A personalized OEE based on the industrial sector is required.

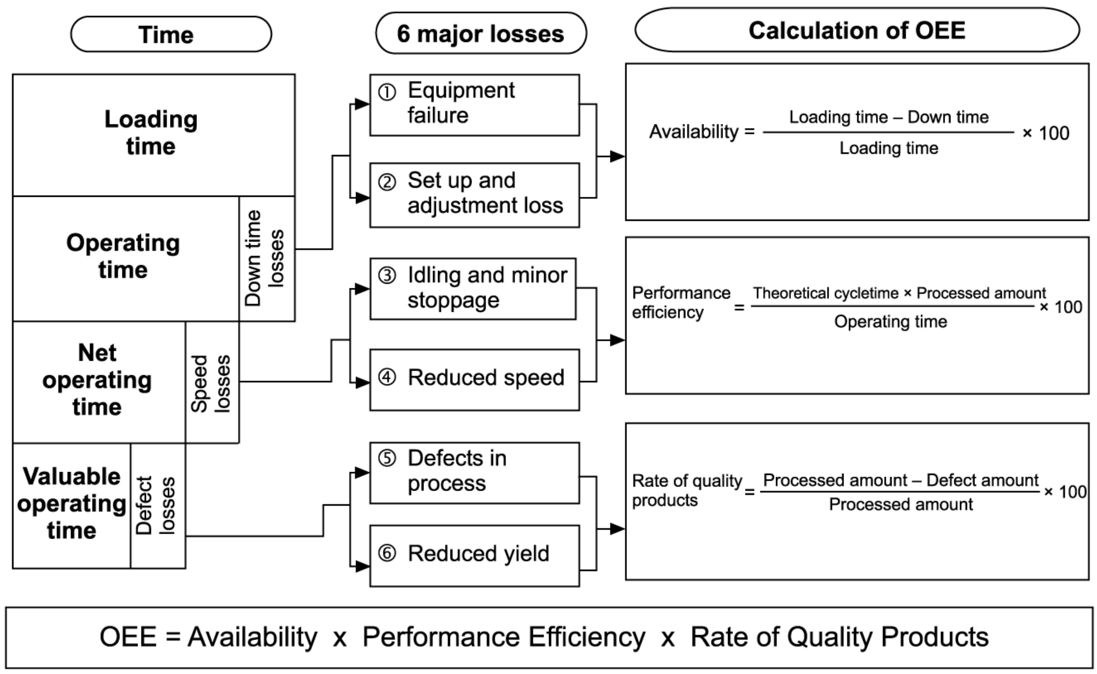

Figure 2.1 OEE calculation

2.1.2

TPM Implementation Key Factors

TPM implementation in companies' reality needs to be well planned and supported with adequate and strategic tools and methods. Its success is related to the joint of production and maintenance functions focusing on team working, continuous improvement and good working practices. In fact success of TPM depends to the way of involving people, because it is a methodology that requires people mind changing as first. Many authors discuss about obstacles and drivers in developing a so complex project. What emerged from the literature is that TPM implementation is not so easy and fluent as it requires specific attention to some critical aspects that can make the project fail. Its criticalities are related to the fact that TPM not only aims to keep machine running, but also to maximize the overall performance, by creating a sense of joint responsibility between supervisors, operators and maintenance workers.

In general the failure of TPM implementation is due to lack of a support system to facilitate learning and transform learning into effective diffusion of the practices of TPM [Ahuja and Khamba, 2008]. The failure of an organization to successfully implement a TPM program has been attributed to various obstacles including lack of management support and understanding, lack of sufficient training, failure to allow sufficient time for the evolution [Bakerjan, 1994]. Cigolini e Turco (1997) studied several Italian industries to individuate influential aspects in TPM implementation, related both to external and internal context; they identified three factors as the firm size, the manager's commitment to the project and the program promoter.

To individuate the principal influential factors of TPM implementation, 15 case studies have been considered and studied in deep. They have been compared each other to individuate common aspects, results and criticalities. For each case study is provided:

1. The country and the production sector
2. The Time for implementation
3. The KPI used to measure TPM progress
4. The success key factors emerged
5. The results obtained

In the Figure 2.2 and Figure 2.3 it is shown a scheme about the case studies that have been considered.

From the analysis of TPM implementation projects, they emerges 6 key factors that need to be considered to gain success as major influential drivers.

1. Management Support

Management is the first division who embraces TPM philosophy, the promoter and principal supporter of the project. Its support is fundamental to the success of the involvement of all employee, both from a financial and economical sustain, and as example of communication and synergy between departments. The mind change required from TPM philosophy starts from management; its support is the beginning and the basis for the project implementation. Structural and culture transformations take place from the company’s higher level of responsibility group; from the case studies is evident that its support is an important driver, as it is the core guideline to create and support the joint between all the company’s functions.

ID	Authors	Year, Journal	Country	Sector	Time	KPI - measures	Success key factors	Results
1	Singh R., Gohil A.M., Shah D.B., Desai S.	2013, Procedia Engineering	India	Automotive components manufacturing		OEE	-Workers Involvement -Top management support	OEE: 63%-->79%
2	Chan F.T.S., Lau H.C.W., Ip R.W.L., Chan H.K., Kong S.	2003, International Journal of Production Economics	China	Semiconductor Industry	2 years	-MUBA -OPL -N° improvemets -Training hours	-Top Management Support -TPM training -Workers involvement -Time -Measurement method	MUBA: +83%
3	Ohunakin O. S., Leramo R. O.	2012, Journal of Engineering and Applied Sciences	Nigeria	Beverage manufacturing plant	7 weeks	-OEE -line utilization -line brekage % -line downtime % -line defective products -crown wastage %	-use a step method	OEE: +50%
4	Tsarouhas P.	2007, Journal of Quality in Maintenance Engineering	-	Pizza production line	5 years	-OEE -Availability -Performance -Quality rate	-use a step method -time -management support	OEE:062%--> 79,5%
5	Ireland F., Dale B.G.	2001, Journal of Quality in Maintenance Engineering	UK	Rubber products plant	2 years	-OEE	-focus on autonomous maintenance -management support -TPM training	TPM leaders in UK
6	Ireland F., Dale B.G.	2001, Journal of Quality in Maintenance Engineering	UK	packaging	3 years	-OEE	-measurement method -management support	-20% customers complaints +40% production volumes -40% overtime costs
7	Ireland F., Dale B.G.	2001, Journal of Quality in Maintenance Engineering	UK	Motorised vehicles	3 years	-OEE -5S	-autonomous maintenance -motivation	JIPM level 2
8	Sun H., Yam R., Wai-Keung N.	2003, International Journal of Advanced Manufacturing Technologies	China	Semiconductors and integrate circuits production	5 years	-MTTF -MUBA -OPLs	-top management support -team work and involvement -training -importance of human resources	-Failures decrease -MUBA +390%

Figure 2.2 TPM implementation case studies (A)

9	**Chand G., Shirvani B.**	**2000, Journal of Materials Processing Technology**	**UK**	**Automotive components production - semi automated assembly cells**		**-OEE -TEEP -NEE**	**- deep operators' training -accurate measuraments and data analysis**	
10	Wakjira M.W., Singh A.P.	2012, Global journal of researches in engineering - Industrial Engineering	Ethiopia	Malt manufacturing industry - boiler plant	6 months	-OEE -Machinery downtime	-Top management involvement and leadership -traditional maintenance practice -holistic TPM implementation initiatives	OEE 70,35% --> 80,23%
11	Ahuja I.P.S., Kumar P.	2009, Journal of Quality in maintenance engineering	India	Tube mill	5 years	-OEE -Productivity -Equipment breakdowns -customer complaints -rejections -skill gap matrix	-Employee extensive training -Managers and supervisors training courses and conferences -time	OEE +59% Productivity +78% Equipments breakdowns -63% Customer complaints - 85%
12	Baglee D.	2008, The International Maintenance Conference	UK	Printing presses manufacturing	1 month	-OEE -ROI (Return On Investment)	-accurate measurements of costs -focused improvement activities -Time -financial support -increased skills -Management involvement	Production time increase Maintenance costs decrease Equipment availability increase
13	Waeyenbergh G., Pintelon L.	2004, International Journal of Production Economics	Belgium	Cigars and cigarillos production plants	3 months	- production output	-use of a defined framework -training -management support -step-implementation	Production increase (unit per day)
14	Wakjira M.W., Singh A.P.	2012, Global Journal of Researchers in Engineering - Industrial Engineering	India	Automobile manufacturing	Not specified	-OEE	-use of a step- method -training both for management and operators -management support	OEE increase (from 60% to 70%)
15	Crosio D.	Manutenzione-Tecnica e Management	Italy	Beverage production plant	1 year	-OEE -skill matrix -MTBF -MTTR	-step implementation -training -management support -time	OEE: +2,9%

Figure 2.3 TPM implementation case studies (B)

2. Sufficient Time

Time for implementation is a basic aspect to consider; as TPM is a cultural change, it requires time and time to be implemented, and often results are not so immediate. After the first step gets started, it needs time to be implemented and improved. Companies that do not gives TPM enough time to evolve, often fails in its implementation [Bakerjan, 1994; Davis, 1997]. Principally this is related to the industry management trend of having rapid results and satisfying economical returns in few time, to confirm their right in investments. Since TPM does not give rapid and visible results in few time, it is often abandoned after few steps. Also Rodrigues and Hatakeyama (2006) affirmed that TPM implementation in a quick way, omitting some consolidation steps, is a failure influence factor. The industry mind change needs time to be root in employee mind, especially in the higher decision maker levels.

3. Employee Involvement

The third driver is represented by the employee involvement: management support is a success prerequisite as staff involvement and participation. First of all operators need to change their mindset from productive to proactive, embrace the project, and improve their knowledge of the machines. Total employee involvement is indeed a pre-requite to successful TPM implementation; it can be ensured by enhancing the competencies of employees towards the jobs, evolving the environment of the equipment and system ownership by the employees [Ahuja et al, 2008]. Moreover TPM is a total cultural transformation that must comprehend all the staff to success. All functions needs to work together and collaborate to reach the same goals: the company's success. That means to create working joint between all the functions, as production, maintenance, but also marketing, design, quality control, etc. This concept can be summarized as the transition from old mind:

"*I operate, you maintain*" to "*I produce, I inspect, I maintain*" [Ahuja and Khamba, 2008].

4. Training and education

Another consideration is about training requirement: TPM needs focused training and education sections for all the company's staff, from management till production department. Management needs training to deep understand TPM paradigm, how to manage it and how to improve its development through the company; operators need training both for the new cultural mindset and to achieve the required technical skills. This key factors it is not only discussed in various case studies, but it is a proper TPM pillar. Operators should be able to anticipate problems, to be autonomous in little preventive actions, to maintain the equipment in a good state through checking, cleaning and lubrication actions. The core aim is to make production staff in a state of feeling machines as their own property. In other word, operators that feel equipment as their "property" are more used to take care of it.

5. Communication and cooperation (team work)

Team work is TPM foundation, and means that maintenance and production functions have to cooperate and communicate to win. Production needs maintenance to reach its performance objectives, and have to communicate with it to improve its output; vice versa maintenance needs production support to prevent failures in the production machinery as they can continuously check it. Operators and maintenance staff require to work in team to follow the win-win strategy; operators should be multi-skills staff and maintenance staff should trust in them and delegate basic maintenance activities. This philosophy of collaboration is not so easy to apply, as often the two functions as different secondary goals, even if the company business goal is the same. For example production, aiming to maximize the throughput, is reluctant in stopping machinery; on the other hand, maintenance, aiming to maintain machine in order to work, need to carry out its activities. Even if the two objective are opposite, the combination of both needs is possible through an adequate planning. That is why communication and mostly collaboration is fundamental to gain a win-win strategy.

6. Integration and visibility of TPM goals

Finally, the last driver is represented by the integration and visibility of TPM, as it is a paradigm, a cultural transformation, of which boundaries are hard to define. To define goals and measure TPM results through maintenance KPI is important to control and underline the project progress. Management uses TPM goals to check their investment and to manage future improvement; on the other side staff use TPM KPIs to follow the development of their actions, and to improve motivation and gratification. TPM purpose and objectives necessitate to be entirely incorporated into the designed and commerce plans of the organizations, since TPM have an effect on the entire association, and is not restricted to manufacture [Darabi et al., 2014].

2.2

Food & Beverage Industry

Food industry is in continuous evolution due to quality and customers' requirements changes. This sector is characterized by high automated production systems, due to repetitive and simple production processes and high quantities. It presents critical factors related to health, safety, quality and delivery of products, over the common criticalities related to automated production systems. Typically products of this sector have short life time, with low possibility to stock, and requires specified characteristics of quality, related to security regulations. Factors as temperature and humidity, high customer expectations, interaction between products, low profit margin and many others, make food companies in condition of continuous improvement to be competitive in their market.

The second session of this chapter is dedicated to answer to the following research question:

RQ.2 ***how is the current automation context in food and beverage sector? Which peculiarities of this sector might influence reliability of machines?***

In order to do that, two studies are presented, as they are the most complete summary of food industry characteristics.

2.2.1

Food Safety, Quality & Sustainability

Akkerman R. Et al. (2010) summarized three main influential factors of food and beverage industry: Food Safety, Food Quality and Food Sustainability.

Food Safety

Food Safety is related to the possibility of illnesses caused by the consumption of contaminated food. Governments defined legislations, parameters and controls to enforce standard processes and traceability of food products among all supply chain. Anyway, this aspect is fundamental for companies not only for legislation reasons, but also for an economical motivation as a safety failure in food market can be commercially devastating. Brand imagine is important as product quality, and sometime also more; one of the most famous case is the recall of peanut butter in USA due to salmonella presence. (2010).

Products recalls, legal fines and image damages are critical motivation for making companies centred on safety importance. For these reasons food industries themselves developed various systems and standards to take under control safety of their products as the Hazard Analysis Critical Control Point system (*HACCP*), the *ISO 22000* standard and the British *BRC standards*. HACCP is a tool that aims to identify food safety risks and so to reduce or eliminate them through control and correct actions. ISO 20000 and BRC, in addiction, provide to involve food safety in management system too.
In conclusion, in food industry, food safety is seen not as an obligation or imposition from governments, but as a commercial success factor.

Food Quality

Food quality is another important driver of this sector and could be identify as the way products are perceived by the final consumer and their grade of appreciation. It includes various costs related to certifications, auditing and quality assurance controls, and it heavily influences production processes and products distribution. Consequently, it influences maintenance activities that are needed not only to restore and maintain the machines but also to guarantee a certain level of product quality.

Food quality and safety are strongly related each other, as a consequence of production process. The main difference is that quality is something more continuous among the production and distribution process, otherwise safety is something that there is or not, as it is a binary characteristic.
Both quality and safety, in this way, influences maintenance activities, in relation to replacement activities, spare parts utilization, maintenance procedures, and so on.

Food Sustainability

Finally there is the sustainability aspect that gained more and more importance especially in these last years, both for legislation and commercial drivers. Sustainable development is the one that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987). This means, for companies, to take into account the ethical trading in procurement of raw materials and animal welfare, for example; Moreover, other aspects related to food sustainability are the distance of food products, related to miles done by products to reach the final consumer, and the carbon footprint, as the impact on environment of production and distribution systems.
As a strategic business and commercial goal, many green projects has been developed in various food and beverage industries, from production processes, energy saving, and green packaging to improve companies reputation and success in the proper market.

2.2.2 *6 Ts*

Another interesting study about Food sector characteristics is carried out by Roth et al. (2008). They summarized food characteristics in a framework called the "Six Ts". The first is *Traceability*, defined as the ability to track product's flow. Behind traceability there are security, safety and quality Reasons, regarding both the company and the customers' interest. Traceability is regulated from legislations and governments, and it is a great source of information.

Figure 2.4 The 6 Ts of the Food industry

Then there is the *Transparency* that regards the product and process information, like ingredients, treatments and packaging. This aspect is regulated by specific safety rules and regulations, and it requires a deep information sharing among the supply chain. It is a complex aspect to manage, and often it requires audit activities through the supply chain.

Testability is the third Ts and it is defined as the possibility to verify a characteristic of the product, like freshness, contamination test, quality, etc.; often this tests are destructive, and this should be take into account in production performance as it affects the production process output. When a test is not positive, the production is blocked and the problem is checked: it could be related to maintenance activities, like cleaning, regulations or little failures, not relevant for the machinery life but for the standard of product;

anyway maintenance activities are carried out in order to solve the anomaly and satisfy products standards.

Time: is the duration of a process as production, packaging, delivery, etc. It is often a very critical factor, due to the short product life time. Time influence all the product process, from the raw material provision, through production process, till the final product delivery.

Then *Trust,* that is the relationship between partners in the supply chain, represents the expected information flow between them. This aspect is important for the efficiency and quality of the supply chain; it influence not only the single companies, but the whole companies network involve in food production.

And finally *Training*: that is the continuous developing of skills, knowledge and attitudes regarding international standards of quality and food safety. It is important for maintaining a high standard of products quality and respects safety rules that are in continuous evolution.

2.3 TPM in Food & Beverage Industry

As introduced in the first chapter, food industry is deeply characterized by automatic systems. Trying to answer to *Research Question 1* and *Research Question 2*, the previous paragraphs presents an overview of Total Productive Maintenance implementation in industry realities with the focus on food sector.

Now it is proposed a new framework for TPM Implementation taking into account the whole peculiarities presented previously. The principal objective is to focus on a critical production line to make results more visible and in a certain way faster. Seeing rapid improvement might be a benefit both for management and for production staff. In fact, as management is reluctant in investing in a long term project, evident results can give enforce to TPM implementation; moreover, the mind change required in production staff can be well supported by visible results. "If it works here, why should I don't try?".

Figure 2.5 summarized aspects that have to be taken into account to avoid TPM implementation Failure.

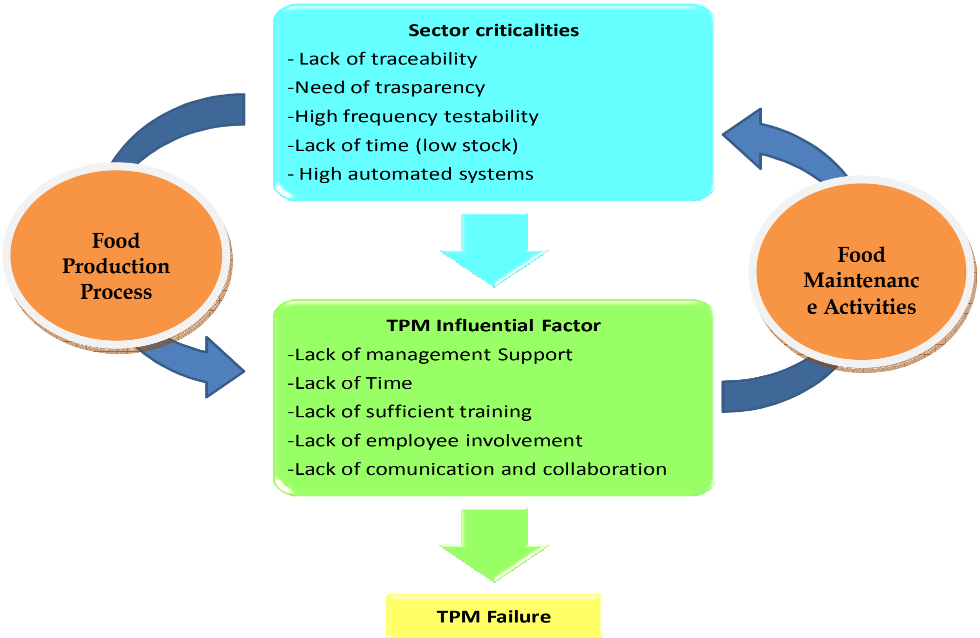

Figure 2.5 TPM Implementation key factors in food and Beverage Industry

Food Production Process is influenced by sector criticalities, in addition to automatic systems characteristics. As well detailed before, parameters like traceability, testability, transparency and so on have to be taken into account in production process. Equipment Effectiveness, in order to satisfy customer demand, must comprehends this factors into account as they define product standard parameters and characteristics. In other words, even if the product can be defined well for equipment parameters, one of those key factor might reject it.

Implementing TPM in food industry means not only consider the typical critical factors of project practice as management involvement, time, training and others, but also the peculiarities of this complex sector.

The aim is to integrate standard maintenance methods and tools with sector specific regulations. In fact TPM critical influential factors are related not only to maintenance activities but also to production process, in order to involve all the employee; in other words, process criticalities deeply influence maintenance activities and tools. For example:

- Replacement time of spare parts is influenced by safety and quality specifications, as deterioration or hygienic regulations.
- Sanitizing products usually reduced machines lifetime, incrementing deterioration and so increasing standard maintenance replacement.
- Spare parts must be food certified, as there is a direct contact between them and food; this aspect influence as costs as availability of spare parts.
- Maintenance procedures should follow hygienic standard and guidelines, as sterilization processes or specific uniforms.
- Often time to repair is influenced by cleaning additional time or quality controls.
- Audit activities comprehends also maintenance standards respect.

Depending on the specific food or beverage sector, there are more aspect and implication that might influence TPM project. Knowing them and analysing their influence is the core part for TPM Implementation success.
Knowing these criticalities and key drivers, it is easier to implement TPM in Food industry, following the framework presented in next session. .

2.3.1 *TPM Implementation Framework*

Finally, it is presented a new TPM Implementation framework, Figure 2.6.

Unlike TPM pillars model, that provides a pyramidal implementation, involving all equipment from autonomous maintenance till improvements activities, this framework aims to give a focused list of activities, with the

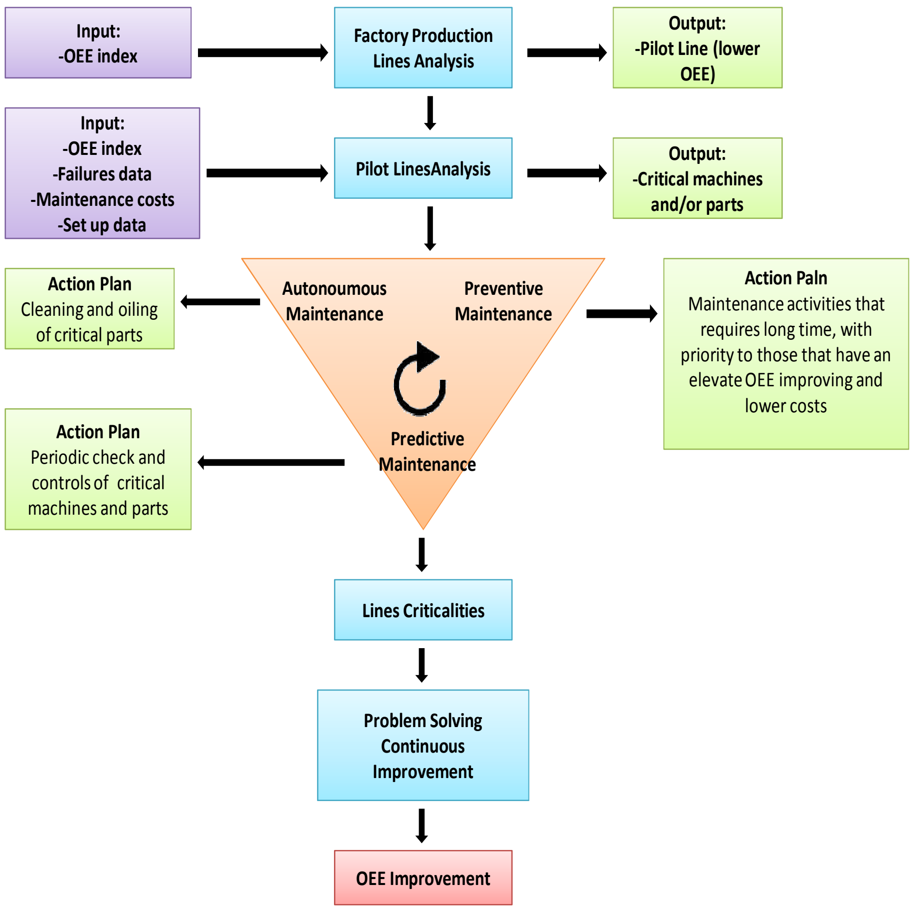

Figure 2.6 TPM Implementation Framework

goal of making arise criticalities and improving OEE in a very visible and faster way; visible results, in fact, should have the effect of make employee involved in the project.

The framework is based on OEE data collection, as it is supposed that companies use the index or are able to construct it. In fact, if OEE is not available, a relevant period of time should be dedicated to its implementation. It requires data about failures, set-up, machines speed, downtime, scraps, defects and re-working pieces. Once obtained an acceptable quantity of data, the framework can be applied.

The FIRST STEP needs as input the OEE data of the whole plant production lines; in fact in order to focus the implementation on one production line, it is important to define the worst one. In general, once analysed the worst equipment, it should be easier to create a standard for the others. But which is the pilot production line for the project? Aiming to have relevant results in a faster way, the line should be the one with the lowest Overall Equipment Effectiveness index (OEE).

The SECOND STEP provides the pilot line analysis to individuate criticalities that affect production efficiency. Data as failures frequency and duration, set-up time, maintenance costs, in addition to OEE index, are required. The output of this step is the individuation of the most critical machines, or working parts. First of all it is important to concentrate on these working machines, to have rapid results, as OEE improvement. Carrying out tangible results, people should be more interested in following TPM paradigm.

The THIRD step is the core TPM Implementation as it provides the construction of three maintenance action plans. As criticalities of the line are identified, TPM team with the support of the analysis and the technicians' staff, works to implement the three action plans, based on three different maintenance approaches:

1. <u>Preventive Maintenance:</u> This approach comprehends those activities that are characterized by a defined period of time, as they need to be cyclically done. The cyclicality could be defined with various criteria, principally it is time based or working hours based. As first failure rates and time to repair are analyzed, to individuate the maintenance interval time. Then costs and benefits are taken into account to re-define the periodicity of activities; quality and hygienic parameters are fundamental part of this process, as influential factors for replacements. In fact some activities are needed not

because of the degradation or malfunctioning, but because of the quality or hygienic rules respect.
After a first list of maintenance actions, activities priority should be assign. Activities with low costs that give a remarkable OEE increment should have higher priority.

2. Predictive Maintenance: This kind of maintenance comprehends those checks and controls of critical machines and particularities to measure and take under control the use and decline of a working part.
This approach is very effective when is possible to act this activities periodically and trace all the information, in order to measure the state of life of the machine. In this way it is possible to plan maintenance activities of revision or substitution when the part is near to the end of its life; the aim is to maximize the use of the part, without wasting costs, and to avoid failures. Predictive controls comprehends visible checks or the use of specified measurement as temperature, vibrations, chemical or residual analysis of oil, and so on.
The major defect of predictive maintenance is that is not always possible to apply it, especially in food and beverage sector. Following the previous guideline, also in this case activities with lower costs and higher OEE improvement should have the priority.

3. Autonomous Maintenance: This plan comprehends all those activities made by the production staff. For example there are activities like cleaning, oiling, lubrication and checking. Over time, the major objective is to implement production operators ownership of machines and let them able to do also little maintenance activities, as simple replacements. In fact, as their competence grown, they will be able to do little checks and control, and do more responsible maintenance activities. The principal aim is to make production feel as the owner of the line.

This part of the project required a strong collaboration between all staff, to plan activities, to form resources, to trace spare parts and to schedule all maintenance actions. Moreover it has no end, as it is in continuous evolution and improvement, and it needs to be reviewed periodically.

The FOURTH STEP provides the implementation of the previous maintenance action plans, in order to improve line criticalities and make OEE increase. Problem solving is a core tool used to analyzed and to solve, when possible, production equipment criticalities, that could be related to maintenance activities, but also to production process flow, machinery design or product specifications.

The framework aims to make arise TPM benefits, and to give a standard guideline for maintenance activities implementation. The core part is represented by the three action plans that are in continuous evolution. Moreover it is proposed the construction of a Cost Performance Indicator (CPI) for the activities proposed; this index compares the cost of the investment with the recoverable OEE in order to individuate the most remarkable OEE in terms of benefits. In fact the lower it is this index the better.

In Chapter 3, it is presented the application of the framework in a beverage industry reality, as the first part of the project.

2.4

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3

TPM in a bottling line

A case study - Part 1

"The performance criteria of world class manufacturing systems are requiring significant and rapid changes in the design and delivery of maintenance for plant systems and equipment. Operating requirements of rapid changeover, short production lead times, and zero levels of defects, and failures are a major change for maintenance."

[Maggard et al. 1992]

3.1
Acqua Minerale San Benedetto S.p.A.

Acqua Minerale San Benedetto S.p.A. is the company where is located the case study of this Ph.D thesis. It is a multinational Italian corporation, whose core plant is located in Scorzè (Ve) and comprehends 23 automatic production lines; its core business is centered on beverage market, in particular Mineral water and beverage products like the, juice, soda, etc.

Next sessions are about the company's background, its products and its plants.

3.1.1
The company

Acqua Minerale San Benedetto S.p.A. was founded in 1956 Scorzè (VE) by Bruno and Ermenegildo Scattolin. Its core business is centered on Mineral water and Beverage, produced and retailed along all over the world.
At the beginning, the company sold water in glass returnable bottles, as it was usual in that period. It was a very limitative market strategy, as it allowed to cover just a limited and local market. Customers had to give back the empty containers, in order to re-use them and taking low products' costs; for this reason the distribution could not cover big distances.
The first evolution of this market strategy came with the no returnable glass bottles, as it let customers free from the return obligation. Anyway also this solutions was limitative for market expansion; in fact, once exceeded the return policy, transport costs were still high for the glass containers and to not make the price increase too much, market distances still remained limited.

The company invested in innovative technologies to expand its core market in all the country and finally in 80's was the first to introduce in Italy the PET bottles. This was the real great innovation and the success factor for the company. It was a great revolution for bottling industry: the weight, the volumes, the fragility and the costs were drastically reduced. PET containers allowed the company to expand itself to all the country market, and moreover, out of Italy.

If at the beginning PET bottles were imported from Japan and USA, soon the company realized the strategic importance of this technology and decided to incorporate bottles production operations in its production processes. Completely independent from container design, production, till sale, the company became one on the pioneer of its market; with the time, it was also able to construct machines and stamps by itself.

The core business aim was, and still is, to offer to customers a high quality product, with high innovation technology and flexibility in production, at a competitive cost.

In 1984 the company started to expand itself; it stipulated an accord with Cadbury Schweppes International to produce and deliver in Italy their products. In 1988, another big commission was done with Pepsi and Co. International. The partnership with these two big companies was fundamental to reach markets over Italian boundaries and make the brand international. The company was in its core expansion years and many automatic production lines were constructed in these years. In 1997 a factory was open in Spain, near Valencia, named *Fuente Primavera;* at the same time another one was acquired in Dominican Republic, with the brand *Agua Santa Clara*. Moreover, one factory was opened also in Poland named Polska Woda. The little local factory reality was far in the owner memories, the company was a real multinational corporation.

Also in Italy other factories were located around the country to be nearest to the final consumer. One was Gran Guizza S.p.A., located in Popoli (Pescara) and another was Alpe Guizza S.p.A., located in Biella (Torino).

Recently it acquired two plants, in south Italy, as Viggianello fonte del Pollino S.p.A. and Fonte Cutolo Rionero in Vulture s.r.l. The expansion in Italy is the confirmation of the leader role of the company in the country market. Thanks to its expansion abroad and its joint venture with Pepsi and Co. and Schweppes, more plants were opened also in France, Belgium, Hungary and Germany.

A second technological revolution invested the company in 1993, as it was the first to introduce the beverage production without preservatives in aseptic rooms; company focus on technology and innovation confirmed its leader role and its customer oriented business goal.

Nowadays, the business goals of the company are oriented to environmental sustainability world, aiming to be a sustainable industry. Investments about new technologies and innovations are focused on PET reduction, Production process optimization and energy consumption decreasing, studying the Life Cycle Assessment (LCA).

3.1.2

The Products

Company turnover is nowadays around €700 million, with 1800 employees and a market presence in 98 countries (2013).

It covers a large number of products that could be divided into:

1. Still and Sparkling Water from different sources:
    a. San Benedetto
    b. Guizza
    c. Acqua di Nepi
    d. Primavera

e. Vivia

2. Sparkling beverage as:
   a. Coke
   b. Orange juice
   c. Tonic water
   d. Chinotto
   e. Others
3. Still Beverage
   a. Fruit Juices
   b. The
   c. Hydrosaline supplements beverage
4. Aperitives
5. Sportsdrinks

In addiction there are all products of the partnerships brands, as Schweppes, Pepsi, Ferrero, Danone and so on.

Containers can be divided into three typologies, as:

- Glass bottles
- PET Bottles
- Cans

Finally, there are also many formats to consider, for example 1L, 2L, 1,5L, 0.5L, 0.4L, 0.33L, 0.25L, 0.75, 0.6L, etc.

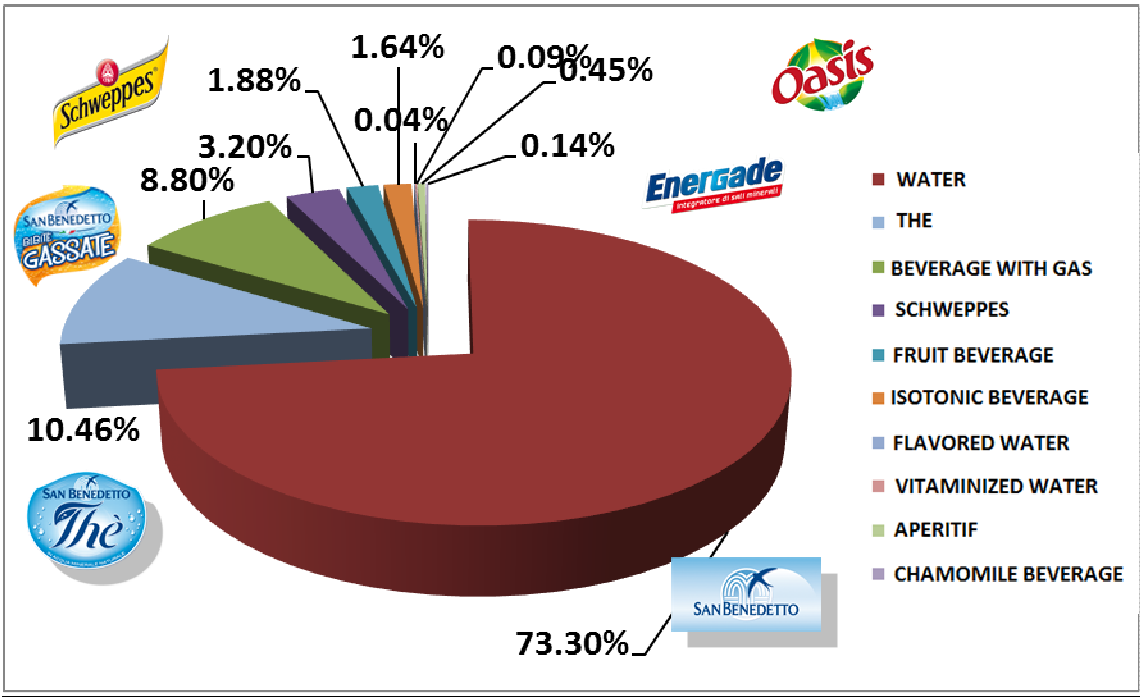


Figure 3.1 Acqua Minerale San Benedetto Products

The numerous products, formats and bottles' material make the production mix very complex and hard to optimize; often customers' demand required high variety, little quantities and shot delivery time. In order to be effective in the market and satisfy the demand, the company invests time and resources in optimizing it production.

OEE index is used to measure production performance and evaluate the forecasting for customers; to increase OEE and optimize equipment performance is the core aim for maintenance function.

In this context, a TPM implementation project is carried out.

3.2 The Pilot Line – Line D

Line D produces mineral water in 1.5L format; the products' mix depends on the type of label, the pallet size, the spring and the water typology as still or sparkling.

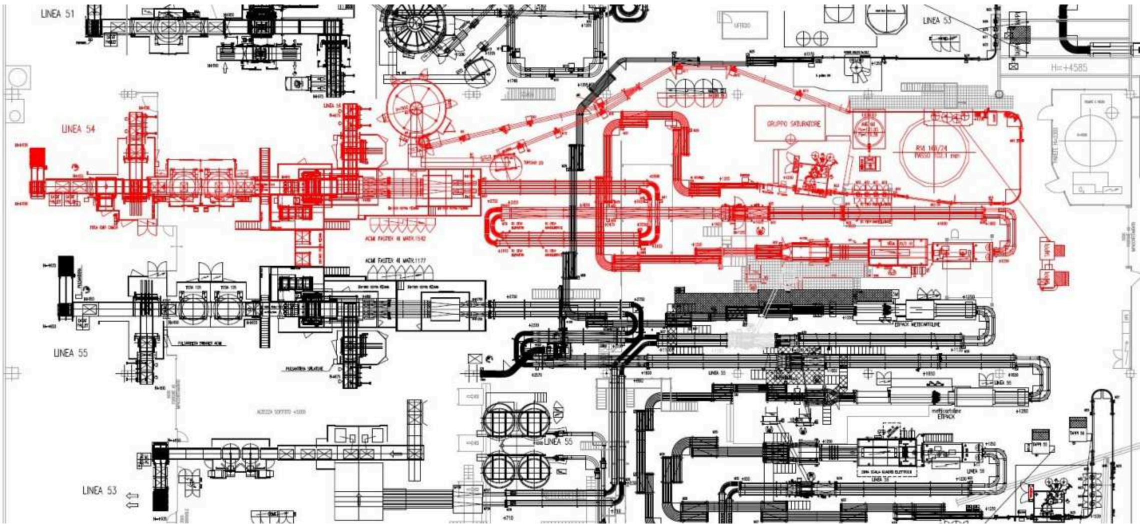


Figure 3.2 Line D layout

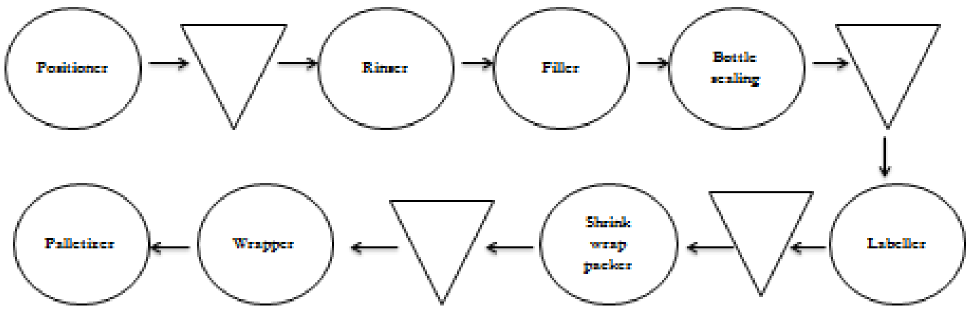


Figure 3.3 Line D - Scheme

It produces on average 15 million bottles per month, at an average rate of 26.000 bottles per hour. It is composed of 8 main working stations, as the positioner, the rinser, the filler, the plug applicator, the labeler, the shrink-wrap packer, the palletizer and the wrapper. Machines are related each other by transport systems. Moreover, along the transports are located specified controller machines that reveals scraps, as lower or higher water level, pollutants' materials, plug and label presence, format conformity, and so on. In addition, products tests are made frequently by quality staff to check the product; these test are destructive as the product, even if is good, is rejected. Below are described the eight principle working stations of the bottling line.

3.2.1

The Positioner

The positioner is the first machine of the bottling line; its function is to take the bottles in order to the conveyors transport systems. In fact bottles arrive randomly from the production area, through transport tapes, and need to be oriented to enter in the filling process.

The machine functioning principle is based on the idea of the "*vibrant cups*" used to feed working stations in the assembly industry. Bottles are loaded in a big rotating overturned cone, in which are located particular traps at the bottom. Traps are based on a pneumatic principle that allows bottles to fall in the appropriate cells with the "neck" on the top. After that, the containers are taken out by a star structured mechanism and send to the conveyors. There is also a pneumatic controller that rejects non conformed items. Line D is composed by two positioners working in parallel, as their single speed is lower than the filler one; the filler speed is the one that determines the line

Figure 3.4 The Positioner

throughput rate. Even if they are in parallel, the rule is that principally works positioner number 1, and positioner number 2 is activated when is needed.

3.2.2

The Rinser

The rinser is the first machine of the so called "*wet zone*", as it is called that part of the process in which bottles are still open and are prepared to be filled. It is composed principally by a big circular structure with two star structured mechanism: one used to bring bottles inside the machine and one to bring them out.

Its function is to wash and disinfect the bottles before the filling phase. An endless screw is located at the ingress of the machine to separate bottles and help pliers to take them. Then pliers, located around the circular structure, bring the bottles in the washing process that is the disinfectant insertion and rinsing. These processes are made in the rotative structure: in the first half rotation bottles are upright in order to receive the disinfectant; while in the second rotation phase, they are downright in order to be rinsered and

Figure 3.5 The Rinser

unloaded. Finally they re-entered in the process upright.

3.2.3

The Filler

The filler is the core workstation of the line, the bottleneck, as its speed determines the total throughput of the line. Its function is to put the product in the containers; it is composed by a rotative structure (as the rinser) with 170 filling valves, one for each bottle. Its speed depends by the format of the line and the number of valves.Line D has one of the biggest rinser of the factory.

As in the rinser, the entering process is similar, with a star structured mechanis for entering and leaving the machine, and an endless screw to adequately separate the bottles in the bigger rotative structure with the valves. Each single bottle is fixed to the valve through a support in the bottom and a garket on the top. The filling valve enter in the bottle and,

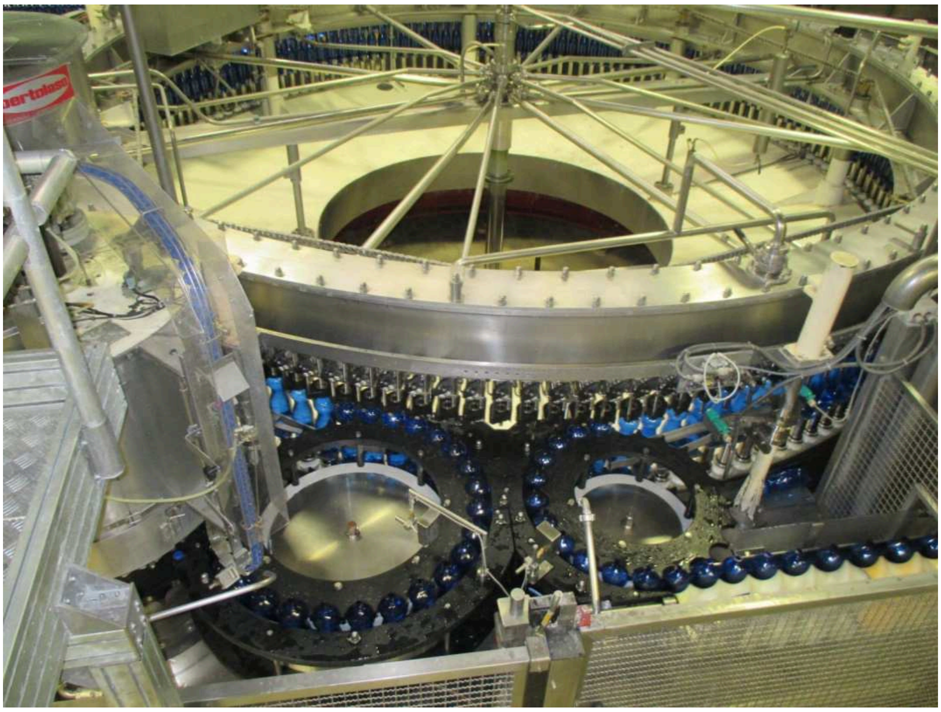


Figure 3.6 The Filler

following a pressure principle to guarantee a laminar flow, it fills the container.
The filler is checked in ingress by an appropriate control system that blocks bottles if there are some allarms, like jammed items, defects, or mashed bottles.

The filler is one of the most stressed machine, with the plugger and the rinser, in terms of disinfectant and washing process, to guarantee the higher level of hygenic and alimentary security. For this, its maintenance is strongly related to quality controls, and a preventive maintenance action plan is preferred to avoid safety risk.

3.2.4

The Plug Applicator

The Plug applicator is located immediately after the filler, connected by another star structured mechanism. Its function is to apply the plug and close the bottles and, as the two previous machines, it is mainly composed by a rotative structure. Located after the rinser and the filler, it closes the "wet zone", sealing the bottles. Plugs are loaded in a hopper and heated to a predefine temperature. In this way, it is easier to fix them on the bottle. They follow an oriented route till the neck of the bottle that is located in order waiting for being close. In fact, while plugs are loading from the upper part of the machine, bottles enter in the rotative structure and are fixed by a particular "stopper collar". Then, while they are rotating, a mechanism called "plugger head" seals the bottle and closes the wet process.

Figure 3.7 The Plug Applicator

The "plugger head" is a very critical part of the process, as it is in continuous contact with the product and need to be maintain frequently to be high performing. It requires calibrating actions, cleaning and frequently replacements of the spare parts more stressed by the disinfectants.

3.2.5

The Labeler

The labeler is the first machine of the "dry zone" as it provides to apply the label around containers. The ingress in the machine of the bottle is regulated by the same previous systems as the endless screw and the star structured mechanism. The labeller is a rotative machine, but is more little then the previous ones, as it is faster. When the bottle is inside the machine, it is located in a rotative flat and blocked by a pressure mechanism. It follows the circumference of the machine, rotating on itself. Around its route, it meets the glue working group, that put the glue on the bottle; then there is the label coil, that apply the cutted label where is located the glue. Finally there are some brushed located near the exit to fix the label. The complexity of the

Figure 3.8 The Labeller

labeler is related to the prsence of various delicate working group as the glue and the cutting one. Their clean is fundamental for the correct functioning of the machine and to respect the quality standards of the project.

3.2.6 *The Shrink Wrap Packer*

The shrink-wrap packer is the machine that provides to make the primary packing, the bundle that could be composed by 4, 6 or 12 bottles. In line D it is composed by 6 bottles. The machine is divided into two macro processes:

1. The bundle composition, in which bottles are taken in order and the shrink-wrap film is applied;
2. The film retraction in the oven

Bottles arrived in the machines untidily; a specific guide systems takes the bottles in order and divided them into predefine lines and queues. Then, a series of guides drive the bottles into the core machine and apply the film around them. Finally, the bundle enter in the oven to activate the retraction action, and then the bundle is finished.

The most delicate part of this process is the cut of the film that takes place before its positioning on the bottles. The film is very delicate and subject to temperature changings; the knife should be well clean and regulated to be performant.

Line D is also provided of a handler machine for the bundle. The function of this machine is to apply the handler to the bundle; it is a secondary machine and it is used just when the format require it. As it works periodically, and its downtime is determinate by production, its maintenance is well hide during production hours.

Figure 3.9 The Shrink Wrap Packer

3.2.7

The Palletizer

The Palletizer is at the end of the production line, and it collocates the bundles arriving from the shrink-wrap packer in order on the pallet, to be placed in the warehouse or loaded in the trucks. Bundles arrives from the previous station and are ordered by a series of guided tapes. A series of ferrules, commanded by a software, located bundles to create a layer. Then a session of the machine is dedicate to the layers placement on the pallet, separate by apposite paper.

Figure 3.10 The Palletizer

The complexity of this machine is related to its composition of numerous part. In fact there is a part dedicate to the pallet warehouse, that should be accessible by the fork lifts; a part dedicate to the paper layer, with a delicate system that pick up them to the pallet; a series of transport that collocate the bundles till the pallet; and finally the joint area, where is made the final pallet.

This machine, as in many industries, is in the final part of the production; it is often located out or in semi-covered zones and so is more affected by weathering penalties In Line D, it results as the most critical machine of the line.

3.2.8

The Wrapper

Finally, the working station that close the production process is the wrapper that apply the final and secondary packaging on the products. Pallets arrive on a roller transport system and stopped in the middle of the machine.

The film is located on the upper part of the pallet and then starts to rotate around, closing the final products. As it is slower, there are two wrapper stations at the end of the line D.

Figure 3.11 The Wrapper

It criticalities are the same of the palletizer, as it is at the end of the production system; anyway, it is less complicate then it and the presence of two machines decreases its criticality.

3.2.9 *Transport Systems*

Transport systems are secondary in automatic production systems, as they do not cover a specified process function. Anyway their presence, size, allocation and speed is fundamental to the correct functioning of the line. In fact, in food industry, the have the double function of handling materials and store items.

They could be divide into three main typologies:

1. Conveyors, that transport the empty bottles
2. Transport tape, that transport the full bottles and the bundles
3. The Roller transport system, that transport the pallets

Figure 3.12 The conveyor

The most critical transports are represented by the second type, the transport tapes, as the more used and diffused in the line and, as it will be presented in following session, the ones that connect the most critical machines.

3.3

Project Steps

The project is divided in 7 focused steps in order to individuate inefficiency criticalities. In this paragraph are presented methods and tools used to construct the case study project, the steps followed and the techniques used for the analysis are presented.

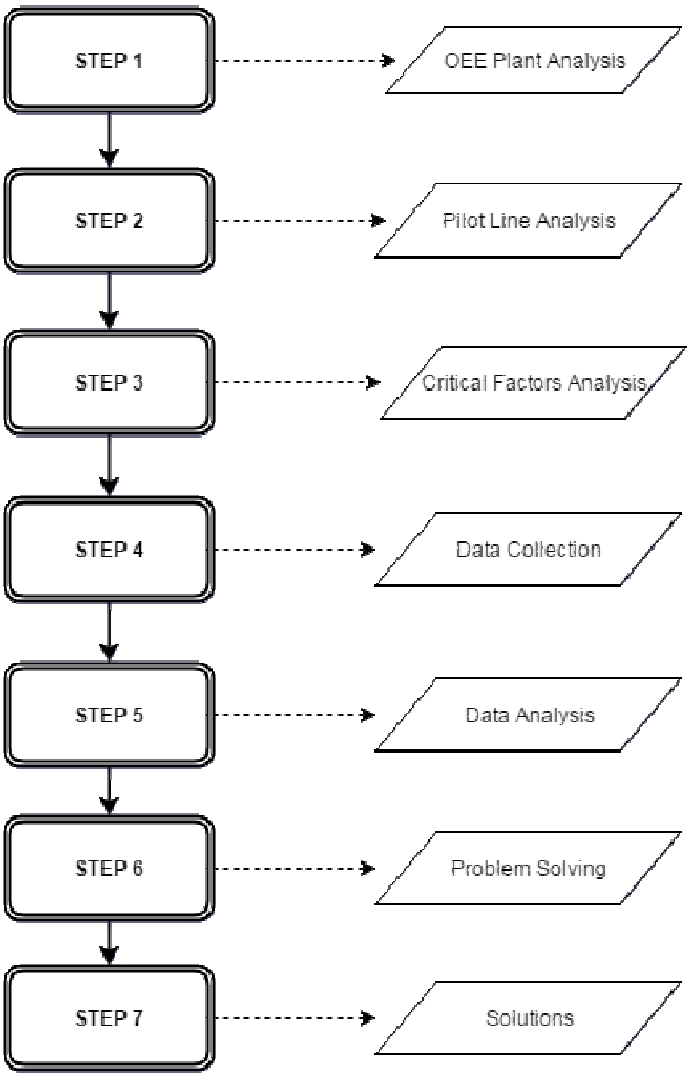


Figure 3.13 Project Steps

The project provides the following steps (Figure 3.13):

1. OEE analysis of the plant - definition of the pilot line;

2. OEE analysis of the pilot line - analysis of the most critical factors;
3. Critical factor analysis - analysis of the worst machines in terms of efficiency;
4. Data collection - tools used;
5. Data analysis - diagrams, reports and charts;
6. Problem solving - discussion and analysis of possible solutions;
7. Evaluation of solutions - decision making.

3.3.1

OEE analysis of the plant

The first step required for OEE is data analysis of the whole plant and production equipment as this is at the core of the project. OEE is the principal TPM index. The approach involves analyzing the worst production line in terms of OEE to make highlight the major factors and achieve visible benefits. In order to determine the pilot line for the project it is necessary to calculate the mean OEE for each production line over a period of time put them in order.

$$\text{Mean OEEn} = \sum_{i=m}^{i=1} \frac{\text{OEEi}}{m} \quad (5)$$

Where n = number of production lines/systems and m = number of relevant periods (for example months). The production system with the lowest OEE is identified as the pilot line.

3.3.2

OEE analysis of the pilot line

Having identified the pilot line the next step is to analyze the principal cause of inefficiency of the line. In other words it is necessary to study the OEE of the line in order to identify the most critical contributor to its poor performance.

OEE is composed of three parameters:

1. Availability
2. Performance
3. Quality

Each parameter is influenced by the following losses:

- Set-up (availability)
- Failures (availability)
- Micro downtime (performance)
- Speed loss (performance)
- Defects (quality)
- Material lack (quality)

Through data it should be possible to identify the major loss by inspecting each of these six losses separately and concentrating the study on the worst critical factor.

3.3.3

Critical factor analysis

The critical factor obviously influences the OEE of the whole line but not to the same extent. This step provides to analyze the machine or work station most affected by the critical factor. Line D presents micro downtime as the major cause of inefficiency, so the third step involves an analysis of the machines most critically affected by micro downtime in order to acquire a representative range of information.

3.3.4

Data collection

Once the major loss and the most affected equipment have been identified it is necessary to construct a relevant data collection process. To carry out a data collection on it is important to define which indexes and reports will be produced from the analysis of the required data. Then it is required to define the time period over which data will be collected, who will collect data and who will manage the database. Sometime data are collected yet, but in different database; otherwise it is require to construct a project on field to collect the required information.

3.3.5

Data analysis

The fifth step involves the analysis of the data collected. This is the core of the project and aims to identify the specific criticalities in order to carry out possible solutions. Once data are collected for a relevant period of time, they can be analyzed with various tools, such as:

- Pareto diagrams
- TTR-TTF diagrams
- Probability distributions
- Radar charts
- Cause-effect diagram
- Other graphics

3.3.6

Problem solving

After data are collected and analyzed a number n problems and criticalities will be identified. Each one of these needs to be analyzed and solutions proposed. There are various techniques that could be applied at this stage such as brainstorming, PDCA and simulation models. In this case brainstorming was the method principally used and this involved production staff, technicians and the engineering group. Using this process it is expected to be able to identify possible solutions for eliminating or reducing the causes of inefficiency and improving production flow.

3.3.7

Solution - cost benefit analysis

The final step is dedicated to the evaluation of the solutions that emerge from the previous steps. A cost-benefit analysis of the investments is carried out to support the management in the decision-making process.

In fact once solutions have been proposed, it is necessary to evaluate their costs and to compare them with the recoverable OEE, the contribution margin and the payback period.

Following data are required:

- Cost of investment [€]
- Cost of labor [€/h]
- Contribution margin [€/pz]
- Increase in production [pz/year]
- Fixed costs [€]

With these data is possible to calculate the NPV (Net Present Value) and to calculate the payback period as the time to recover the cost of the investment.

$$\text{NPV} = \sum_{t=0}^{n} \frac{Rt}{(1+i)^{t}} \qquad (6)$$

Where:

- R is the net cash flow referred to time t
- t is the time of the cash flow
- i is the discount rate

It is also proposed the construction of an index to evaluate investments in comparison to recoverable OEE.
It is required to calculate:

1. The expected OEE recoverable from the improvement proposed.
2. The cost of the new technology or of the technical modification proposed to solve the production flow obstacle.

These two parameters are compared in order to construct an index to support managers in their decision. The question is: "*Is the cost of investment reasonable given the OEE recoverable?*" . The CPI (*Cost Performance Indicator*) is constructed as follow:

$$\text{CPI} = \frac{\text{Cost Equipment Improvement}[€]}{\text{OEE Improvement }[\%]} \; . \qquad (7)$$

This index carries out the advantages (or not) of an investment in terms of OEE benefits; the lower the CPI, the better. In fact, a low CPI identify those investments that are cheaper in terms of €/OEE, but at the same time provides a great OEE improvement.

3.4

Project Implementation

This paragraph summarizes the phases followed in the project implementation, showing data collection, analysis and results.

3.4.1

OEE Analysis

Table presents the analysis of the OEE index of the whole plant, covering a

LINEA D	giu-16															
Giorni / Causali di arresto	25		26		27		28		29		TOT TEMPI PERSI	% TOT TEMPI PERSI	TOT GUASTI / SET-UP	% GUASTI / SET-UP	TOT MICROF.	% MICROF.
	tot	g/ s	tot	g/ s	tot	g/ s	tot	g/ s	tot	g/ s						
Silos	3				2		3		41		91	0,3%	0	0,0%	91	0,4%
Linee aeree	19		31		39		45				489	1,8%	0	0,0%	489	1,9%
Depallettizzatore											0	0,0%	0	0,0%	0	0,0%
Decassettatrice											0	0,0%	0	0,0%	0	0,0%
Radrizzatori	6						6				212	0,8%	114	0,4%	98	0,4%
Lavatrice											0	0,0%	0	0,0%	0	0,0%
Lavacasse											0	0,0%	0	0,0%	0	0,0%
Sciacquatrice 1											31	0,1%	0	0,0%	31	0,1%
Sciacquatrice 2											0	0,0%	0	0,0%	0	0,0%
Tunnel di sterilizzazione											0	0,0%	0	0,0%	0	0,0%
Sciacquatrice dopo tunnel											0	0,0%	0	0,0%	0	0,0%
Piattaforma disinfettante											0	0,0%	0	0,0%	0	0,0%
Piattaforma acqua sterile											0	0,0%	0	0,0%	0	0,0%
Cip											0	0,0%	0	0,0%	0	0,0%
Piattaforma acqua surriscaldata											0	0,0%	0	0,0%	0	0,0%
Centrale aria / Flusso laminare											0	0,0%	0	0,0%	0	0,0%
Ispettrice											0	0,0%	0	0,0%	0	0,0%
Sala sciroppi automatica											0	0,0%	0	0,0%	0	0,0%
Premix											0	0,0%	0	0,0%	0	0,0%
Pastorizzatore prodotto											0	0,0%	0	0,0%	0	0,0%
Riempitrice 1									5		33	0,1%	0	0,0%	33	0,1%
Riempitrice 2											0	0,0%	0	0,0%	0	0,0%
Azoto liquido											0	0,0%	0	0,0%	0	0,0%
Trattamento tappi											0	0,0%	0	0,0%	0	0,0%
Tappatrice 1											75	0,3%	0	0,0%	75	0,3%
Tappatrice 2											0	0,0%	0	0,0%	0	0,0%
Controllo livello											0	0,0%	0	0,0%	0	0,0%
Espulsore bottiglie			20								30	0,1%	0	0,0%	30	0,1%
Etichettatrice 1	36		63		24		68		68		1150	4,1%	0	0,0%	1150	4,4%
Etichettatrice 2											0	0,0%	0	0,0%	0	0,0%
Forno retrazione											0	0,0%	0	0,0%	0	0,0%
Datatrice											35	0,1%	0	0,0%	35	0,1%
Incassettatrice											0	0,0%	0	0,0%	0	0,0%
Cluster pack											0	0,0%	0	0,0%	0	0,0%
Twin pack											0	0,0%	0	0,0%	0	0,0%
Termoformatrice											0	0,0%	0	0,0%	0	0,0%
Avvolgitrice 1	97		96		42		41		17		716	2,6%	0	0,0%	716	2,8%
Avvolgitrice 2											0	0,0%	0	0,0%	0	0,0%
Manigliatrice	18		6		6				5		456	1,6%	120	0,4%	336	1,3%
Cartolinatrice	9										40	0,1%	0	0,0%	40	0,2%
Etichettatrice fardello											0	0,0%	0	0,0%	0	0,0%
Cartonatrice											0	0,0%	0	0,0%	0	0,0%
Pallettizzatore	10				22		28		51		860	3,1%	454	1,6%	406	1,6%
Mettifoglio											0	0,0%	0	0,0%	0	0,0%
Fasciatrice	41	40									126	0,5%	80	0,3%	46	0,2%
Twinner											36	0,1%	0	0,0%	36	0,1%
Reggettatrice											140	0,5%	100	0,4%	40	0,2%
Datatore bancali			8						23		127	0,5%	31	0,1%	96	0,4%
C.M.A.											0	0,0%	0	0,0%	0	0,0%
Trasportatori					8				73		151	0,5%	0	0,0%	151	0,6%
Altro											0	0,0%	0	0,0%	0	0,0%

Figure 3.14 OEE data collection schedule

period of one year. Data are daily collected by the production operators in a common database, following specific procedures.
For each day the following are noted:

1. time loss for machine downtime, distinguishing between failures and micro downtimes;
2. time loss for set ups;
3. time loss for lack of raw materials;
4. time loss for preventive maintenance (planned downtime)
5. time loss for lack of resources
6. planned and final output

Figure 3.14 shows the downtime data collection of a line. In the first column are indicated the various working stations of the line. That, for each machine and for each day is signed the total downtime (white column) and the failure time (grey column). At the end, the three final columns summarize data of the month: for each machine is indicated the total downtime expressed in minutes and percentage (violet column), the failures (yellow column) and the micro downtime (blue column).

	gen-13	feb-13	mar-13	apr-13	mag-13	giu-13	lug-13	ago-13	set-13	ott-13	nov-13	dic-13
Totale tempo assegnato	19966	9218	17075	17099	20886	19017	21354	19620	15092	16750	11486	15583
Tempo disponibile lavoro	26427	12584	24151	22704	27290	27400	29250,2	29098	20815	23878	17589	22965
Tempo funzionamento	25277	12226	22733	21709	26103	25776	27812,2	27269	19431	21878	16337	20606
DISPONIBILITA'	95,65%	97,16%	94,13%	95,62%	95,65%	94,07%	95,08%	93,71%	93,35%	91,62%	92,88%	89,73%
EFFICIENZA	78,99%	75,40%	75,11%	78,76%	80,01%	73,78%	76,78%	71,95%	77,67%	76,56%	70,30%	75,62%
QUALITA'	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
OEE	75,55%	73,25%	70,70%	75,31%	76,53%	69,41%	73,00%	67,43%	72,50%	70,15%	65,30%	67,85%

Figure 3.15 OEE calculation database

Finally Figure 3.15 shows how the company uses previous data to calculate the OEE. Knowing the following times as:

- Planned Production time ("Totale tempo assegnato"), that corresponds to the starting production time
- Effective production time ("Tempo disponibile al lavoro")that is affected by failures and set-ups
- Running time ("tempo di funzionamento") that is affected by micro downtime, defects, lack, etc.

With these three times the company measured the OEE of its production plant.
The quality is assumed 100% as scraps are measured a part.
The OEE plant data for one year (2013) has been analysed and can be seen in Figure 3.16; line are ordered from the lowest OEE till the higher, with fictions names for privacy reasons.

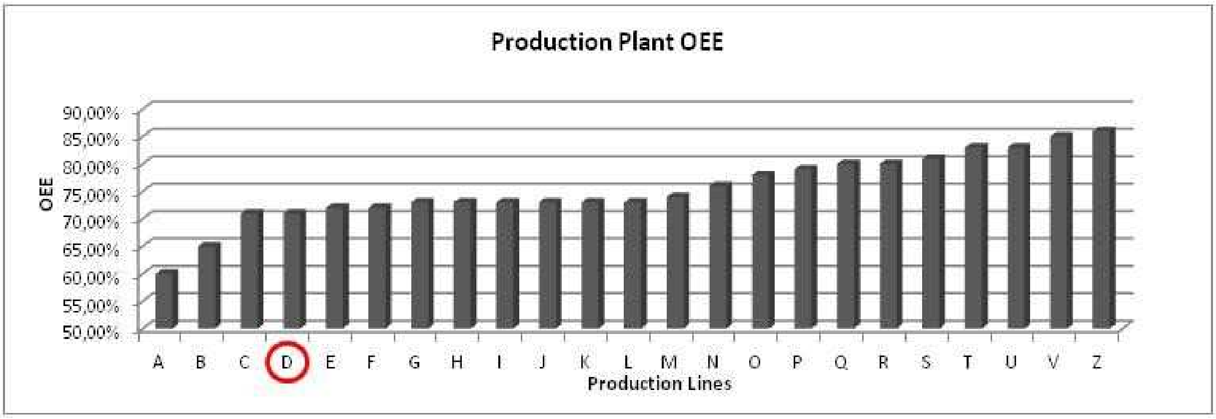


Figure 3.16 OEE Analysis of the Plant

From the graph the worst line is A. However it was soon to be taken out of commission. Lines B and C were quite new so a low OEE was to be expected. Therefore line D was chosen as the pilot line for the project.

3.4.2

Line D OEE Analysis

Line D produces mineral water in 1.5L format. It produces on average 15 million bottles per month, with at an average rate of 23.000 bottles per hour. The OEE analysis of the line aims to understand which the principal factors that most affected production efficiency are. It is a detailed OEE study, individually examining each step and its influences. Data are taken from the same database as the previous analysis, collected by the production staff. Time loss is examined for each machine and for each cause.

In the Figure 3.17the principal causes of inefficiency that affect the OEE of the pilot line are shown. These fall into the following categories:

- Failures
- Set-Ups
- Lack of materials
- Micro downtime
- Defects

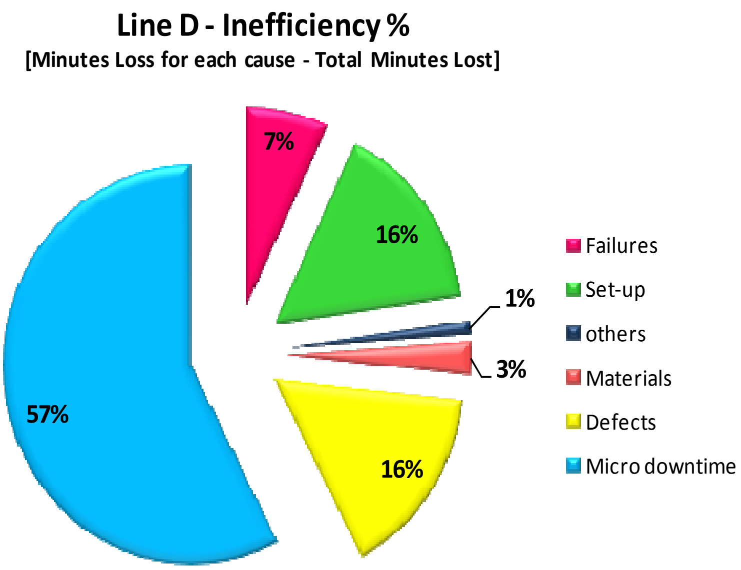


Figure 3.17 Line D Inefficiency causes: Failures, set-up, micro downtime, materials and defects

The Figure 3.17 shows in % which are the principal factors that affect the line efficiency per month. It is evident that, with an average of 57%, the principal cause is micro downtime. This means that the 57% of the line inefficiency (in terms of minutes of production lost) is caused by micro downtimes. Moreover the impact of each factor in terms of OEE% is calculated and points recoverable from each one (Table 3.1). If it were not for micro downtime the OEE could be of 87.76%. With an improvement margin of 16.2%, this points out that micro downtime is the most critical factor with the largest margin of improvement.

OEE	OEE+Loss Time	Improvement Margin
OEE (Start)	71.57 %	-
OEE + Time loss for Microdowtime	**87.78%**	**16.20%**
OEE + Time loss for Defects	76.01%	4.44%
OEE + Time loss for Set-Ups	76.01%	4.44%
OEE + Time loss for Failures	73.55%	1.98%
OEE + Time loss for Materials Lack	72.29%	0.72%

Table 3.1 OEE Recoverable for each microdowtime

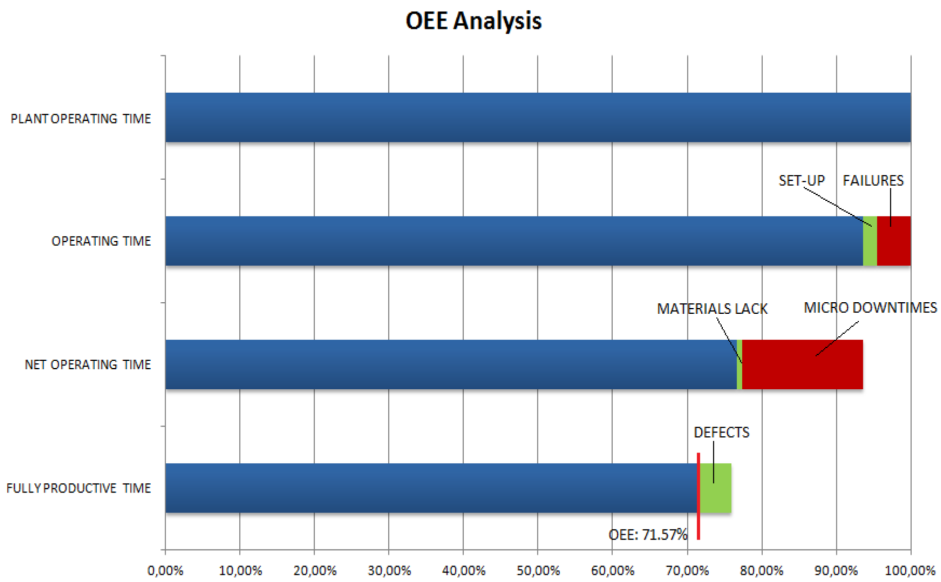


Figure 3.18 OEE Analysis graphic

In the same way, Figure 3.18 shows OEE division for each cause. Plant operating time corresponds to an OEE of 100%, representing all of the time that is theoretically planned for production. Operating time represents the residual time without time loss for failures and set-ups. The net operating time is influenced by the performance of the production systems, in terms of lack of materials and micro downtime. Finally the fully productive time is net operating time without losses in production such as defects and non-conforming products (i.e. quality of the final output). This figure highlights clearly the major impact of micro downtime on the OEE index, with the red area being the net operating time. For these reasons the analysis from here on concentrates on micro downtime.

3.4.3

Critical factor analysis

This section provides the analysis of the micro downtime inefficiency factor of the entire line in order to determine which machines are most critically affected by this inefficiency.

Figure 3.19 shows, in order of impact, the machines most affected by micro downtime. These are the palletizer (M1), the shrink-wrap packer (M2) and the labeller (M3). Anyway, from OEE database it was no possible to understand which micro downtimes affect machines, how often and their duration in terms of Time to Failure (TTF) and Time to Repair (TTR).

Having identified the most critical machines, the next step will be to collect data about the causes of micro downtime of these.

Machines Names	
Machine N°1	Palletizer
Machine N°2	Shrink wrap packer
Machine N°3	Labeller
Machine N°4	Positioner 1
Machine N°5	Handler Machine
Machine N°6	Data Machine
Machine N°7	Positioner 2
Machine N°8	Strap Applicator
Machine N°9	Filler
Machine N°10	Wrapper
Machine N°11	Transport

Table 3.2 Machines codes

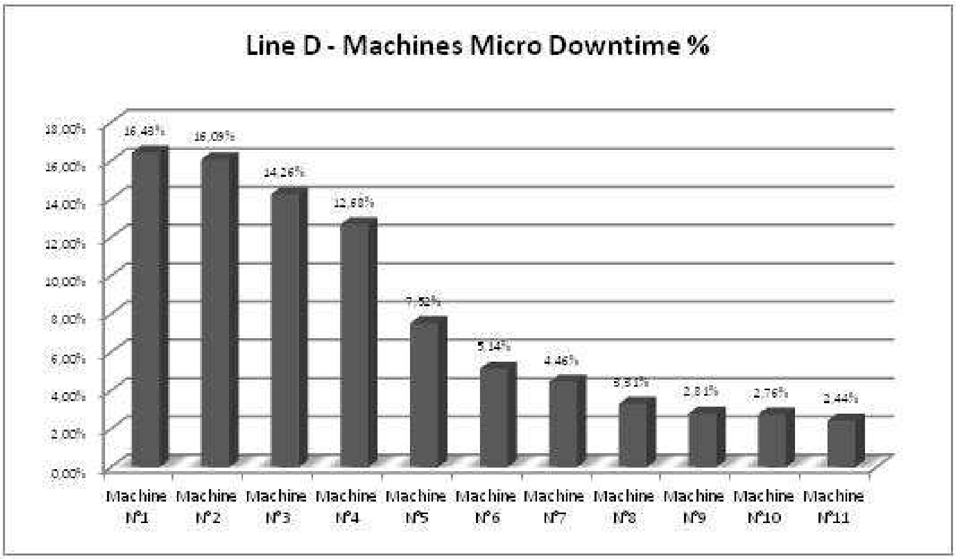
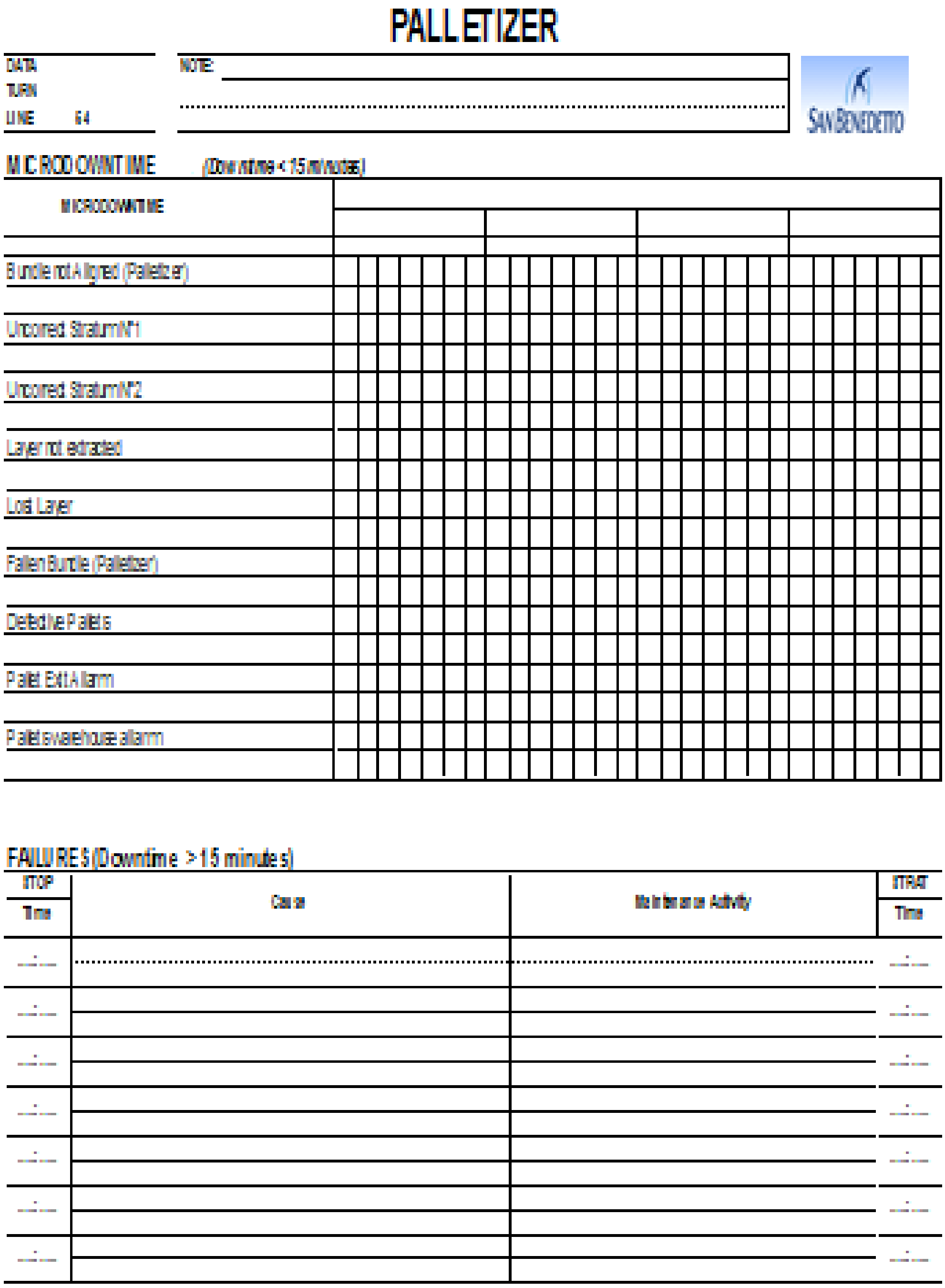


Figure 3.19 Line D - Micro downtime per machine %

3.4.4

Data Collection

This step aims to study in detail micro downtime of the three most critical machines. For each machine the principal causes of micro downtime has been identified by speaking with both production and maintenance staff.



PALLETIZER

DATA
TURN
LINE 64

NOTE:

MICRODOWNTIME (Downtime < 15 minutes)

MICRODOWNTIME

Bundle not Aligned (Palletizer)
Uncorred Stratum N°1
Uncorred Stratum N°2
Layer not extracted
Lost Layer
Fallen Bundle (Palletizer)
Defective Pallets
Pallet Exit Allarm
Pallets warehouse allarm

FAILURES (Downtime > 15 minutes)

STOP Time	Cause	Maintenance Activity	START Time
..:..			..:..
..:..			..:..
..:..			..:..
..:..			..:..
..:..			..:..
..:..			..:..
..:..			..:..

Figure 3.20 Palletizer Data Collection Sheet

Working with them, a data collection form was produced. This summarized the causes of micro downtime for each machine. For each cause the frequency and the duration were recorded. Figure 3.20 shows the data sheet for the palletizer: the upper section is dedicated to little stops shorter than 15.minutes (micro downtime); most common micro downtime were identified and listed in the paper to facilitate data collection. in the bottom part, instead, bigger downtime were reordered, defined as failures. Data were collected by production operators and by the supervisor of the project for a period of two months (March and April) for 8 hours per day with random shifts and days of the week.

Working Station	Micro Downtime	Frequency	Duration [min]	MTTR [min]
Machine N°3	Labeller Exit Backlog	7	4,3	0,62
Machine N°3	Data Application Error	3	10,0	3,33
Machine N°3	Label Transfer Error	1	0,2	0,17
Machine N°3	Flawed Label Reel	2	3,5	1,75
Machine N°3	Fallen Bottle in Entrance	21	12,8	0,61
Machine N°3	No Plug	1	1,0	1,00
Machine N°3	Empty Bottle	5	4,8	0,95
Machine N°3	Brush Change	1	1,0	1,00
Machine N°3	Entry Allarm	9	5,5	0,61
Machine N°3	FT System Allarm	45	29,3	0,65
Machine N°3	Label Lack	228	78,5	0,34
Machine N°3	Machine Cleaning	15	41,8	2,79
Machine N°3	Machine Regulations	34	50,8	1,50
Machine N°3	Bottles lack	170	74,7	0,44
Machine N°3	High Plug	7	2,7	0,38
Machine N°3	FT System Allarm	7	31,0	4,43
Machine N°2	Film Centering	2	2,5	1,25
Machine N°2	Double Label	67	44,4	0,66
Machine N°2	Film tensioning system Allarm	8	9,8	1,23
Machine N°2	Bottles Divider Blockage	64	28,3	0,44
Machine N°2	Mechanical Activity	4	15,0	3,75
Machine N°2	Lack in pusher bottles compacting	42	26,3	0,63
Machine N°2	Film not cutted	2	6,8	3,38
Machine N°2	Open Bundle	4	3,2	0,79
Machine N°2	Malformed Bundle	7	4,8	0,69
Machine N°2	Bundle Not Alligned (Shrink - wrapper)	5	2,2	0,43
Machine N°2	Card Allarm	79	41,9	0,53
Machine N°2	Encoder Allarm	1	7,0	7,00
Machine N°2	Fallen Product Feed Guides	338	106,5	0,32
Machine N°2	Fallen Product Pusher entry	18	20,2	1,12
Machine N°2	Fallen Product Film trasport	18	15,7	0,87
Machine N°2	Fallen Product (selection)	20	14,0	0,70

Machine N°2	Technical Tests on new film	7	10,7	1,52
Machine N°2	Film Sign search	2	0,7	0,33
Machine N°2	Film Breack	1	8,0	8,00
Machine N°2	Lower Film Trasport	31	29,8	0,96
Machine N°2	Security switch oven exit	3	5,0	1,67
Machine N°2	Film Regulation	1	5,0	5,00
Machine N°2	Sign not found for film set-up	3	2,7	0,89
Machine N°2	Film Cutting Right side	6	13,5	2,25
Machine N°2	Film Cutting Left side	2	3,0	1,50
Machine N°5	Handle brush Allarm	2	1,5	0,75
Machine N°5	Handle Change (scotch)	48	32,6	0,68
Machine N°5	Handle Change (paper)	180	100,2	0,56
Machine N°5	Air Leak Control	3	1,2	0,39
Machine N°5	Handle Application error	18	10,8	0,60
Machine N°5	Handle brush error	1	0,3	0,33
Machine N°5	Handle cut error	96	75,5	0,79
Machine N°5	Handler machine Failure	1	3,0	3,00
Machine N°5	Open Bundle (Handler)	23	17,0	0,74
Machine N°5	Bundle not alligned (Handler Machine)	25	16,6	0,66
Machine N°1	Layer Applicator (Spider) not in position	2	7,0	3,50
Machine N°1	Defective Pallets	16	18,0	1,13
Machine N°1	Pallet exit Allarm	13	7,0	0,54
Machine N°1	Layer Loading Uncorrect	2	6,0	3,00
Machine N°1	Number of Bundlers in Entrance Allarm	10	10,3	1,03
Machine N°1	Layer Fallen on Transports	16	13,5	0,84
Machine N°1	Layer not Alligned	22	19,2	0,87
Machine N°1	layer not deposited	7	5,7	0,81
Machine N°1	Layer not extracted	29	12,8	0,44
Machine N°1	Lost Layer	31	9,3	0,30
Machine N°1	Pallets Warehouse - Allarm	150	130,6	0,87
Machine N°1	Open Bundle (Palletizer)	42	48,4	1,15
Machine N°1	Fallen Bundle (Palletizer)	52	60,7	1,17
Machine N°1	Bundle Not Alligned (Palletizer)	598	253,7	0,42
Machine N°1	pallet not Alligned (palletizer Entry)	66	36,8	0,56
Machine N°1	Pallet not alligned (Divider)	46	25,0	0,54
Machine N°1	Pallet Positioner	5	3,2	0,63
Machine N°1	Uncorrect Stratum (N°1)	130	72,8	0,56
Machine N°1	Uncorrect Stratum (N°2)	182	108,0	0,59

Table 3.3 Line D - Micro downtime data: Machine, Duration, Frequency and MTTR

Table 3.3 summarized data collected in these two months. It is reported the machine, micro downtime, frequency, duration and mean time to repair (MTTR).

Then it has been confirmed the incisiveness of micro downtime in terms of frequency and duration on OEE; Figure 3.21 and Figure 3.22 show that data collected prove the criticality of the micro downtime in the first three machines, both in terms of frequency and duration.

Next paragraph is dedicated to the analysis of these data.

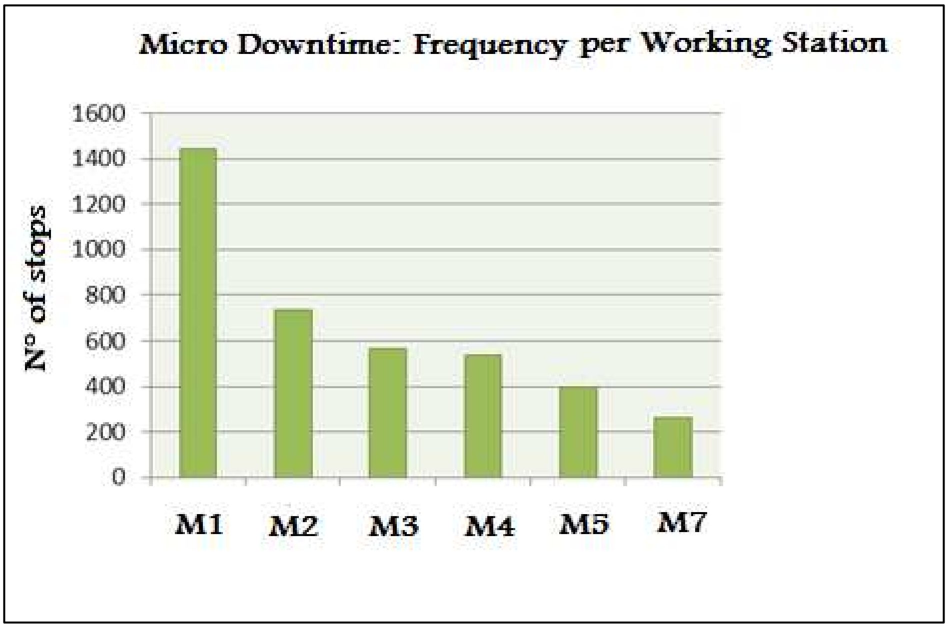


Figure 3.21 Micro Downtime - Frequency per Working Station

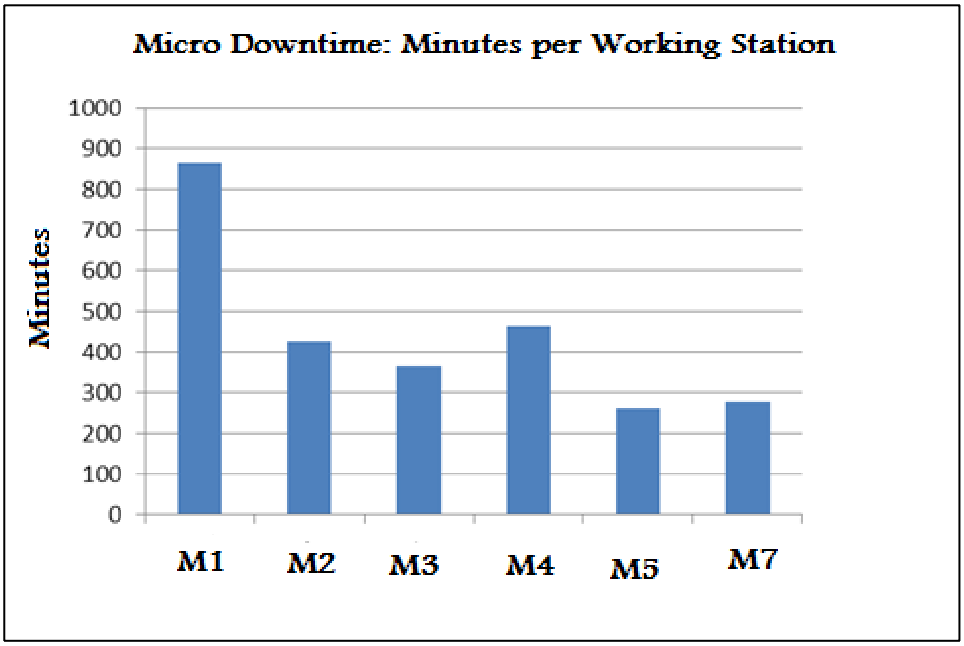


Figure 3.22 Micro Downtime - Minutes per Working Station

3.5

Data Analysis

In the following section data collected is displayed on graphs and charts.

It is used standard graphs and diagrams, as Pareto chart, Radar chart, plotting diagrams, etc.

3.5.1

Radar Chart Analysis

This section presents the radar charts constructed for the months of March and April.

Figure 3.23 and Figure 3.24show the OEE areas per day during the data collection. Blue area represents the measured OEE while the red area represent the potential OEE calculated assuming that micro downtime of the three critical machines was equal to zero. The area between the two lines, therefore, represents the improvement margin per month. It is evident that OEE improvement margin is considerable, both in March and in April.

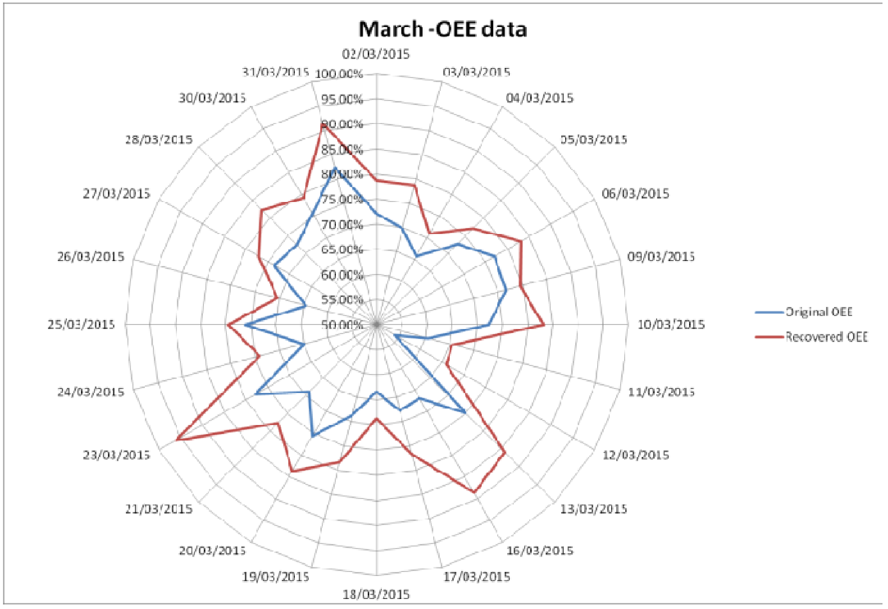


Figure 3.23 Radar Chart - OEE (March)

In the same way it has been studied the Availability of the line in the months of March April (Figure 3.25 and Figure 3.26): the green area represents the real availability, while the red one is the one it is possible have without micro downtime measured. Table 3.4 represents OEE improvement margin per month summarizing data from the radar graphics. As data was collected for 8 hours per day and the line operates for 16 hours per day, it has been assumed that micro downtime measured during the eight hours are half of that for the entire production time. In this way the possible recoverable OEE without micro downtime was calculated.

The OEE improvement margin is on average 7 % per month. This result shows that the improvement margin is significant, as supposed in the initial hypothesis.

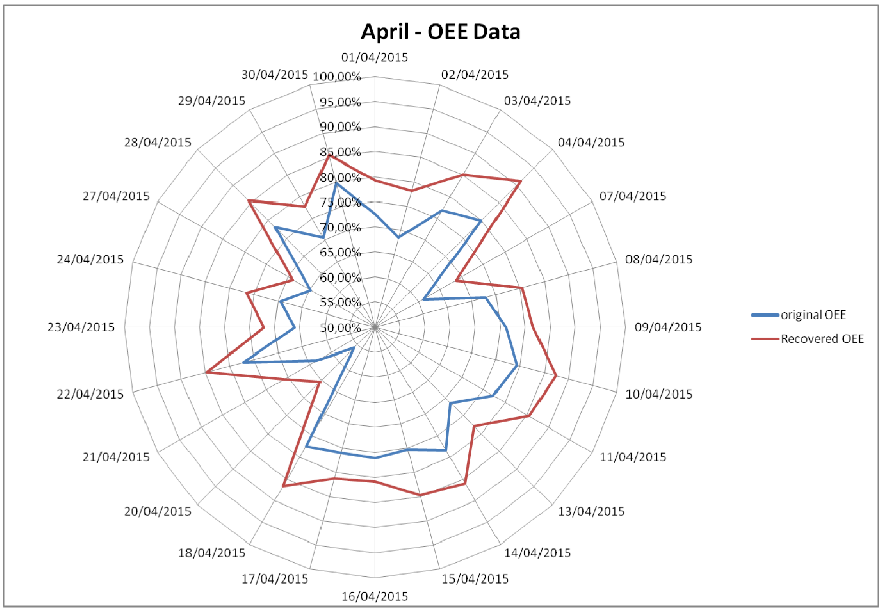


Figure 3.24 Radar Chart - OEE (April)

	March	April
Original OEE	70,62%	72,68%
New OEE	78,42%	79,95%
Improvement margin	7,80%	7,28€
Production Loss [Bottles]	1.016.509	921.264
Production Loss [Hours]	33,88	30,71

Table 3.4 OEE Improvement Margin and Production Loss per month

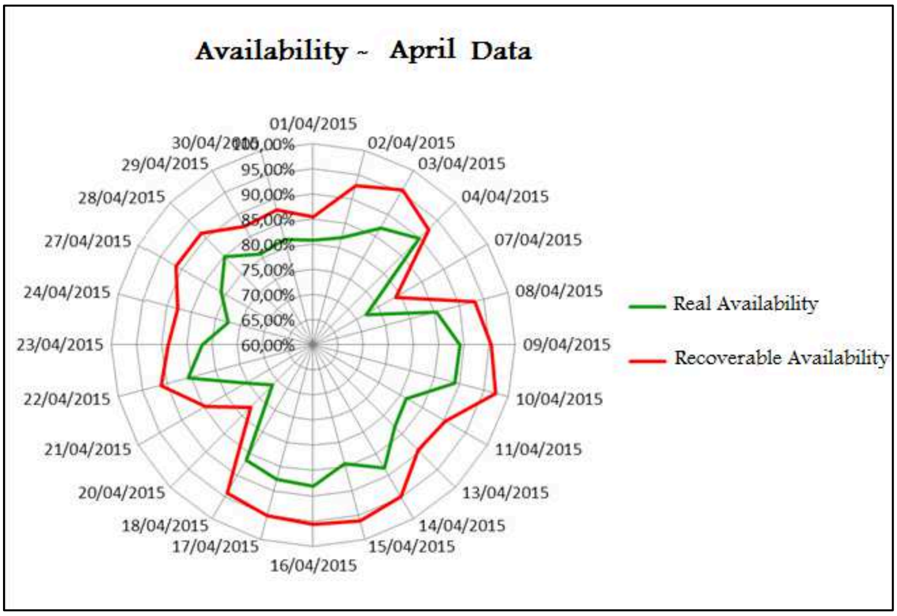


Figure 3.25 Radar Chart - Availability (April)

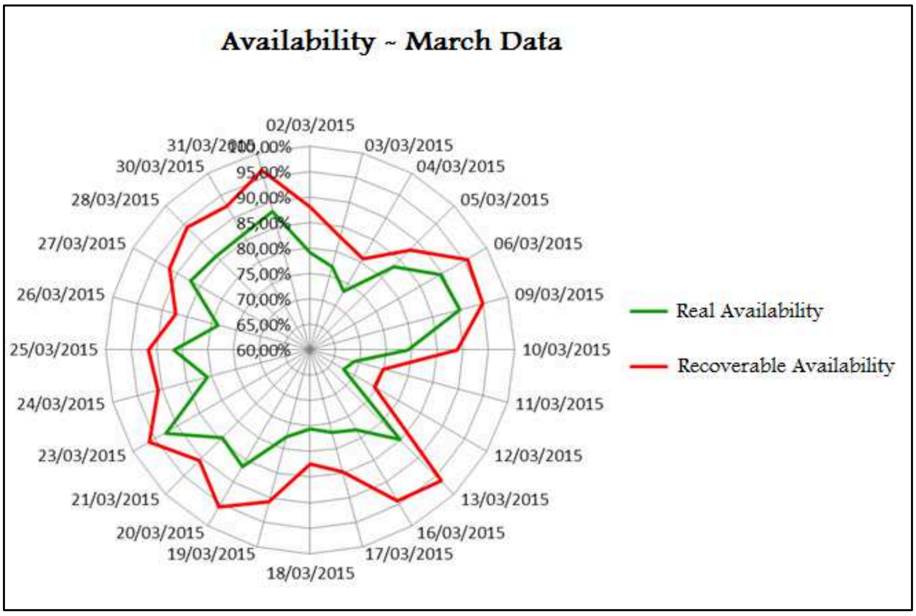


Figure 3.26 Radar Chart -Availability (March)

3.5.2

Pareto Analysis

After evaluating the effectiveness of the overall impact of micro downtime on OEE, the causes of each micro downtime were analysed in detail. It is presented now the Pareto Analysis of the Palletizer (M1), the Shrink wrap Packer (M2) and the Labeller (M3)

M1 - The Palletizer

Table 3.5 represents micro downtime identified for the palletizer. They have been identified in collaboration with production staff and maintenance technicians.

Figure 3.27shows micro downtime Pareto analysis. It indicates the impact of each process failure in terms of frequency (number of stops). Figure 3.28 presents the same analysis but showing the impact in terms of time lost (minutes) per process failure.

M1 MICRO DOWNTIME	
A	Bundle not Alligned (Palletizer)
B	Uncorrect Stratum (N°2)
C	Pallets Warehouse Allarm
D	Uncorrect Stratum (N°1)
E	Pallet not Alligned (Palletizer Entry)
F	Fallen Bundle (Palletizer)
G	Pallet not Alligned (Divider)
H	Open Bundle (Palletizer)
I	Lost Layer
J	Layer not Extracted
L	Layer Not Alligned
N	Defective Pallets
M	Layer Fallen on Transports
O	Pallet Exit Allarm
P	Number of Bundlers in Entrance Allarm
Q	Layer not Deposited
R	Pallet Positioner
T	Layer Applicator (Spider) not in position
S	Layer Loading Uncorrect

Table 3.5 M1 Micro downtime

The main causes both in terms of frequency and time loss are the same, as supposed by Pareto principle: the 20% of the causes covers the 80% of effects. In fact the first six causes are responsible for 80% of the time loss for micro downtime (81.52% in terms of frequency) as shown in Table 3.6, and 77.94% in terms of time (Table 3.7).

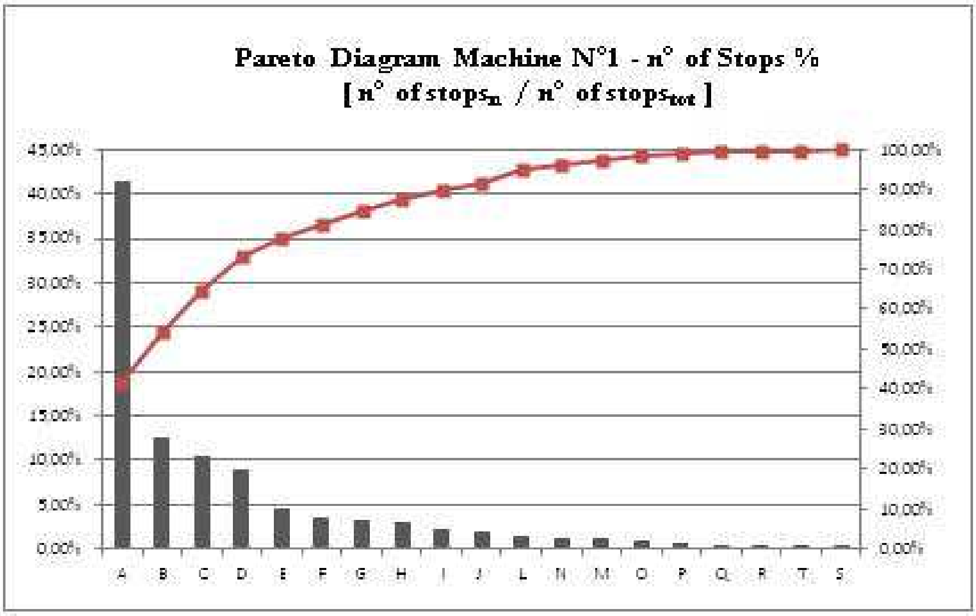


Figure 3.27 Pareto Diagram - M1 Micro Downtime Frequency

	Micro Downtime	% n° of stops	% n° of stops cum
A	Bundle not Alligned (Palletizer)	41,38%	41,38%
B	Uncorrect Stratum (N°2)	12,60%	53,98%
C	Pallets Warehouse Allarm	10,38%	64,36%
D	Uncorrect Stratum (N°1)	9,00%	73,36%
E	Pallet not Alligned (Palletizer Entry)	4,57%	77,92%
F	Fallen Bundle (Palletizer)	3,60%	81,52%

Table 3.6 M1 Micro downtime: Frequency (%)

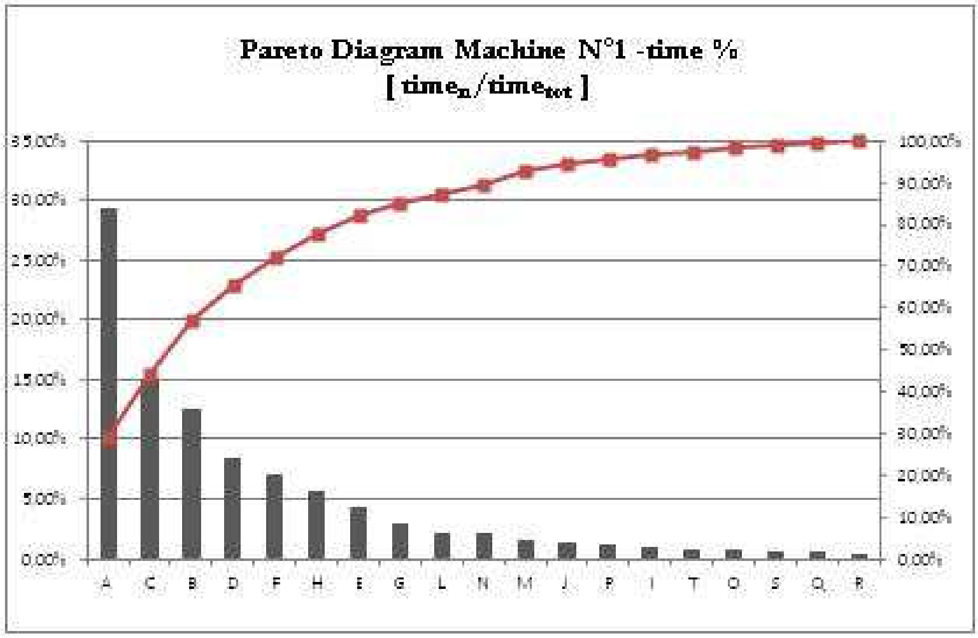


Figure 3.28 Pareto Diagram - M1 Micro Downtime Duration

	Micro Downtime	% Duration (time)	% Duration cum (time)
A	Bundle not Alligned (Palletizer)	29,33%	29,33%
C	Pallets Warehouse Allarm	15,10%	44,42%
B	Uncorrect Stratum (N°2)	12,49%	56,91%
D	Uncorrect Stratum (N°1)	8,42%	65,33%
F	Fallen Bundle (Palletizer)	7,01%	72,34%
H	Open Bundle (Palletizer)	5,60%	**77,94%**

Table 3.7 M1 Micro downtime: Duration (%)

After the analysis of the most critical micro downtime causes of the machine N°1, it has been studied the TTF and TTR of these ones to understand if these factors affected OEE in a random way or in a chronic way. In fact if TTF and TTR are situated in a specific area of the graphic, the problem is chronic and probably it could be solved. Otherwise, if there is not a specific trend, the cause is random and probably related to the physiological production operations of the line.

M2 - The Shrink Wrap Packer

In the same way has been analysed the Shrink Wrap Packer Table 3.8 represents micro downtime identified for M2.

Figure 3.29 shows micro downtime Pareto analysis in terms of frequency (number of stops) and Figure 3.30 presents the same analysis but showing the impact in terms of time lost (minutes).

M2 MICRO DOWNTIME	
A	Fallen Product Feed Guides
B	Card Allarm
C	Double Label
D	Bottles Divider Blockage
E	Lack in pusher bottles compacting
F	Top Film Transport
G	Fallen Product (selection)
H	Fallen Product Film Wrapping Transport
I	Fallen Product Pusher Entry
K	Film-Tensioning System Allarm
L	Malformed Bundle
J	Technical test on new Film
M	Film Cutting Right Side
N	Bundle not Alligned (Shrink-Wrap Machine)
P	Mechanical Activity
O	Open Bundle
Q	Security Switch Oven Exit
R	Sign not found for Film Set-Up
V	Film Centering
S	Film Cutting Left Side
T	Film not Cutted
U	Film Sign search
X	Encoder Allarm
Y	Film Breack
W	Film Regulation

Table 3.8 M2 Micro downtime

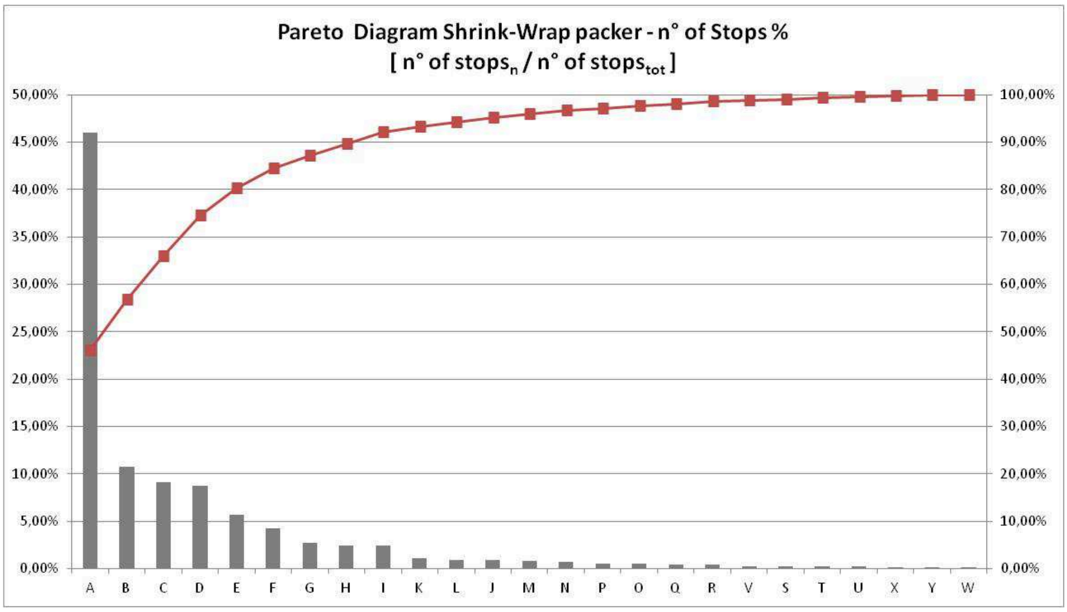


Figure 3.29 Pareto Diagram - M2 Micro Downtime Frequency

	Micro Downtime	% n° of stops	% n° of stops cum
A	Fallen Product Feed Guides	45,99%	45,99%
B	Card Allarm	10,75%	56,73%
C	Double Label	9,12%	65,85%
D	Bottles Divider Blockage	8,71%	74,56%
E	Lack in pusher bottles compacting	5,71%	80,27%
F	Top Film Transport	4,22%	**84,49%**

Table 3.9 M2 Micro downtime: Frequency (%)

In this case, the first six micro downtime cover the 84.5% of the downtime of the whole machine in terms of frequency, but not in terms of duration (Table 3.9 and Table 3.10).

	Micro Downtime	% Duration (time)	% Duration cum (time)
A	Fallen Product Feed Guides	24,96%	24,96%
C	Double Label	10,41%	35,36%
B	Card Allarm	9,82%	45,19%
F	Top Film Transport	6,99%	52,18%
D	Bottles Divider Blockage	6,62%	58,80%
E	Lack in pusher bottles compacting	6,15%	**64,95%**

Table 3.10 M2 Micro downtime: Duration (%)

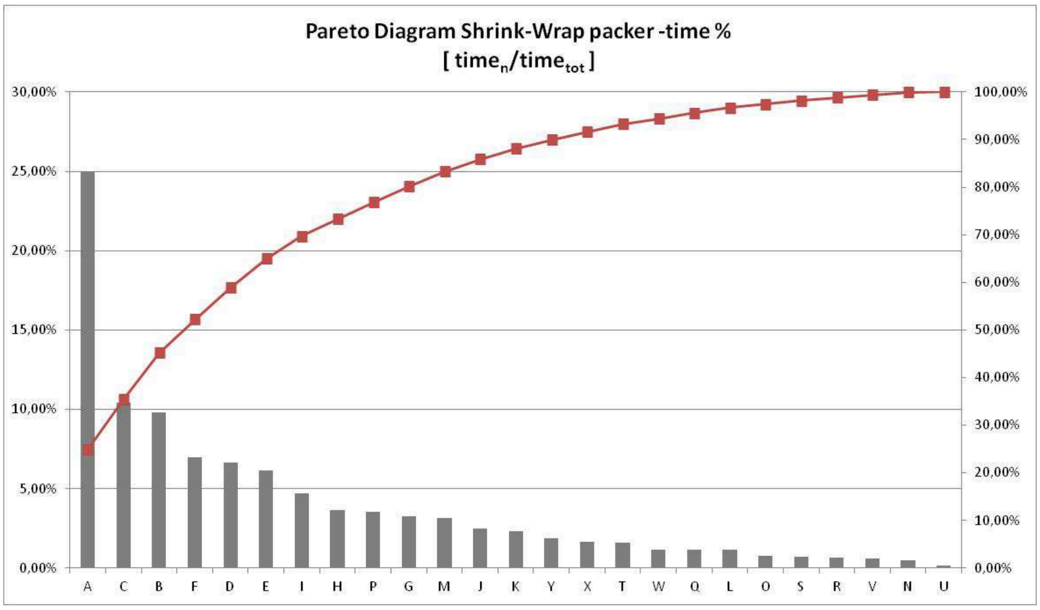


Figure 3.30 Pareto Diagram - M2 Micro Downtime Duration

M3 - The Labeller

Finally, Pareto Analysis has been done also for the Labeller.

Table 3.11represents micro downtime identified for M3.

Figure 3.31 shows micro downtime Pareto analysis in terms of frequency (number of stops) and Figure 3.32 presents the same analysis but showing the impact in terms of time lost (minutes).

M3 MICRO DOWNTIME	
A	Label Lack
B	Bottles Lack
C	FT System allarm 1
D	Machine Regulations
E	Fallen Bottle in Entrance
F	Machine Cleaning
G	Entry Allarm
I	FT System allarm 2
H	High Plug
J	Labeller Exit Blockage
K	Empty Bottle
L	Data Applicator Error
M	Flawed Label Reel
N	Brush Change
O	Label Transfer Error

Table 3.11 M3 Micro downtime

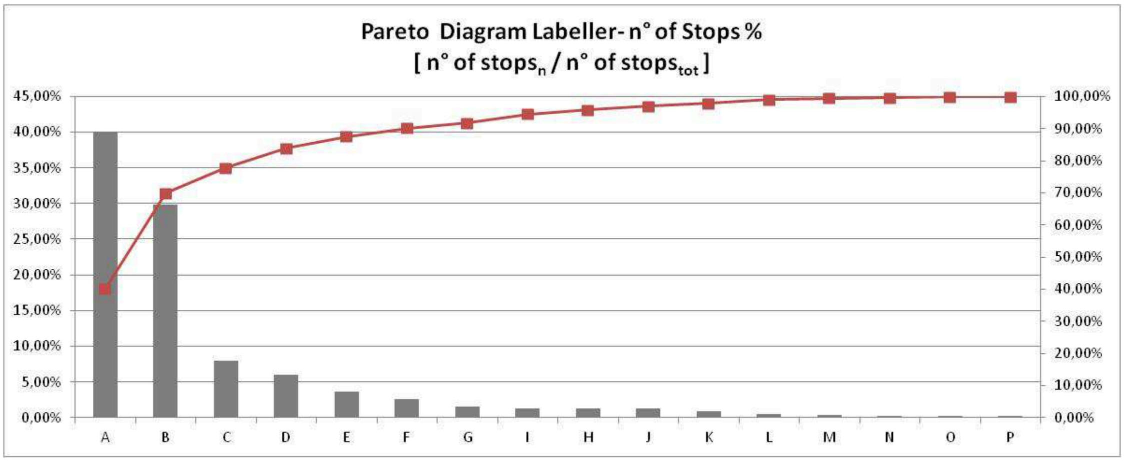


Figure 3.31 Pareto Diagram - M3 Micro Downtime Frequency

	Micro Downtime	% n° of stops	% n° of stops cum
A	Label Lack	40,07%	40,07%
B	Bottles Lack	29,88%	69,95%
C	FT System allarm 1	7,91%	77,86%
D	Machine Regulations	5,98%	83,83%
E	Fallen Bottle in Entrance	3,69%	87,52%
F	Machine Cleaning	2,64%	**90,16%**

Table 3.12 M3 Micro downtime: Frequency (%)

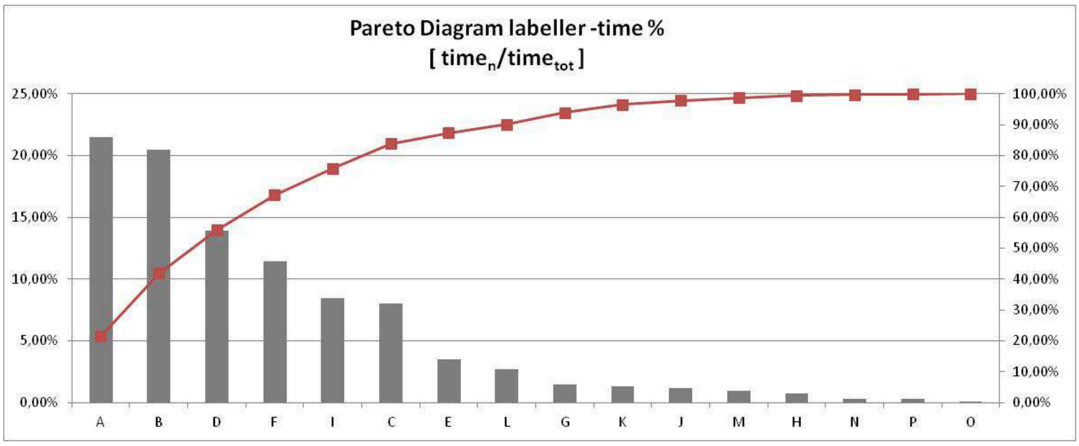


Figure 3.32 Pareto Diagram - M3 Micro Downtime Duration

	Micro Downtime	% Duration (time)	% Duration cum (time)
A	Label Lack	21,50%	21,50%
B	Bottles Lack	20,45%	41,95%
D	Machine Regulations	13,92%	55,87%
F	Machine Cleaning	11,46%	67,32%
I	FT System allarm 2	8,49%	75,81%
C	FT System allarm 1	8,01%	**83,82%**

Table 3.13 M3 Micro downtime: Duration (%)

The Labeller, as the palletizer, presents more or less the same critical micro downtime in terms of frequency and duration. The first six micro downtime covers the 90% of the number of stops and the 84% in terms of duration (Table 3.12 and Table 3.13).

Next consideration are about the incisiveness of these "process failures" on OEE, on Production throughput and on planned working hours.

3.5.3

Other analysis - considerations

Once principal micro downtime causes have been identified and studied, the potentially recoverable OEE per month for each one has been calculated to identify the most critical problems (Figure 3.33).

This graph points out the principal criticalities of the line, based on the OEE index, in terms of micro downtime. It is useful for quantifying the impact in terms of OEE of all micro downtimes, to highlight the improvement margin and to support a cost-benefit analysis. Management are easily able to see the criticalities and their impact in terms of production efficiency. From this analysis it is possible to propose solutions and compare their costs and benefits in terms of time recovered for production (OEE improvement), and to calculate a CPI (Cost Performance Indicator) index.

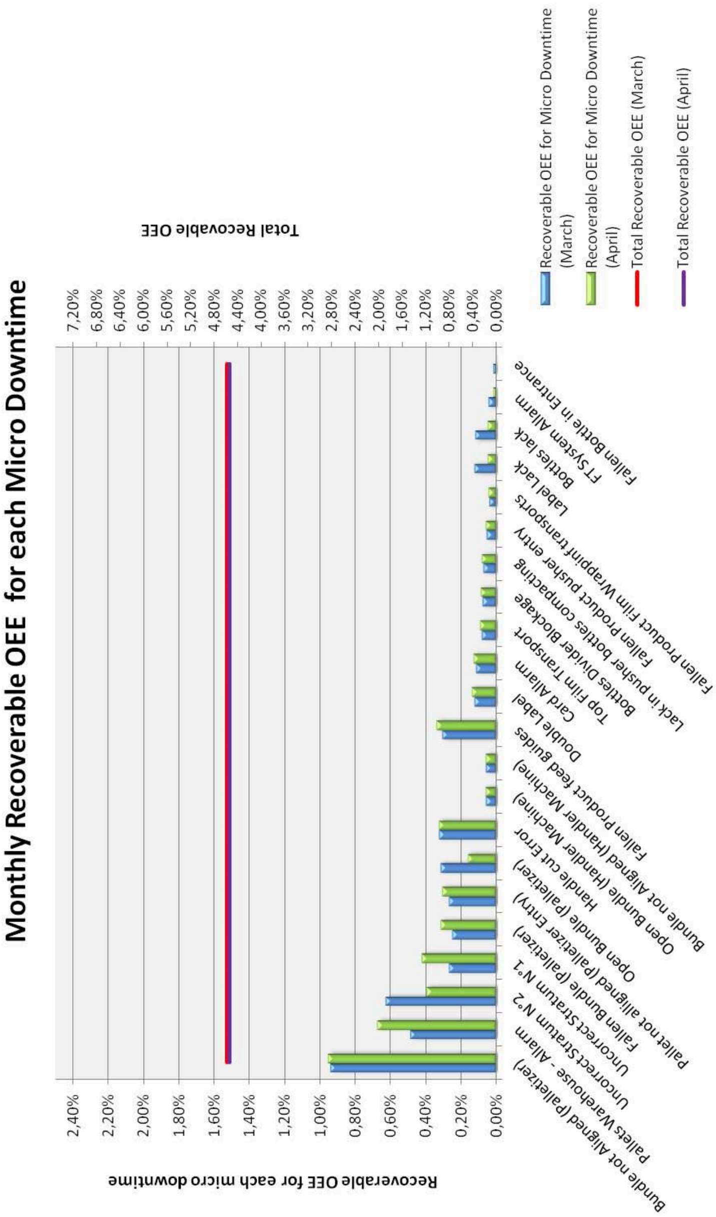


Figure 3.33 OEE improvement for each micro downtime measured

Other considerations had been done about the OEE recoverable for each micro downtime, the production (bottles) and the working time (hours). Table 3.14 summarizes the OEE recoverable for micro downtime, referred to data collected in March and in April. The first five are about the Palletizer.

Micro Downtime	OEE March	OEE April
pallet not Alligned (palletizer Entry)	1,43%	1,46%
Pallets Warehouse - Allarm	0,75%	1,03%
Uncorrect Stratum (N°1)	0,96%	0,61%
Uncorrect Stratum (N°2)	0,42%	0,65%
Fallen Bundle (Palletizer)	0,39%	0,49%
pallet not Alligned (palletizer Entry)	0,42%	0,47%
Open Bundle (Palletizer)	0,49%	0,25%
Handle cut error	0,50%	0,41%
Open Bundle (Handler)	0,10%	0,08%
Bundle not alligned (Handler Machine)	0,10%	0,08%
Fallen Product Feed Guides	0,55%	0,64%
Double Label	0,23%	0,27%
Card Allarm	0,22%	0,25%
Top Film Trasport	0,15%	0,18%
Bottles Divider Blockage	0,15%	0,17%
Lack in pusher bottles compacting	0,14%	0,16%
Fallen Product Pusher entry	0,10%	0,12%
Fallen Product Film wrapping trasport	0,08%	0,09%
Label Lack	0,37%	0,18%
Bottles lack	0,28%	0,14%
FT System Allarm	0,14%	0,07%
High Speed	0,07%	0,03%
Fallen Bottle in Entrance	0,05%	0,02%

Table 3.14 OEE Recoverable per Month for each Micro Downtime (March - April)

At the same time, the number of bottles can be calculated, for March and April, for each micro downtime (Table 3.15). It is important to highlight this data to remark the incisiveness of downtime inefficiency in automatic production lines.

Micro Downtime	Bottles March	Bottles April
pallet not Alligned (palletizer Entry)	186912	184638
Pallets Warehouse - Allarm	97453	130307
Uncorrect Stratum (N°1)	125007	76823
Uncorrect Stratum (N°2)	54288	81935
Fallen Bundle (Palletizer)	50426	61594
pallet not Alligned (palletizer Entry)	54465	59601
Open Bundle (Palletizer)	63625	31803
Handle cut error	65722	51291
Open Bundle (Handler)	12954	10109
Bundle not alligned (Handler Machine)	12636	9862
Fallen Product Feed Guides	71798	80801
Double Label	29944	33699
Card Allarm	28259	31802
Top Film Trasport	20113	22635
Bottles Divider Blockage	19045	21433
Lack in pusher bottles compacting	17697	19916
Fallen Product Pusher entry	13596	15300
Fallen Product Film wrapping trasport	10562	11886
Label Lack	47760	22715
Bottles lack	36707	17458
FT System Allarm	17796	8464
High Speed	8721	4148
Fallen Bottle in Entrance	6490	3087

Table 3.15 Production (bottles) Recoverable per Month for each Micro Downtime (March - April)

Finally, last consideration is about production hours recoverable from micro downtime (Table 3.15).

The first five micro downtime are about M1, in all three tables (OEE, Bottles and production hours). The palletizer is defined as the most critical machine for line D and also the one with the higher margin of improvement.

In particular, micro downtime A (Bundle not Aligned) is the one with the highest incisiveness: 1.45% OEE per Month, 185.000 bottles/month lost and 6 hours/month of lost production time. For this reasons, in next paragraph is proposed a cause-effect diagram about this problem.

Micro Downtime	Hours March	Hours April
pallet not Alligned (palletizer Entry)	6,23	6,15
Pallets Warehouse - Allarm	3,25	4,34
Uncorrect Stratum (N°1)	4,17	2,56
Uncorrect Stratum (N°2)	1,81	2,73
Fallen Bundle (Palletizer)	1,68	2,05
pallet not Alligned (palletizer Entry)	1,82	1,99
Open Bundle (Palletizer)	2,12	1,06
Handle cut error	2,19	1,71
Open Bundle (Handler)	0,43	0,34
Bundle not alligned (Handler Machine)	0,42	0,33
Fallen Product Feed Guides	2,39	2,69
Double Label	1,00	1,12
Card Allarm	0,94	1,06
Top Film Trasport	0,67	0,75
Bottles Divider Blockage	0,63	0,71
Lack in pusher bottles compacting	0,59	0,66
Fallen Product Pusher entry	0,45	0,51
Fallen Product Film wrapping trasport	0,35	0,40
Label Lack	1,59	0,76
Bottles lack	1,22	0,58
FT System Allarm	0,59	0,28
High Speed	0,29	0,14
Fallen Bottle in Entrance	0,22	0,10

Table 3.16 Production (hours) Recoverable per Month for each Micro Downtime (March - April)

3.5.4

Cause-effect diagram

Finally, for the most important and relevant causes, a fishbone diagram has been constructed, again with production and maintenance staff involvement. In the Figure 3.34 the analysis of micro downtime A "bundle not aligned" of M1 is proposed. The primary causes are divided into materials, personnel, methods, etc. Looking into this particular problem in more depth, it turned out that the primary problem was related to the transport in ingress, in particular to a curve tape composed by a series of rollers.

Figure 3.35, Figure 3.36, Figure 3.37 and Figure 3.38 shows the fishbone diagrams of the other micro downtime; As micro downtime A, these diagrams are constructed with maintenance and production staff to highlight the primary cause of the micro downtime.

The principal aim of this instrument is to pointed out the nature of the inefficiency and to make emerged possible solutions.

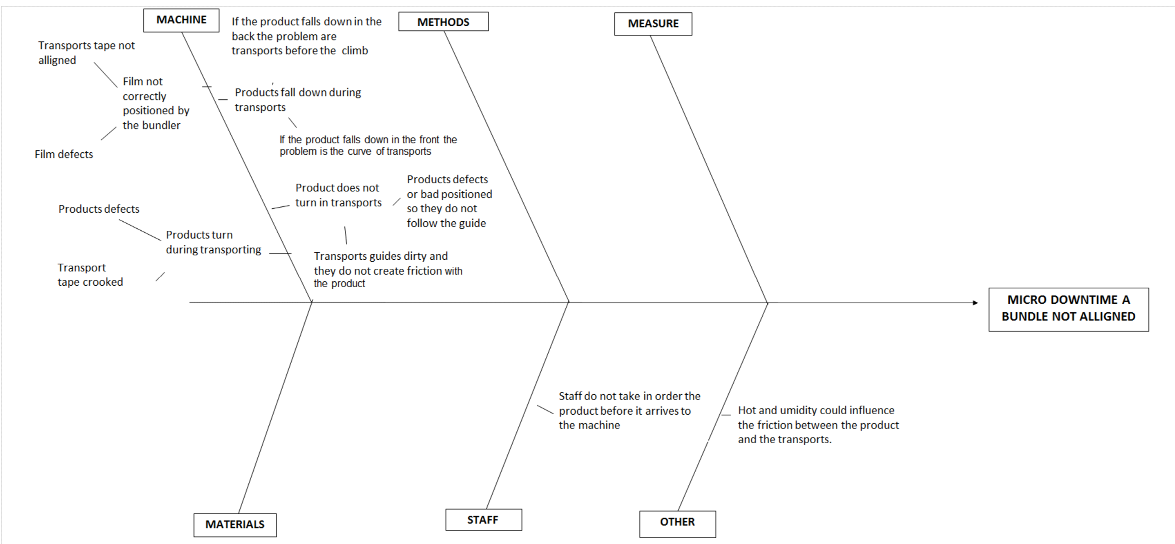


Figure 3.34 Fishbone Diagram - Micro downtime A, Bundle not aligned

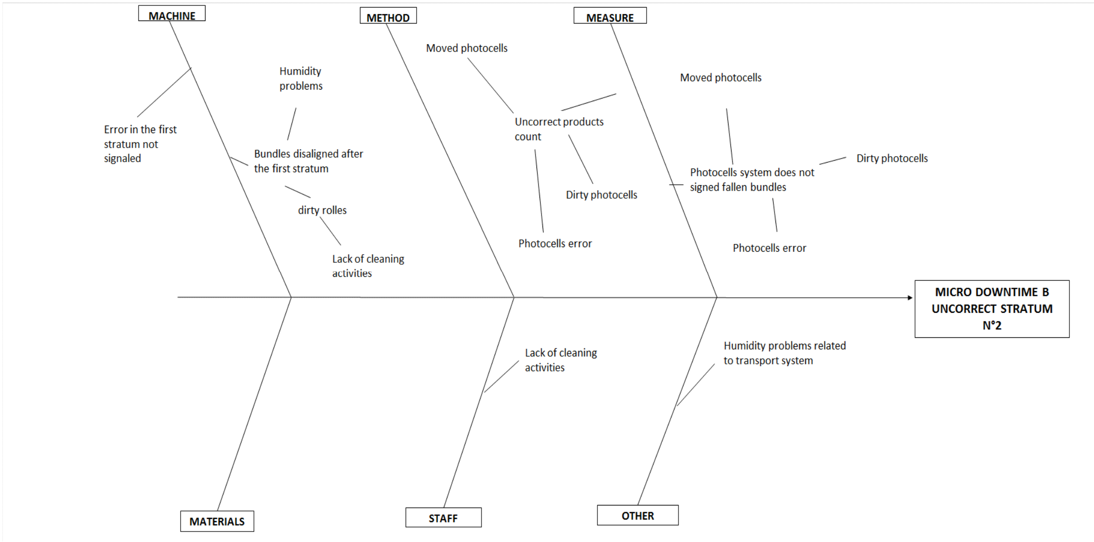


Figure 3.35 Fishbone Diagram - Micro downtime B, Uncorrect stratum N°2

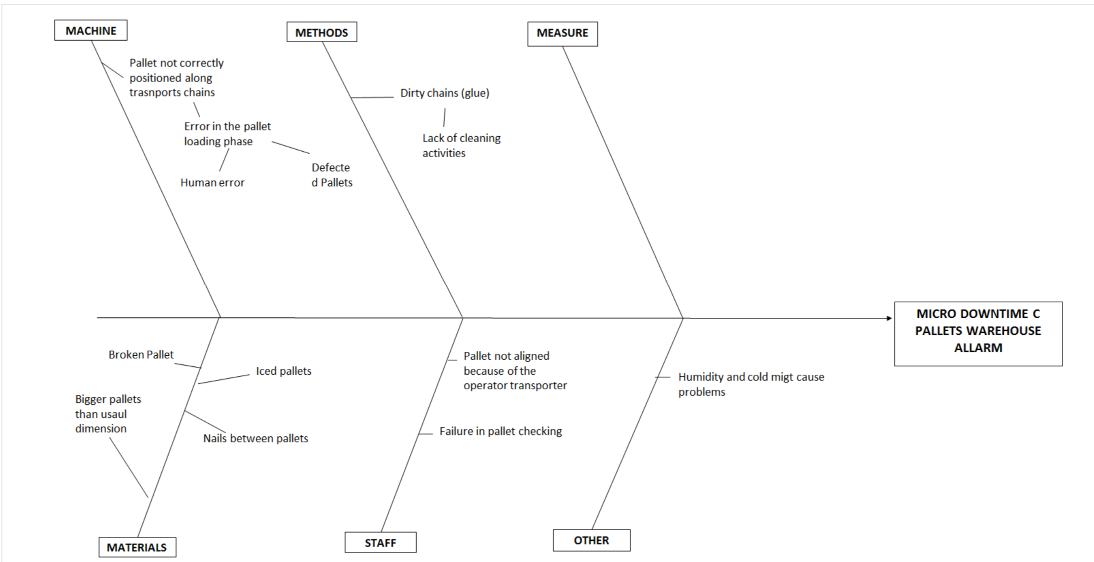


Figure 3.36 Fishbone Diagram - Micro downtime C, Pallets warehouse allarm

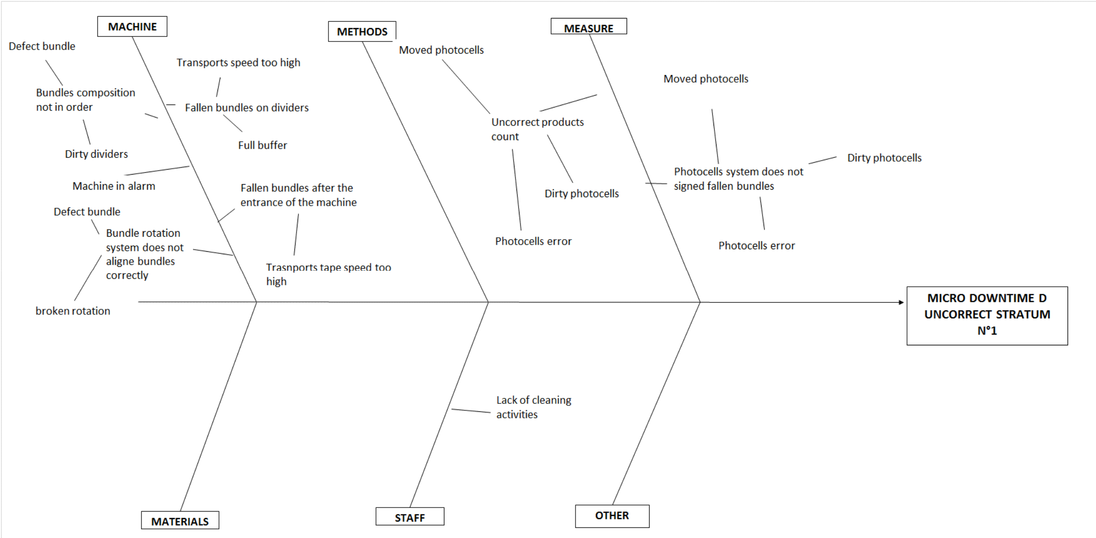


Figure 3.37 Fishbone Diagram - Micro downtime D, Uncorrect stratum N°1

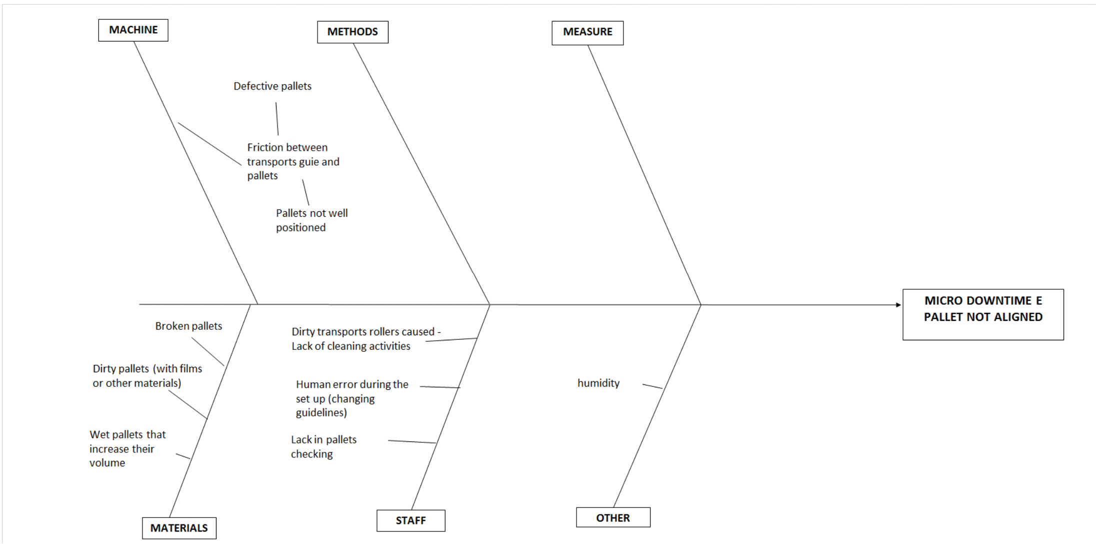


Figure 3.38 Fishbone Diagram - Micro downtime E, Pallet not alligned

3.5.5

Problem Solving

Having identified the most critical causes of inefficiency in terms of micro downtime, they have been analyzed with production, maintenance and engineering staff through focused team work sessions. In this context a very useful tool is the cause-effect diagram. This can be used to identify the primary cause of a micro downtime.

Analyzing micro downtime of palletizer, in particular the first five as the most critical ones, possible solutions and improvements have been carried out. For micro downtime A, for example, a solution was proposed by the technical department: the replacement of a curve transport tape with a different system that has a different inclination and should avoid bundle to fall down. Also for the others micro downtime solutions are proposed and the cost of investments are carrying out.

Finally, it was calculated the CPI index for each micro downtime of the palletizer considered, as the cost of the investment or maintenance activities vs the OEE Recoverable. Table 3.17 provides the CPI Index calculation for M1's principal micro downtime, showing that Micro downtime A is the most convenient in terms of €/OEE. In fact it has the lowest CPI that means it is the most suitable one as it has the lower costs in comparison with the recoverable OEE.

	Micro Downtime	OEE %	Investment Cost	CPI
A	**Bundle not Alligned (Palletizer)**	**1,44**	**€ 15.000**	**10,417**
E	Pallet not Alligned (Palletizer Entry)	0,44	€ 8.000	18,182
B	Uncorrect Stratum (N°2)	0,79	€ 40.000	50,633
C	Pallets Warehouse Allarm	0,89	€ 60.000	67,416
D	Uncorrect Stratum (N°1)	0,54	€ 40.000	74,074

Table 3.17 CPI for M1 Microdowntime

3.5.6

Cost – Benefit Analysis

The final step of this first part of the project is related to the cost benefit analysis to evaluate the solutions proposed. Economy data are fictitious for privacy reasons.

As Micro downtime A results as the most convenient, it is carried out the payback period of the investment, calculating the NPV varying the contribution margin.

The cost of the investment is around € 15.000,00 and the labour cost of the project was estimated as € 3.000,00. Given the estimated increase in production (1.482.324 item/year), the contribution margin for the 1st Level is the production increase for the unitary contribution margin without fixed costs. As the contribution margin is a useful measure, we show the results with a unitary contribution margin range that varies from €0,01 to €0,15€ per piece. Then for the 2nd Level also fixed costs have been considered (Table 3.18).

With the second level contribution margin the payback period has been calculated, as well as the cash flow, using the NPV formula for the following year and assuming an increase in production with an interest rate of 5%.

Results show that the payback period is decreasing as the contribution margin increase, as well show the Table 3.19 and Figure 3.39.

	CM n°1	CM n°2	CM n°3	CM n°4	CM n°5	CM n°6
Investment Cost [€]	€ 15,000.00	€ 15,000.00	€ 15,000.00	€ 15,000.00	€ 15,000.00	€ 15,000.00
Labor Cost (Project) [€]	€ 3,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00
Total [€]	€ 18,000.00	€ 18,000.00	€ 18,000.00	€ 18,000.00	€ 18,000.00	€ 18,000.00
CM 1° Level [€/pz]	**€ 0.01**	**€ 0.02**	**€ 0.03**	**€ 0.05**	**€ 0.10**	**€ 0.15**
Increase in Production [pz/years]	1,482,324.00	1,482,324.00	1,482,324.00	1,482,324.00	1,482,324.00	1,482,324.00
CM 1° Level [€]	**€ 14,823.24**	**€ 29,646.48**	**€ 44,469.72**	**€ 74,116.20**	**€ 148,232.40**	**€ 222,348.60**
Fixed Costs [€]	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00
CM 2° Level [€]	**€ 2,823.24**	**€ 17,646.48**	**€ 32,469.72**	**€ 62,116.20**	**€ 136,232.40**	**€ 210,348.60**

Table 3.18 Cost of the investment with Variable Contribution Margin

YEAR	0,01 € CM	0,02 € CM	0,03 € CM	0,05 € CM	0,10 € CM	0,15 € CM
0	-€ 18,000.00	-€ 18,000.00	-€ 18,000.00	-€ 18,000.00	-€ 18,000.00	-€ 18,000.00
1	-€ 15,311.20	-€ 1,193.83	€ 12,913.54	€ 41,158.19	€ 111,745.14	€ 182,332.00
2	-€ 12,750.44	€ 14,812.05	€ 42,374.54	€ 97,499.51	€ 235,311.95	€ 373,124.38
3	-€ 10,311.62	€ 30,055.74	€ 70,423.10	€ 151,157.82	€ 352,994.61	€ 554,831.41
4	-€ 7,988.93	€ 44,573.54	€ 97,136.02	€ 202,260.97	€ 465,073.35	€ 727,885.72
5	-€ 5,776.85	€ 58,400.02	€ 122,576.90	€ 250,930.64	€ 571,815.00	€ 892,659.36
6	-€ 3,670.10	€ 71,568.10	€ 146,806.30	€ 297,282.70	€ 673,473.71	€ 1,049,664.72
7	-€ 1,663.68	€ 84,109.12	€ 169,881.92	€ 341,427.53	€ 770,291.54	€ 1,199,155.54
8	€ 247.20	€ 96,052.95	€ 191,858.71	€ 383,470.22	€ 862,498.99	€ 1,341,527.76
9	€ 2,067.09	€ 107,428.03	€ 212,788.98	€ 423,510.87	€ 950,315.61	€ 1,477,120.34
10	€ 3,800.31	€ 118,261.44	€ 232,722.57	€ 461,644.83	€ 1,033,950.48	€ 1,606,256.13

Table 3.19 Pay Back period with variable contribution margin

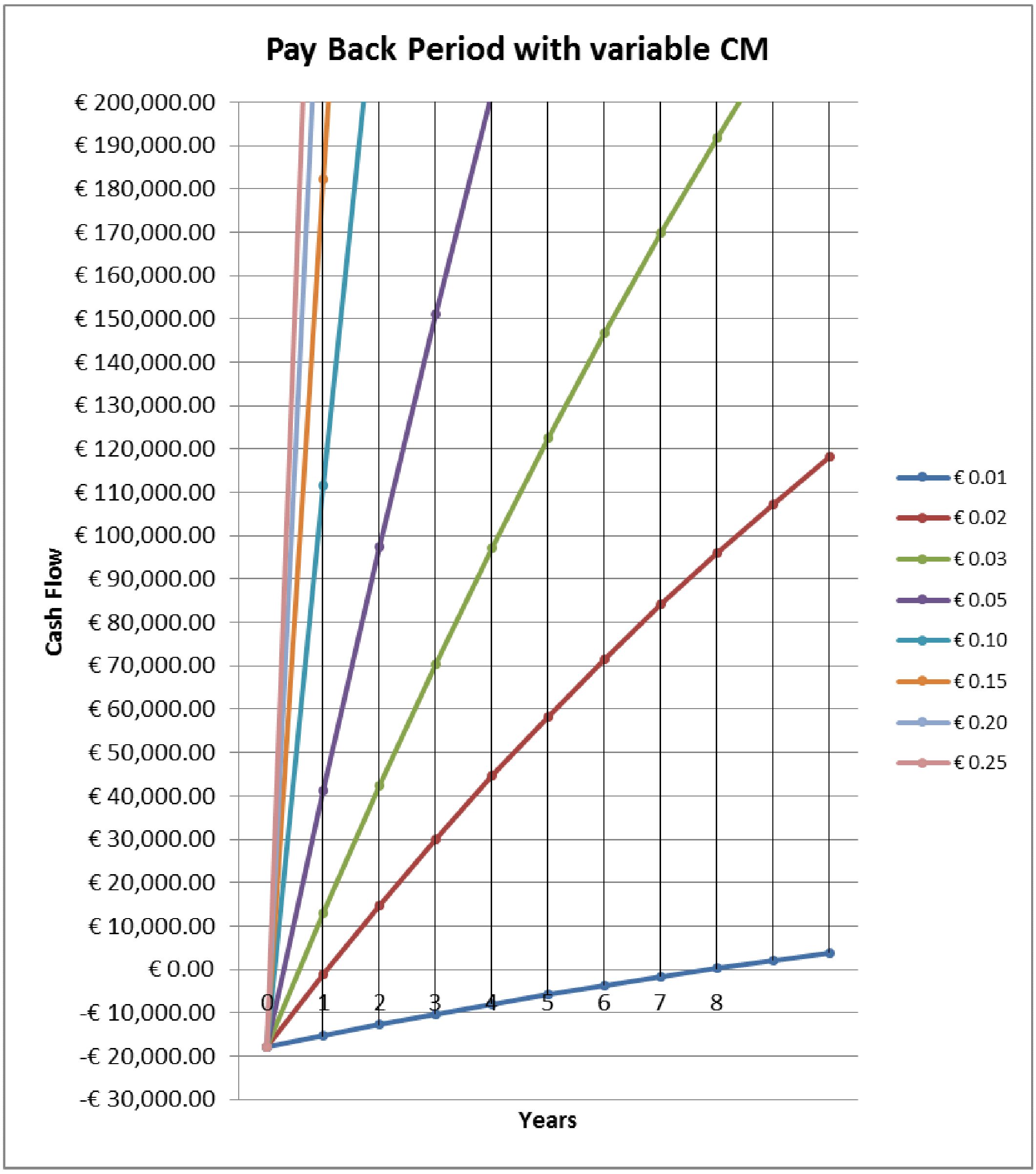


Figure 3.39 Pay Back Period with Variable Contribution Margin

3.6
Final Considerations

In conclusion, this chapter describes the implementation of the TPM framework proposed in chapter 2 in a food and beverage company. It is carried out a deep analysis of the OEE index and its inefficiency. What emerges is that downtime deeply affects production effectiveness. In particular, since the equipment belong to automation systems, the downtime is related to short stops of few minutes (less than 15) that are called micro downtime. Focusing on micro downtime of the most critical work stations, it is carried out a focused data collection and analysis to individuate the most critical ones.

It is also proposed a technical solution to reduce the most critical micro downtime cause, supported by a cost benefit analysis. In particular it is carried out the construction of the CPI index to compare the OEE improvement and the cost of investment of the most critical micro downtime of the Palletizer. As micro downtime A arise as the more convenient in terms of €/OEE, it is calculated the NPV (net present value) to individuate the payback period, varying the contribution margin of the product.

The second part of the case study is centred on buffer allocation problem, as a secondary solution to micro downtime. Chapter 4 is about the literature review of downtime analysis and buffer sizing in automatic production systems.

Chapter 5, instead, presents the second part of the case study, as the implementation of a focused statistical analysis of micro downtime.

Finally the simulation approach is applied to validate results.

3.7

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4

Micro Downtime in Automatic Production Systems

"As the increasing of personalization of products, mix variability, requirement of short time to market and risk of products obsolescence, the need of continuous flow and JIT solutions forces the industries to achieve constant improvements in terms of product quality, operation efficiency and production capacity utilization."

[Battini et al. 2006]

4.1
Downtime in Automatic Production Flow Lines

Automated manufacturing systems are now being deeply influenced by the changing in market requests. A growing multitude of variants and an increasing product differentiation, due to various factors as more customization, shorter product lifecycles, uncertainty in demand, have to go along with an increase in effectiveness, to rise in the market competition [Mourtzis et al., 2012]

Production systems effectiveness represents the principal aim of each industry, to be competitive and get success, but it is deeply influenced by the previews market requests. Optimization of Overall Equipment Effectiveness, that is the traditional evaluation index of Total Productive Maintenance, is the core objective of all industries; it compares the operating level with the ideal potential of the plant performance [Lanza et al., 2013].

The question is: *which factors affects overall equipment effectiveness in automatic production systems?*

Reliability is an important and strategic driver in the design, planning and utilization of automatic production systems. The implication of equipment failure is a very critical factor: an unplanned failure can result in significantly higher repair costs than a planned maintenance or repair, in addition to the loss of the production associated to the failure. [Baradaby et al., 2005]

In this context, downtime of machinery is one of the most relevant waste in production time and deeply affects OEE index. Downtime of machinery could be define as the time in which machines are not able to produce for some reasons. The study of its nature and influence on equipment performance is carried out in the following session.

4.1.1

Downtime Impact on Production Equipment

Downtime deeply affects machinery performance as it does not let production complete its function. In automation production, where human factor has a secondary role, machines reliability is essential to guarantee the planned throughput. As machines work in series, related by transport systems, the fail of just one influenced the performances of the whole line, or worse can caused the downtime of the whole production system. Reliability, Availability and Maintainability (RAM) of production equipment are strategic goals for production processes; they might influence production equipment since their design and till the functioning, looking to the maximization of the throughput.

Downtime can be defined as that period of time in which production machinery is not allowed to perform its output because it is not working. It could be caused by failures, set-ups, planned stops, material lacks, etc.

It is divided in three big categories:

1. *Planned Stops*: Downtime planned in accord with production plan but in which machines usually can produce. In other words maintenance and production function organize equipment stops for preventive maintenance, autonomous maintenance, cleaning activities, etc.
2. *Failures*: Unplanned downtime due to breakages or damages; it is unpredictable and its duration depends by the severity of the damage.
3. *Set-ups*: Downtime define as the time spend to arrange the equipment for produce a specific item.

These "lost" time, that is necessary or unpredictable, has an impact on OEE, in particular on the availability of the machines, as it could be time in which

the equipment could be productive. It represents a waste for production equipment, and its optimization is an objective for TPM implementation.
Anyway good preventive maintenance activities and further integration with production plans can reduce this waste; set-ups and planned stops, if well organized, can be minimized in order to maximize production. They are known and predictable stops that could be discussed and located in the most convenient period of production time. Failures, instead, are random and could difficulty been predictive; optimize preventive, predictive and autonomous maintenance is the principal solution to decrease breakdowns inefficiency.

Downtime as defined previously covers long periods, as stops of more than 15 minutes. Anyway automation is often characterized by shorter stops or speed loss, due to "process failures" or other caused related to the physiological functioning of machines. While downtime principally affects equipment availability, these short process failures decrease machines performances, as the second factor of the OEE index. These short stops can be defined as “Micro Downtime” and deeply influence reliability of production equipment. Before continuing with micro downtime peculiarities, Reliability of production equipment is presented.

4.1.2

Reliability of Production Equipment

Reliability R(t) is defined as the probability that a system (machine or component) will perform a required function for a given period of time T. It is strongly related to the breakage process of a component, depending on the working hours and damages.
Before presenting the statistical analysis, it is important to give some definition.

First of all, it is defined the *f(t)* as the density failure probability function. As all components have a specified duration, it is possible to say that:

$$\int_{-\infty}^{+\infty} f(x)dx = 1 \quad (8)$$

F(t) is defined as the probability to have a failure in a certain period t, given a density failure probability *f(t);* consequently F(t) is expresses as:

$$F(t) = \int_0^t f(s)ds \quad (9)$$

On the other side, reliability R(t) is the probability to have a functioning component after a specific period of time, as:

$$R(t) = \int_t^{\infty} f(s)ds \quad (10)$$

These two equations are strongly related as:

$$R(t) = 1 - F(t) \quad (11)$$

Another useful parameter in reliability analysis is the Failure Rate Function λ(t), called also Hazard function; it represents the "failure speed", as how often a failure occurs.

The failure rate function is define as:

$$\lambda = \frac{f(t)}{1-F(t)} \quad (12)$$

Other two fundamental parameters are the Mean Time to Failure (MTTF), that is the average time between two failures occurred, and the Mean Time to Repair (MTTR), that is the average time of repairing an item.

MTTF is defined as:

$$MTTF = \int_0^{\infty} t * f(t)dt \quad (13)$$

In the same way, it could be define the mean time to repair as:

$$\text{MTTR} = \int_0^{\infty} t * g(t)dt \quad (14)$$

Where g(t) is the density repair time probability function.

4.1.3

Micro Downtime in Automatic Production Lines

Micro downtime can be defined as time loss in production related to short stops (few minutes) and slowing down in production speed. These stops could be named as "process failures", as are not directly related to a machine failure, but to the production process or to the machine functioning.

Automatic Flow Production Lines are often affected by the presence of micro-downtimes (i.e. speed losses due to work-pieces blocking or congestion, momentary stiff or stuck pieces on machines, etc.), which can penalize the productivity of the system and increase losses in availability for the whole plant. Moreover, micro breakdowns cause inability of the system not to respond to sudden changes in demand due to capacity restrictions. (Battini et al. 2008).

This short downtime can be divided in:

1. *Micro downtime*, that is when machine is not working, for a very short time (few minutes), because of equipment malfunctioning, lack of products, jamming, etc.;
2. *Reduction in production speed*, that is when machines are not running as required, because of process failures, as products fall, jamming, and others.

The main difference between micro downtime and failures is that the first has high frequency and low duration, while downtime related to failures has usually low frequency and higher duration. Both have relevant impact on OEE, but often Micro downtime is underestimated. Moreover, failures can often be reduce through preventive maintenance optimization, while micro downtime are difficult to "prevent".

A very typical phenomena of automation is represented by starved and blocked work stations. In fact, due to the sequentially of machines, downtime or speed reduction of one has effects to both for the upstream and downstream workstations. In particular it is defined:

- *Blocked Machine* - a machine that could not work because the downstream one is off (no more space for materials in exit);
- *Starved Machine* - a machine that could not work because the upstream one in off (no materials in ingress)

These waste are very common in production flow line systems and deeply affected OEE index in terms of performance and total throughput. In the following paragraphs they are presented methods and tools used to solve or reduce this inefficiency source.
Next session is dedicated to the analysis of 26 case studies about downtime and micro downtime analysis in food industry and other sectors characterized by automatic production systems. The aim is to individuate methods and tools used to reduce this inefficiency and to highlight the lack of a focused micro downtime analysis in Food Industry. In it then proposed the study of Buffer Allocation Problem as a solution to improve Micro Downtime inefficiency, focusing on three methods. Finally it is carry out a new simulative model, based on TTF probability distributions of Micro downtime fitted by Weibull Distribution.

4.1.4

Downtime and Micro Downtime in Food Industry

Year	Authors	Industrial Sector	Objectives	Methods	Results
1998	Ljungberg, Õ. (1998).	Generic	Downtime analysis to improve machinery performance.	Availability, performance and quality analysis (OEE) of various companies.	Results: - Mean availability 80%, mean performance 68%, and mean quality 99% (*OEE* 55%).
2004	Adebiyi, K. A., Ojediran, J. O., & Oyenuga, O. A. (2004)	Food & Beverage	Evaluation of maintenance Practice in food industries in Nigeria.	Questionnaire and interviews in 40 food industries	Diffusion of maintenance strategies 81.94%
2005	Barabady, J., & Kumar, U. (2005)	Mining	Reliability and maintainability analysis and TBF probability distribution determination.	*TBF* and *TTR* data collection, *trend analysis* and probability distribution.	TBF data are well fit by Weibull distribution and it has been carried out the optimal maintenance interval for a 75% of availability.
2005	Liberopoulos, G., & Tsarouhas, P. (2005)	Food & Beverage	Evaluation of production process in a pizza production line	Statistical analysis of failures data	Failures data are well fitted by weibull distribution
2006	Battini, Manzini, Persona, Regattieri, (2006)	Food & Beverage	Buffer design analysis focused on micro downtime.	Software Simulation using MTTR and MTBF .	Methodological Framework to define optimal buffer size to improve effectiveness of machines.
2007	Tsarouhas, P. (2007).	Food & Beverage	Increase of production equipment efficiency, quality and reduction of costs through TPM.	Loss data collection and analysis; OEE measurement.	Improve of production and maintenance control, and reduction in production delays.
2008	Babbs, D., & Gaskins, R. (2008).	Semiconductor	Evaluation of productivity and maintenance policies through simulation software analysis.	*TTR* e *TTF* probability distribution determination, software simulation, MTTR and Planned Maintenance downtime calculation.	Identification of downtime as core criticality of the production, especially in smaller production.
2009	Tsarouhas, P. H., Arvanitoyannis, I. S., & Varzakas, T. H. (2009).	Food & Beverage	Reliability and Maintainability Analysis	Probability distributions (*goodness-of-fit analysis*).	TTF are well fitted by Weibull distribution, while TTR are well represented by the Lognormal distribution.
2009	Tsarouhas, P. H., Arvanitoyannis, I. S., & Varzakas, T. H. (2009).	Food & Beverage	Reliability determination	*TTR* and *TTF* data collection, Pareto Analysis of machinery, *goodness-of-fit* (Anderson-Darling test)	TTF and TTR are well fitted by Weibull distribution.
2009	Tsarouhas, P. H., Arvanitoyannis, I. S., & Varzakas, T. H. (2009)	Food & Beverage	Individuation of avalilability and reliability of a cheese production line	Data collection and analysis (Failures and downtime)	Calculation of availability and individuation of criticalities
2010	Patti, A. L., & Watson, K. J. (2010)	Generic	Downtime variability analysis Impact on production equipment performance	Software simulation through *Kanban* or *DBR* (Drum-Buffer-Rope) system	Downtime with high duration and low variability in frequency are more critical.
2010	Tsarouhas, P. H., & Arvanitoyannis, I. S. (2010).	Food & Beverage	Reliability determination	*TTR* and *TTF* data collection, Pareto Analysis of machinery, *goodness-of-fit* (Anderson-Darling test)	TTR are well fitted by lognormal distribution while TTF are well described by normal one.
2010	Regattieri, A., Manzini, R., & Battini, D. (2010)	Automotive	Reliability Analysis	*TTR* and *TBF* Data Collection, *stationary test*, *dependence test*, probability distributions, surv*ival function* determination	Weibull Distribution applied to *TTR* and *TBF*; highlight of censured data importance and influence on analysis.

2010	Al-Hawari, T., Aqlan, F., Al-Buhaisi, M. A., & Al-Faqeer, Z. (2010)	Food & Beverage	Evaluation of productivity through simulation software analysis.	Data collection for the simulation software.	Individuation of best benefits that could be obtained from improvements as downtime reduction.
2011	Zammori, F., Braglia, M., & Frosolini, M. (2011)	Waterproof materials production	OEE Analysis of the plant	Downtime probability distribution determination and Monte Carlo simulation.	OEE Analysis framework supported by Monte Carlo simulation (valid if OEE is lower than 90%)
2012	Ohunakin, O. S., & Leramo, R. O. (2012)	Food & Beverage	TPM impact on Downtime reduction.	Pareto diagram; OEE analysis and *why-why* analysis.	*OEE* improvement of 50% (using in particular *Kobetzu Kaizen*)
2012	Abdul Samat, H., Kamaruddin, S., & Abdul Azid, I. (2012).	Semiconductor	Maintenance policies efficiency analysis.	Pareto Analysis, *FMEA* analysis, efficiency and reliability of machines calculation (*ME)*	Highlight the inefficiency of maintenance policies applied as *ME=41,5%.*
2012	Tsarouhas, P. H., & Arvanitoyannis, I. S. (2012).	Food & Beverage	Reliability and Maintainability Analysis	*TTR* e *TBF* data collection, probability distribution (Anderson-Darling test).	TBF are well fitted by Weibull distribution, while TTR are well represented by the Lognormal distribution.
2012	Xie, X., & Li, J. (2012).	Food & Beverage	Production increase in a meat shaving and packaging line	Simulation of production line process	Individuation of the bottleneck machine and improvements
2013	Abele, E. (2013)	Mechanical treatments	Impact of uncertainty and variability of downtime on OEE.	Fuzzy set theory	Improvement of OEE trustworthiness by including variability.
2013	Tsarouhas, P. H. (2013a).	Food & Beverage	Evaluation of maintenance policies applied.	TTR and TBF data collection, application of statistics models and OEE calculation.	Identification of principal line and consequently improvement of preventive maintenance.
2013	Tsarouhas, P. H. (2013b).	Food & Beverage	Evaluation of maintenance policies applied.	TTR and TBF data collection, application of statistics models and OEE calculation.	Identification of micro downtimes as critical, its impact on OEE and need to improve spare parts warehouse.
2014	Rahman, C. M., Hoque, M. A., & Uddin, S. M. (2014)	Packaging	TPM Impact Evaluation	Pareto diagram and *t-test* to analyse downtime causes.	Reduction of downtime of 14.5% in two years.
2014	Singh Jolly, S., & Jit Singh, B. (2014)	Special Purpose Machines	Reliability and maintainability analysis	*MTBF* data collection, *MTBF* probability distribution analysis, *survival plot*, *cumulative failure plot*, *hazard plot*, *TTT plot*.	As *MTBF* increase, reliability improve, through downtime reduction and betterment of availability.
2014	Tsarouhas, P. H., & Arvanitoyannis, I. S. (2014).	Food & Beverage	Reliability and Maintainability Analysis	Probability distributions (*goodness-of-fit analysis*).	TBF and TTR are well fitted by Weibull distribution.
2014	S. Al-Chalabi, H., Lundberg, J., Wijaya, A., & Ghodrati, B. (2014)	Mining	Downtime analysis of mining equipment.	*TTR* e *TBF* Data Collection, *jack-knife diagram* (*log-log plot*), *TTR* and *TBF* probability distribution identification.	Technological modifications suggestions on critical parts and components.

Table 4.1 Downtime Analysis - Case studies

In this session is presented the study of 26 downtime analysis in automatic production systems reality. The purpose is to discuss what has been done in literature till today about downtime evaluation and analysis in order to highlight the lack of a deep analysis of micro downtime in food and beverage sector

Table 4.1 presents the analysis of principal papers and case studies that discuss themes as downtime impact on OEE, tools and methods for downtime analysis and maintenance strategies applications; it is summarized the year of publication, the authors, the industrial sector application, the project objective, the followed methods and the obtained results.

Papers in the table highlight various points related to downtime, as:

1. Downtime data collection and analysis
2. OEE evaluation in industries
3. Reliability and Maintainability of production equipment
4. Importance of probability distribution of data collected
5. Simulation of production systems as a tool of improvement
6. Tools and Methods for Downtime Analysis

1. Downtime data collection and analysis

Ljungberg (1998), studying various different industries, make emerged the lack of a systematic analysis tool of downtime, planned or unplanned, micro downtime and set-ups in many companies; this lack has an impact on equipment effectiveness. Also Tsarouhas (2013) verified that reductions in production speed, micro downtime, failures and defects deeply influence production machinery performance.

Instead, Patti and Watson (2010) remarked that downtime of long duration and low frequency has a considerable impact on OEE. Rahman et al. (2014), implementing TPM, observed a reduction of downtime of 14.5% in two years in a packaging company. Finally Singh et al. (2014) studied as an increase in MTBF (Mean Time Between Failure) entails a reduction in machines downtime. S. Al-Chalabi et al. (2014) used TTR and TBF data collection and analysis, to study downtime of a mining equipment; they individuated statistical distribution of TBF and TTR of the various working station. Finally

Tsarouhas et al. (2009), applied a deep failure data collection and analysis in a cheese production plant.

In conclusion downtime is a relevant parameter that influences equipment performance and consequently the production final rate; it is important to construct a strategic data collection system to register and control downtime of production systems in order to improve and optimize OEE.

2 OEE Evaluation in Industries

OEE index is the most used industrial efficiency index; it allows companies to measure availability, performance and quality of its equipment.

Ljungberg (1998) verified that in media the availability of a production system goes around 80%, performance around 68% and the quality 99%; the OEE, in consequence, has a media of 55%.

Abele et al. (2013), in their work, demonstrated the importance of including variability of time loss in OEE analysis and calculation; the same demonstrated also the work of Zammori et al. (2011), in which is explained the relevance of time variability to obtain a valid OEE analysis, through the utilization of Monte Carlo simulation.

Ohunakin et al. (2012) make emerged the importance of OEE as TPM measurement trough the evaluation of a real study in which they registered an increase of 25% points of OEE. Finally Tsarouhas (2007) highlighted as OEE is an efficient tool to control and check both production and maintenance, through the measurement of various aspects as quality, downtime, set-ups and others.

In conclusion, OEE index is a complete and strategic parameter that involves production, equipment and quality aspects in a single parameter; its decomposition is useful to make arise waste and inefficiency of production systems.

3 Reliability and Maintainability of production equipment

Reliability and maintainability are strictly related each other to guarantee Equipment Effectiveness. Abdul Samat et al. (2012) studied maintainability and reliability of production equipment by evaluating maintenance policies effectiveness. Barabady et al. (2005) proposed the analysis of the optimal maintenance interval in order to guarantee a reliability of 75%. Tsarouhas et al. (2014) analyzed the reliability of a bottle production plant to improve maintainability and maintenance activities intervals. Al-Chalabi et al. (2014), to improve maintainability, proposed technical modifications to the most critical components, as a method to reduce inefficiency. Finally Regattieri et al. (2010) explained the relevance of censured data in equipment reliability definition, as lack in data might give deviant results.

In conclusion most of presented case studies highlight the importance of downtime data to estimate reliability and maintainability of equipment and to guarantee production systems effectiveness; moreover reliability is strongly related to maintainability as a consequence of a good maintenance strategy.

4 Importance of probability distribution of data collection

Data analysis usually requires to assume a probability distribution of data collected; many authors discussed about the most suitable probability distribution for data as TTF, TBF, MTTF, etc.

Barabady et al. (2005), Tsarouhas et al. (2012), Regattieri et al. (2010) remarked that Weibull distribution well fit Time Between Failures (TBF) data in most of cases. For Time To Repair (TTR) data, instead, Tsarouhas et al. (2012) assumed that the best distribution is the lognormal one. Finally, for Time To Failure (TTF) data, the most appropriate distribution is Weibull one, as affirmed Tsarouhas et al. (2009) in their work.

In conclusion probability distribution of failures data is strategic to understand machines trend, as failures could be random, or decreasing or in the worst case increasing.

5 Simulation of production systems as a tool of improvement

Simulation could be a useful industrial tool to analyze downtime data and verified its impact on production. Zammori et al. (2011) proposed Monte Carlo simulation to confirm and validate OEE reliability. Al-Hawari et al. (2010) used a simulation software to analyze the impact on downtime on focused investments; they explained advantages and benefits of this tool. Babbs and Gaskins (2008) proposed the simulation method as a useful tool to highlight benefits of modifications of different parameters, focusing on preventive maintenance policy to improve machines performance. Finally Xie et al. (2012) used simulation to improve production in a meat shaving and packaging line, through the individuation of the bottle neck machine.

In conclusion many authors raised the benefits of simulation as a tool to support management decision on investments, remarking the importance of a specified data collection and statistical analysis to construct an appropriate model.

6 Tools and Methods for Downtime Analysis

Finally, many tools and methods are used to carry out downtime analysis; below are listed the main tools used in the case studies:

- *Pareto Analysis*, to individuate downtime causes (Rahman et al., 2014; Ohunakin e Leramo, 2012; Tsarouhas, 2013b; Abdul Samat et al., 2012; Tsarouhas et al., 2009; Tsarouhas e Arvanitoyannis, 2010);
- *TTF, TTR, TBF, MTTR and MTBF indexes*, to evaluate production performance (Battini et al., 2006; Tsarouhas, 2013a, 2013b; Singh Jolly

et al., 2014; Barabady, 2005; Tsarouhas e Arvanitoyannis, 2010, 2012; Tsarouhas et al., 2009 Al-Chalabi et al., 2014; Regattieri et al.);

- *OEE index*, to control and check production equipment (Ohunakin et al., 2012; Tsarouhas, 2007, 2013a, 2013b; Ljungberg, 1998);
- *Reliability and maintainability calculation* (Abdul Samat et al., 2012; Singh Jolly et al., 2014; Barabady, 2005; Tsarouhas et al., 2009; Tsarouhas e Arvanitoyannis, 2010, 2012, 2014; Regattieri et al., 2010);
- *FMEA and why-why analysis*, to individuate downtime causes and effects (Ohunakin et al., 2012; Abdul Samat et al., 2012);
- *Stationary test and dependence test*, to describe the data collected of the downtime (Tsarouhas, 2013a, 2013b; Tsarouhas et al., 2009; Tsarouhas e Arvanitoyannis, 2010, 2014);
- *Goodness-of-fit test*, to identify the proper probability distribution of data (Tsarouhas et al., 2009; Tsarouhas e Arvanitoyannis, 2010, 2012, 2014);
- *Software simulation*, to evaluate changing in production systems (Patti et al., 2010; Zammori et al., 2011; Al-Hawari et al., 2010; Babbs et al., 2008).

What emerges from this analysis is the relevance of downtime in equipment effectiveness. Its control, analysis and optimization is fundamental to achieve strategic benefits for production systems. In particular, micro downtime are a relevant cause of inefficiency. Methods and tools presented consider this inefficiency as a unique failure related per working station. This work aims to point out the lack of a deep micro downtime analysis, carrying out the principal micro downtime causes of each working stations and fitting them in a simulative model. Moreover, buffer capability is presented as a possible improvement to reduce micro downtime impact on production equipment.

Next session is dedicated to buffers role in automatic production systems.

4.2

Buffer in Automatic Production Systems

Automatic production systems effectiveness is deeply affected by downtime waste; in particular, micro downtime, defined as short production stops with high frequency, deeply influences productivity and increases loss in equipment availability. In this context, buffers represent a strategic tool to decrease downtime caused by these phenomena that often are physiological in the production process. In general downtime can be reduced with good preventive maintenance activities, as they prevent and might solve failures (Eliiyi and Gurler, 2008). But, on the other hand, buffer allocation and size is an important strategy for guarantee machines independence and continuity in production.

In automatic production systems, the size of intermediate buffers significantly affects the success of the production system, especially when their functions is to protect the system from the inevitable processing time fluctuations caused by machine disruptions (Battini et al. 2013).

Buffer Allocation Problem (BAP) is a combination of various optimization aspects as it aims to find the optimal buffer size, number and location in a production flow line to achieve a specific objective. First of all buffers aims to reduce starving and blocking time between working stations, and ensuring products presence in order to make machines independence from each other. On the other hand, buffers represent a cost in terms of capital investment and space.

4.2.1

BAP – Buffer Allocation Problem

The BAP focuses on three main objectives:

1. Maximization of the throughput
2. Minimization of buffer size
3. Minimization of the average work-in-process inventory

Maximization of the throughput

The maximization of the throughput is the first aim of BAP; given a defined number of buffers N, with the corresponding buffer size B_i, and K-1 possible locations between the working stations, the final function is:

$$\text{MAX } f(B) \qquad \text{where } B = (B_1, B_2, \ldots B_{k-1}) \qquad (15)$$

$$\text{Subject to } \sum_{i=1}^{K-1} Bi = N$$

the function f(B) represents the throughput of the production line depending on the buffer size.

Minimization of buffer size

The second part of the problem is to minimize the total buffer size, in order to minimize costs. The function is:

$$\text{MIN } \sum_{i=1}^{K-1} Bi = N \qquad \text{where } B = (B_1, B_2, \ldots B_{k-1}) \qquad (16)$$

$$\text{Subject to } f(B) \geq f^*$$

where f* is the desired throughput rate.

Minimization of the average work-in-process inventory

Finally, the third objective is to minimize the average work-in-progress inventory, to reduce the capital investment.

$$\text{MIN } Q(\text{B}) \qquad \text{where B} = (\text{B}_1, \text{B}_2, \ldots \text{B}_{k-1}) \qquad (17)$$

$$\text{Subject to } \sum_{i=1}^{K-1} \text{Bi} \leq N \text{ and } f(\text{B}) \geq f^*$$

Where Q(B) represents the average work-in-progress inventory as a function of B.

BAP aims to optimize these three functions through the application of various methods and approaches. In chapter 1 it is presented an overview about methods and approaches utilized during last years.
Next session, instead, is centered on three approaches, utilized in the case study of chapter 5. The first is the *graphical approach*, used to understand in practice the meaning of buffer sizing; it is a theoretical approach, useful more as a guideline than in real calculation cases. Then there is the simulation approach model, or BDFA (Buffer Design For Availability), presented by a Battini et al. in 2013. And finally there is the empirical approach that is the method used from the company to determine the optimal buffer size.

In the case study of Chapter 5 it is proposed the application of BDFA; but instead of applying Weibull probability distribution for TTF of the whole downtime of each working station, it is proposed to apply Weibull distribution to each singular micro downtime.

4.2.2

Graphical Approach

This method aims to define the optimal buffer size between two machines through production performance analysis. It is a very easy and direct tool that requires only production machines rate data; the biggest lack of this method is that it does not consider inventory costs, but just machine availability and production maximization.

In fact it can be used to give a guideline about the size of the buffer, but it requires further considerations regarding inventory costs and capital investments. A cost-benefit analysis might be carried out to complete this approach.

The input of this approach are machines performances (items/hour) for a given period of time, and the output is the maximum difference of machines speeds registered.

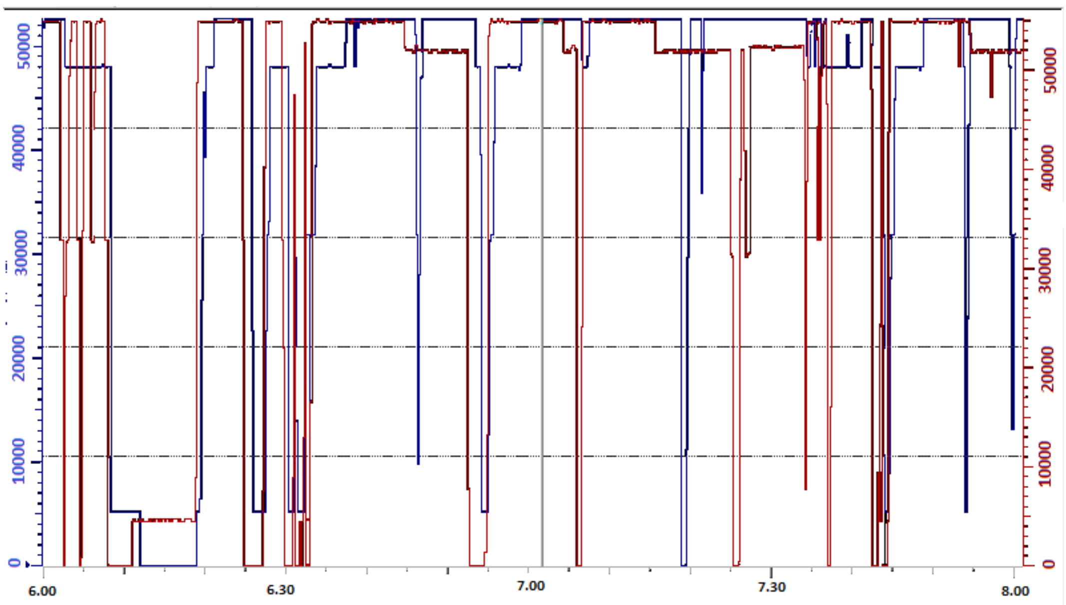

Figure 4.1 Graphic Method - Working Stations' speed

Buffer size is calculated considering two machines working in sequence; the speed of the working station is registered for a relevant period of time, considering the throughput rate, downtime, speed reduction, etc.

Figure 4.1shows the graphic that is registered from the machines of the case study: blue line is the production speed of machine N°1 and red line is the production speed of machine N°2.

The maximum distance between the two lines represents the buffer size, as the products need between the considered working stations.

4.2.3

Simulation Approach

This method is focused on simulation approach to optimize buffer size; it needs ad hoc data and a software for simulation to fit production reality.

Battini at al. (2009) proposed a Buffer Design For Availability (BDFA) approach based on simulation, focused on machines availability and inventory costs. This method aims to compensate machines downtime due to short maintenance activities and micro breakdown. Each machine is supposed to be a reparable system, with a deterministic and constant production rate; time to failure and time to repair (TTF and TTR) are normally distributed.

Other assumptions are:

- Availability parameters of workstations are known
- Short failures duration (0.02 – 30 minutes)
- Random deterioration process occurrence in micro downtime
- Buffer capacity in the simulation model is supposed to be infinite to carry out the maximum accumulation level.

This method is focused on micro downtime inefficiency; it is based the formulation of a new index, G, that is the maximum MTTR between two machines in sequence.

$$\mathbf{G} = \text{MTTRmax} = \max\left(\text{MTTR (M1)}; (\text{MTTR (M2)})\right) \quad (18)$$

Where M1 and M2 are two machines working in series in an automatic line. To calculate the optimal buffer size it is used the following formulation:

$$\textbf{Optimal Buffer Capacity} = K\,(\text{P, R}) * G * Qu\_max \quad (19)$$

Where:

- *Qu_max* is the maximum workstation throughput
- *K* (P, R) is a safety factor depending on P and R parameter:
  - P = $\frac{A(M1)}{A(M2)}$ it is the ratio between the availabilities of the two machines.
  - R = $\frac{MTTR(M1)}{MTTR(M2)}$ it is the ratio between the MTTR of the two machines.

Table 4.2 represents standard parameters for K.

The definition of G index is helpful to estimate the optimal buffer capacity and it results very easy and rapid to apply.

In another model, Battini at al. (2013), proposed to use of Weibull distribution to fit TTF probability distribution of each working stations.

In this work it is proposed the application of this model with the difference that each micro downtime TTF statistical distributions is fitted by Weibull one. Their parameters are calculated from on field data with the utilization of MINITAB® software.

P= Aa/Ab

R= MTTRa / MTTRb	0,93 < P< 0,98	0,98 <= P <= 1,03	1,03 < P< 1,08
0,00 – 0,08	K=1	K=1	K=1
0,08 – 0,20	K=1,1	K=1,1	K=1,1
0,20 – 0,30	K=1,2	K=1,2	K=1,1
0,30 – 0,80	K=1,4	K=1,3	K=1,2
0,80 – 0,90	K=1,8	K=1,8	K=1,6
0,90 – 1,10	K=1,1	K=1,1	K=1,1
1,10 – 2,00	K=1,8	K=1,8	K=1,7
2,00 – 2,50	K=1,8	K=1,2	K=1,7
2,50 – 6,00	K=1,2	K=1,1	K=1,1
> 6,00	K=1	K=1	K=1

Table 4.2 K parameters considering Machine a and Machine b

4.2.4

Empirical Approach

Finally last method presented is the one used by the company of chapter 3 to define the optimal buffer size in line equipment design. It is based on historical data and experience.

Since it is a flow line production system, buffers are represented by transport systems between machines.

First of all it is considered the nominal production speed of two machines working in sequence, to evaluate the minimum transport system size needed. In fact it is known the space (meters) between two working stations and, knowing their speed, it is possible to carry out the minimal transport area.

Then, from an empirical table, based on historical data and experience, it is known the recommended time that should be provided as "accumulation time" between two machines. Knowing the product size (depending on the format) and machines speeds, transport system size is evaluated. The company uses this method as they are pioneer in its market and were the first that construct machines by themselves. Figure 4.2 shows how it is divided transports between two machines in a production line:

- The blue and the yellow area are respectively the minimum exit and minimum ingress area of the two machines;
- The grey area is the normally transport system between the machines as they were completely reliable.
- Finally red area represents the buffer accumulation area.

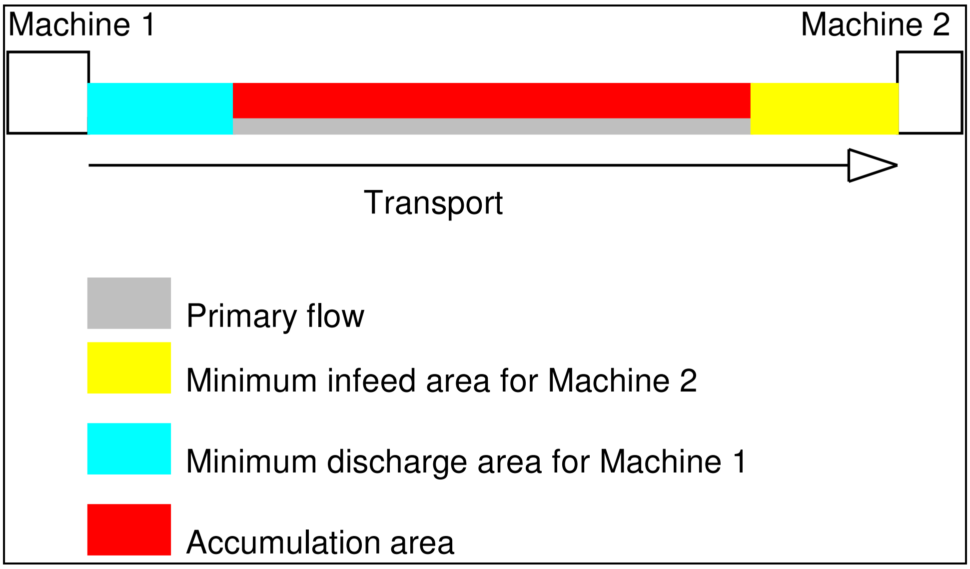

Figure 4.2 Accumulation area between two working stations

4.3 Final Considerations

This Chapter aims to present the relevance of micro downtime in automatic production systems in terms of inefficiency for production equipment. Micro downtime is a very common inefficiency problem in this reality and many authors proposed models and solutions about these them. Anyway it arise a lack of a focused analysis in food industry that carry out the different micro downtime relevance on OEE depending on their nature. It is proposed the evaluation of buffer sizing to reduce micro downtime inefficiency and three methods are taken into account:

1. Graphical Approach, based on machines performance that is useful after equipment developing
2. Simulative model, based on simulation of production reality; it can be use both in the design phase and after
3. Empirical Approach, used by the company, through the use of historical data.

Next Chapter, in particular, is focused on the comparison of the company method, and so the actual state of the production system, with the simulative approach. In particular it is proposed a new model based on ad hoc Weibull Distributions for TTF of each micro downtime individuated.

4.4

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5

TPM in a bottling line

A case study – Part 2

"Throughout the years, the importance of the maintenance function, and therefore also of maintenance management, has grown… what has been the value of maintenance optimization models for maintenance management? How often and in what sense have these models been applied successfully? "

[Dekker, 1996]

5.1
Statistical Analysis - Overview

In this chapter is presented the Statistical Analysis of micro downtime data about the Palletizer, as the most critical machine of the case study of Chapter 3. After the micro downtime data collection, it emerges that the Palletizer was the most critical machine influenced by this inefficiency and so it affects the whole line.

OEE recoverable from its micro downtimes had been calculated; moreover, problem solving techniques, brainstorming and design engineering department had been involved to carry out possible solutions to eliminate or decrease micro downtime effects. A CPI (Cost Performance Indicator) had been carried out to highlight benefits of possible investments. An investment had been proposed to eliminate the most critical one, as Micro downtime A of the Palletizer (Bundle not aligned).

Anyway, the evaluation of a new buffer is carried out, to evaluate the possibility of reduce all micro downtime of the Palletizer, as the machine mostly affected by this phenomena. The final aim is to construct an innovative simulative model of the line to highlight benefits (or not) of implementing a buffer before the palletizer.

For doing this, a statistical analysis of micro downtime A, B, C, D and E is carried out. The idea is to define ad hoc probability distributions for TTF and TTR data of each micro downtime and to apply them in a simulative model of the line.

The final aim is to carry out costs and benefits for a new buffer, as a secondary solution to micro downtime inefficiency. In other words, buffer is considered a solution when it is not possible to solve directly micro downtime problem or the improvement activity is too expensive. Moreover simulative model is a great tool for management to better evaluate investment benefits and criticalities.

5.1.1

TTR and TTF distributions

In this paragraph it is proposed the study of the probability distribution of the first five micro downtime of the palletizer, as they results as the most critical ones. It has been supposed that the inefficiency of the other micro downtime it is not relevant as they cover less than the 20% of machine inefficiency.

The aim is to identify the evolution of micro downtime in the production process during with time. To do this analysis we used MINITAB® software.

First of all, for each cause of micro downtime, the main statistical parameters such as the mean, the maximum, the minimum and standard deviation were studied.

Table 5.1 summarizes the principal statistical parameters for the TTR data.

Micro downtime (TTR)	N	Mean	SD	CV	Minimum	Maximum	Skewness	Kurtosis
MD A	598	25.79	27.35	1.0604	5	300	4.83	34.08
MD B	182	36.99	44.95	1.2153	10	480	6.49	55.57
MD C	150	52.85	34.51	0.653	10	184	1.67	3.44
MD D	130	34.35	28.75	0.8371	10	180	2.35	6.51
MD E	66	33.71	21.71	0.6439	10	120	2.31	6.47

Table 5.1 TTR data - statistical analysis

All the micro downtime causes data have a CV below or close to 1 which means that the downtime variability is low. Moreover the skewness index is positive and this means that the probability distribution presents an asymmetric curve with the tail on the right hand side (right-skewed). The

Kurtosis index is high for all micro downtimes, so the probability distribution shape is high.

The same analysis has been done for TTF data (Table 5.2). In this case the CV is again lower or close to 1, so the variability is low. The skewness index is positive, except for micro downtime C which presents the tail on the left side (left-skewed), while the others are right-skewed. Finally, the Kurtosis index of micro downtimes A and B are positive, and this means a sharp peak in the probability distribution, while the others are negative, so the distribution is flatter.

Micro downtime (TTF)	N	Mean	SD	CV	Minimum	Maximum	Skewness	Kurtosis
MD A	158	566.8	761.2	1.343	0	6240	3.72	20.63
MD B	7	2931	2925	0.9978	180	8160	1.03	0.35
MD C	4	780	467	0.5991	240	1200	-0.33	-3.98
MD D	8	2070	1546	0.7471	540	4680	0.67	-1.09
MD E	16	3799	3082	0.8114	360	9420	0.6	-0.9

Table 5.2 TTF data - statistical analysis

Following this initial analysis, the distribution that better fits data, both for TTR and TTF, for each micro downtime has been identified. The aim is to define if there is a correlation between the distributions of the various micro downtime looking at their similarities.

To do this a goodness-of-fit test was used with a statistical significance of 5%. Three indexes were used:

1. Anderson-Darling index (AD)
2. P-value index
3. LRT P Index

The AD index was considered as the primary one as recommended in Tsarouhas, P. H et al. The distribution used were:

- Normal;
- Lognormal;
- 3-parameter lognormal;

- Exponential;
- 2-parameter exponential;
- Weibull;
- 3-parameter Weibull;
- Smallest extreme value;
- Largest extreme value;
- Gamma;
- 3-parameter gamma;
- Logistic;
- Log-logistic;
- 3-parameter log-logistic

Table 5.3, Table 5.4, Table 5.5, Table 5.6 and Table 5.7 present the analysis of TTR distribution of micro downtime A, B, C, D, and E with the selected distribution in red.

Table 5.8, instead, summarized the most suitable probability distribution for each TTR distribution of the various micro downtime. Each one is different from the other and it seems there is no a correlation between them.

Bundle not Aligned (Palletizer) - A			
Distribution TTR	**AD**	**P**	**LRT P**
Normal	55.244	<0.005	
LogNormal	3.311	<0.005	
3-Parameter LogNormal	**3.121**	*****	**0**
Exponential	30.491	<0.003	
2-Parameter Exponential	4.621	<0.010	0
Weibull	16.28	<0.010	
3-Parameter Weibull	5.375	<0.005	0
Smallest Extreme Value	126.673	<0.010	
Largest Extreme Value	12.193	<0.010	
Gamma	10.454	<0.005	
3-Parameter Gamma	4.764	*	0
Logistic	20.301	<0.005	
Log-Logistic	4.893	<0.005	
3-Parameter Loglogistic	4.085	*	0

Table 5.3 Micro downtime A - TTR Probability Distribution

Uncorrect Stratum (N°2) - B			
Distribution TTR	**AD**	**P**	**LRT P**
Normal	25.499	<0.005	
LogNormal	2.427	<0.005	
3-Parameter LogNormal	1.198	*	0
Exponential	15.4	<0.003	
2-Parameter Exponential	3.468	<0.010	0
Weibull	10.865	<0.010	
3-Parameter Weibull	3.725	<0.005	0
Smallest Extreme Value	46.129	<0.010	
Largest Extreme Value	6.68	<0.010	
Gamma	7.565	<0.005	
3-Parameter Gamma	3.597	*	0
Logistic	10.143	<0.005	
Log-Logistic	1.374	<0.005	
3-Parameter Loglogistic	**0.828**	*****	**0**

Table 5.4 Micro downtime B - TTR Probability Distribution

Pallets Warehouse Allarm - C			
Distribution TTR	**AD**	**P**	**LRT P**
Normal	6.211	<0.005	
LogNormal	1.768	<0.005	
3-Parameter LogNormal	1.728	*	0.324
Exponential	12.689	<0.003	
2-Parameter Exponential	4.826	<0.010	0
Weibull	2.786	<0.010	
3-Parameter Weibull	**1.698**	**<0.005**	**0**
Smallest Extreme Value	13.786	<0.010	
Largest Extreme Value	2.547	<0.010	
Gamma	2.059	<0.005	
3-Parameter Gamma	1.711	*	0.001
Logistic	3.947	<0.005	
Log-Logistic	1.984	<0.005	
3-Parameter Loglogistic	2.003	*	0.152

Table 5.5 Micro downtime C - TTR Probability Distribution

Uncorrect Stratum (N°1)- D			
Distribution TTR	**AD**	**P**	**LRT P**
Normal	10.866	<0.005	
LogNormal	1.811	<0.005	
3-Parameter LogNormal	**1.027**	*****	**0**
Exponential	9.134	<0.003	
2-Parameter Exponential	1.694	0.018	0
Weibull	4.885	<0.010	
3-Parameter Weibull	1.223	<0.005	0
Smallest Extreme Value	17.737	<0.010	
Largest Extreme Value	4.857	<0.010	
Gamma	4.001	<0.005	
3-Parameter Gamma	1.362	*	0
Logistic	7.156	<0.005	
Log-Logistic	1.527	<0.005	
3-Parameter Loglogistic	1.067	*	0

Table 5.6 Micro downtime D - TTR Probability Distribution

Pallet not Alligned (Palletizer Entry) - E			
Distribution TTR	**AD**	**P**	**LRT P**
Normal	4.552	<0.005	
LogNormal	0.902	0.02	
3-Parameter LogNormal	0.694	*	0.11
Exponential	8.146	<0.003	
2-Parameter Exponential	2.489	<0.010	0
Weibull	2.704	<0.010	
3-Parameter Weibull	1.346	<0.005	0
Smallest Extreme Value	8.451	<0.010	
Largest Extreme Value	1.513	<0.010	
Gamma	1.751	<0.005	
3-Parameter Gamma	1.166	*	0.006
Logistic	2.701	<0.005	
Log-Logistic	0.703	0.039	
3-Parameter Loglogistic	**0.687**	*****	**0.082**

Table 5.7 Micro downtime E - TTR Probability Distribution

Microdowntime	TTR Distribution
A	3-Parameter Lognormal
B	3-Parameter Loglogistic
C	3-Parameter Weibull
D	3-Parameter Lognormal
E	3-Parameter Loglogistic

Table 5.8 Total Micro downtime - TTR Probability Distribution

Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5 present goodness-of-fit graphics for the selected distributions from Minitab® software.

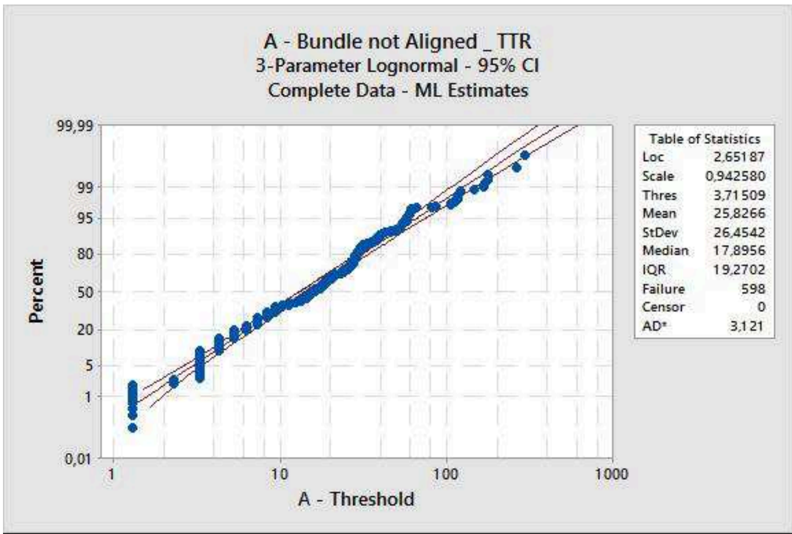

Figure 5.1 TTR probability distribution plot - Micro Downtime A

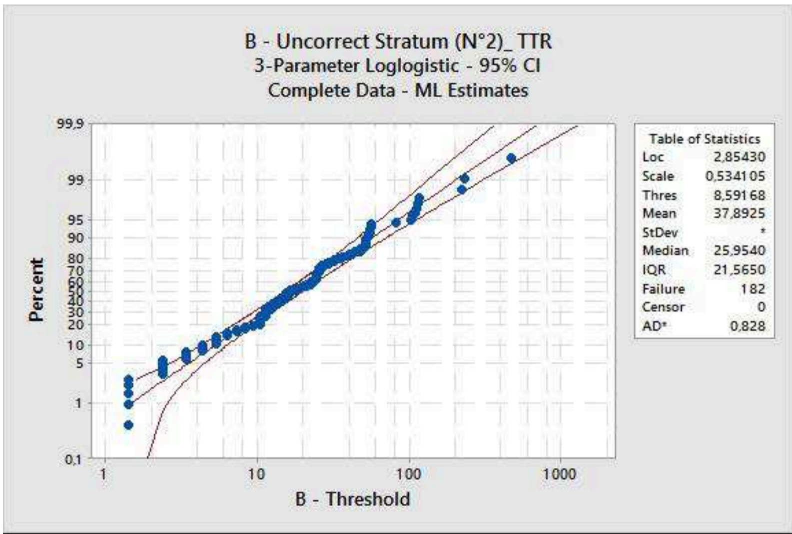

Figure 5.2 TTR probability distribution plot - Micro Downtime B

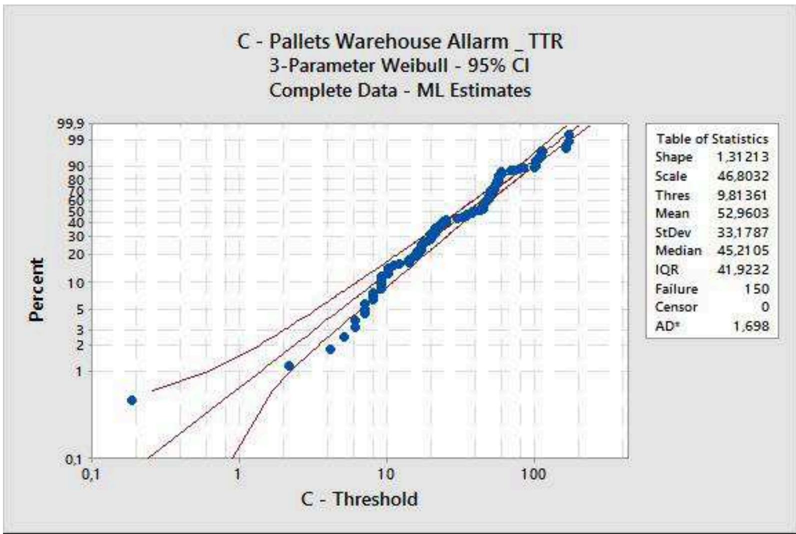

Figure 5.3 TTR probability distribution plot - Micro Downtime C

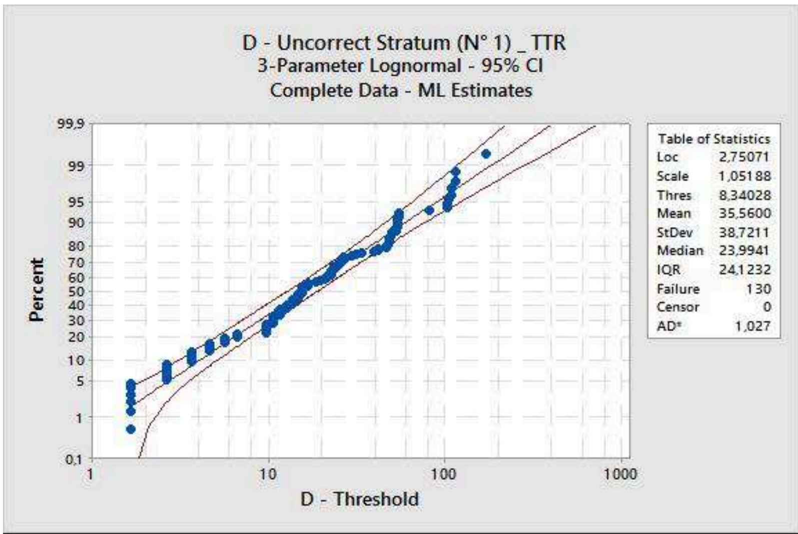

Figure 5.4 TTR probability distribution plot - Micro Downtime D

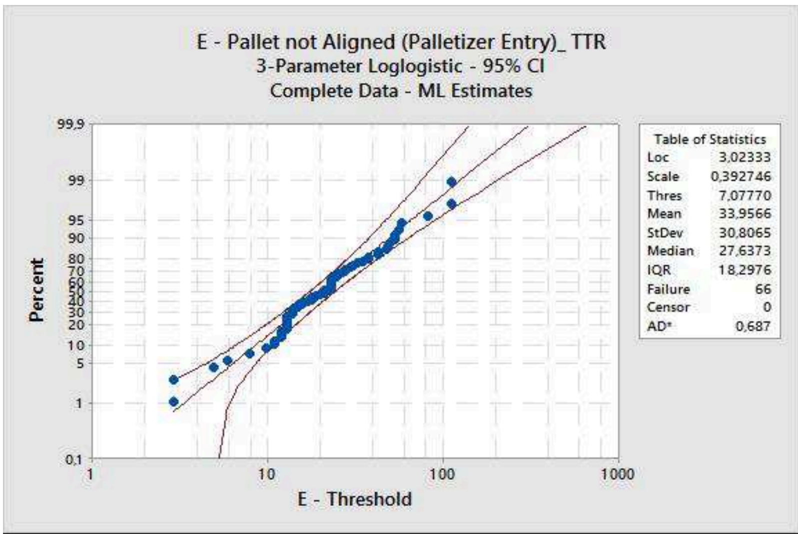

Figure 5.5TTR probability distribution plot - Micro Downtime E

The same has been done for TTF data.

Table 5.9, Table 5.10, Table 5.11, Table 5.12 and Table 5.13 present the analysis of TTF distribution of Micro downtime A, B, C, D and E, with the selected distribution in red.

Bundle not Aligned (Palletizer) - A	
Distribution TTF	**AD**
Weibull	2,143
Lognormal	**1,162**
Exponential	2,379
Loglogistic	1,339
3-Parameter Weibull	4,979
3-Parameter Lognormal	2,028
2-Parameter Exponential	7,117
3-Parameter Loglogistic	5,203
Smallest Extreme Value	27,73
Normal	13,823
Logistic	8,574

Table 5.9 Micro downtime A- TTF Probability Distribution

Uncorrect Stratum (N°2)- B	
Distribution TTF	**AD**
Weibull	1,925
Lognormal	2,026
Exponential	1,948
Loglogistic	**1,881**
3-Parameter Weibull	1,89
3-Parameter Lognormal	1,944
2-Parameter Exponential	1,897
3-Parameter Loglogistic	1,882
Smallest Extreme Value	2,099
Normal	2,036
Logistic	2,106

Table 5.10 Micro downtime B- TTF Probability Distribution

Pallets Warehouse Allarm - C	
Distribution TTF	**AD**
Weibull	3,092
Lognormal	3,076
Exponential	3,203
Loglogistic	**2,939**
3-Parameter Weibull	3,804
3-Parameter Lognormal	4,175
2-Parameter Exponential	3,164
3-Parameter Loglogistic	3,307
Smallest Extreme Value	3,1
Normal	3,086
Logistic	2,993

Table 5.11 Micro downtime C- TTF Probability Distribution

Uncorrect Stratum (N°1)- D	
Distribution TTF	**AD**
Weibull	1,939
Lognormal	1,981
Exponential	2,024
Loglogistic	1,94
3-Parameter Weibull	1,937
3-Parameter Lognormal	1,909
2-Parameter Exponential	**1,892**
3-Parameter Loglogistic	1,937
Smallest Extreme Value	1,964
Normal	2,012
Logistic	2,039

Table 5.12 Micro downtime D- TTF Probability Distribution

Pallet not Alligned (Palletizer Entry) - E	
Distribution TTF	**AD**
Weibull	1,173
Lognormal	1,327
Exponential	1,183
Loglogistic	1,182
3-Parameter Weibull	1,172
3-Parameter Lognormal	1,346
2-Parameter Exponential	**1,171**
3-Parameter Loglogistic	1,174
Smallest Extreme Value	1,504
Normal	1,352
Logistic	1,366

Table 5.13 Micro downtime E- TTF Probability Distribution

Microdowntime	TTF Distribution
A	LogNormal
B	LogLogistic
C	LogLogistic
D	2-Parameter Exponential
E	2-Parameter Exponential

Table 5.14 Total Micro downtime - TTF Probability Distribution

Table 5.14 instead, present the summary of the TTF micro downtime probability distribution. Aldo for TTF distributions it seems there is no correlation as they are different from each other.

Figure 5.6, Figure 5.7, Figure 5.8, Figure 5.9, Figure 5.10 show goodness-of-fit graphics for the selected distributions.

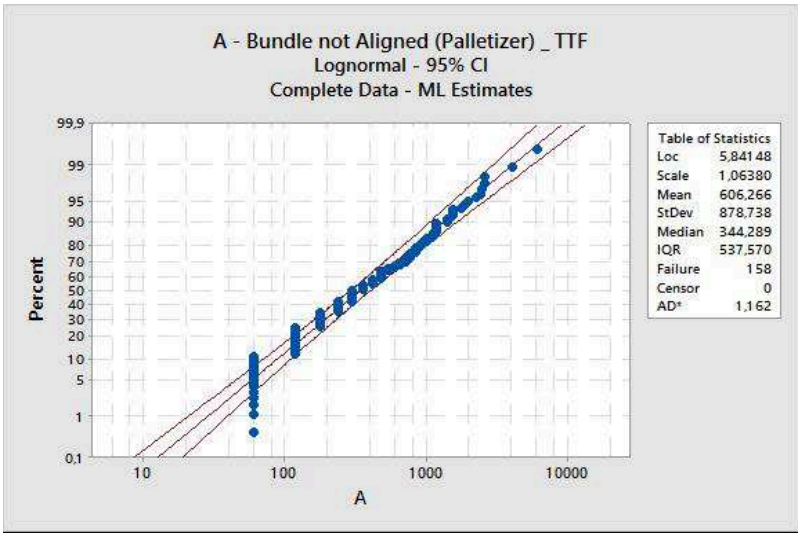

Figure 5.6 TTF probability distribution plot - Micro Downtime A

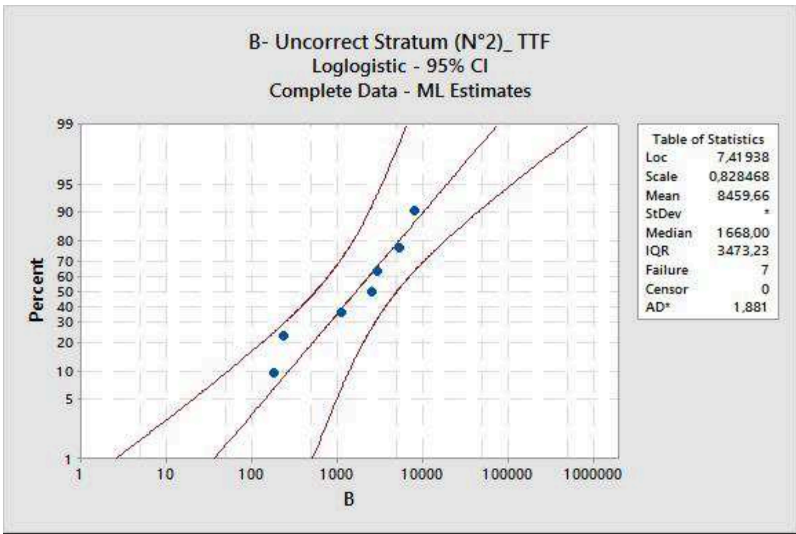

Figure 5.7 TTF probability distribution plot - Micro Downtime B

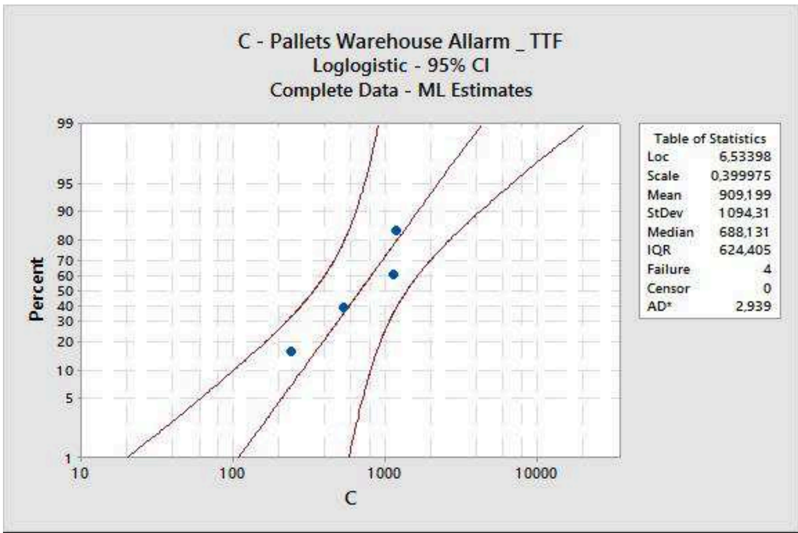

Figure 5.8 TTF probability distribution plot - Micro Downtime C

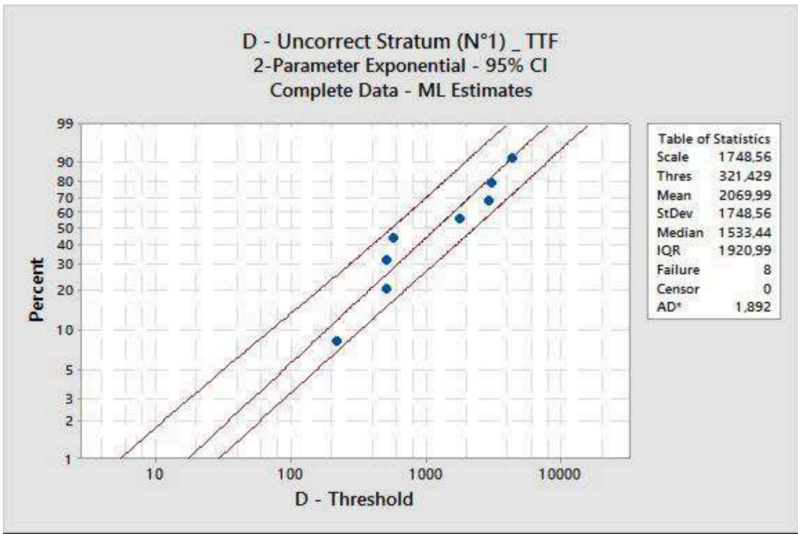

Figure 5.9 TTF probability distribution plot - Micro Downtime D

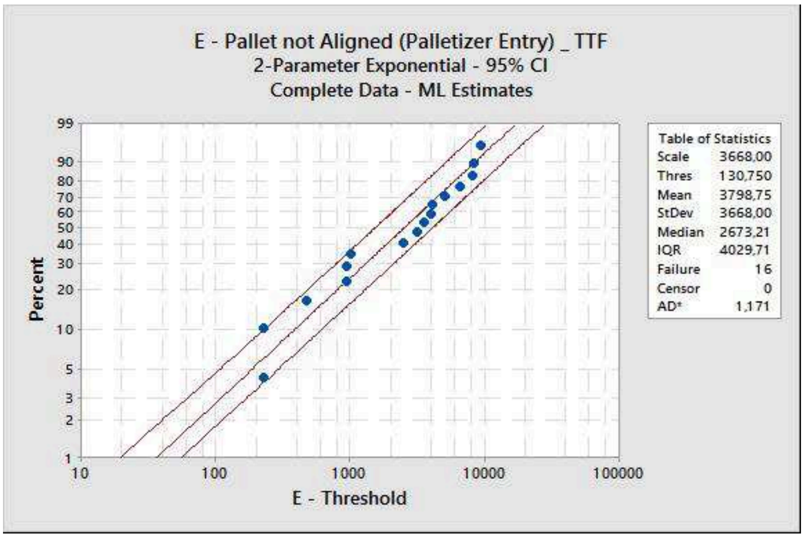

Figure 5.10 TTF probability distribution plot - Micro Downtime E

5.1.2

TTR and TTF correlation

The statistical analysis of the previous paragraph (5.1.1) points out different distributions for TTR and TTF data of micro downtime.

A second part of the TTR and TTF analysis was concentrated on the relationship between them; for this, TTR vs TTF graphics are carried out about micro downtime A, B, C, D and E. Plotting TTR and TTF data about micro downtime is possible to determine their trend focusing on the relationship between the duration and the frequency. In fact, if frequency is standard and high, with a normal distributed TTR, the micro downtime could be related to a chronic cause. Otherwise, if both frequency and duration are random, micro downtime is probably related to random effects of production process.

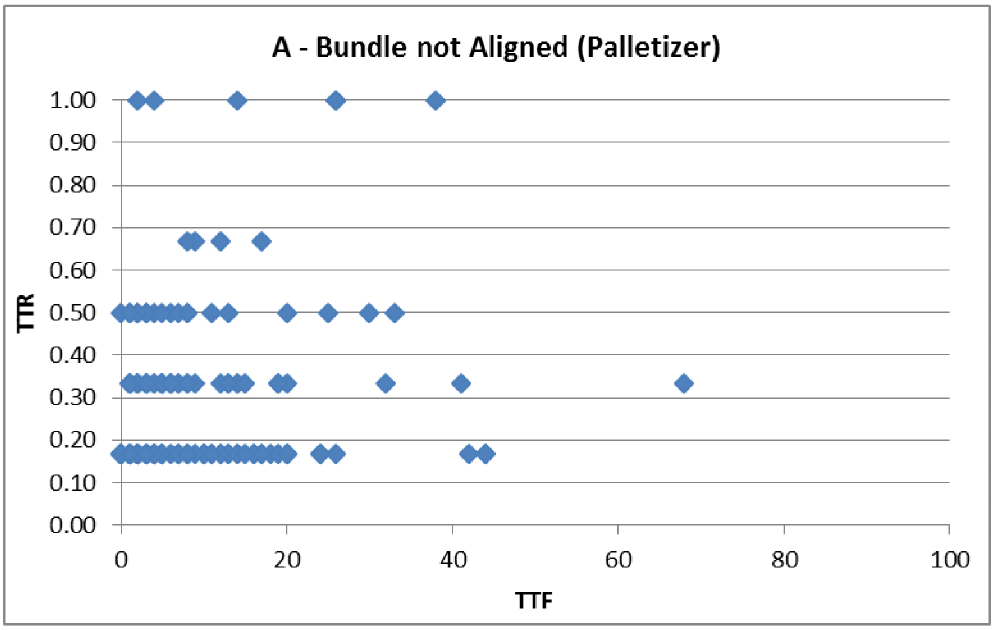

Figure 5.11 TTF-TTR Plot - Micro Downtime A

Graphic of micro downtime A, for example, shows that this process failure might be related to a chronic cause, as data are concentrated in the right part (Figure 5.11). TTF is a limited range of values (between zero and 20 minutes), while TTR range is more extended (between zero and 1 minutes); this is probably due to the human factor incisiveness. The previous analysis demonstrate that the nature of the problem was in the inclination and speed of the transport tapes in ingress; so that the problem was effectively chronic.
Figure 5.12, Figure 5.13, Figure 5.14 and Figure 5.15 show the other graphics of micro downtime B, C, D and E.
They highlight that the others micro downtime have a largest TTF range; this means that the other micro downtime might have a random nature, depending on the normal functioning of the machine or that they are difficult to predict as they are not constant.

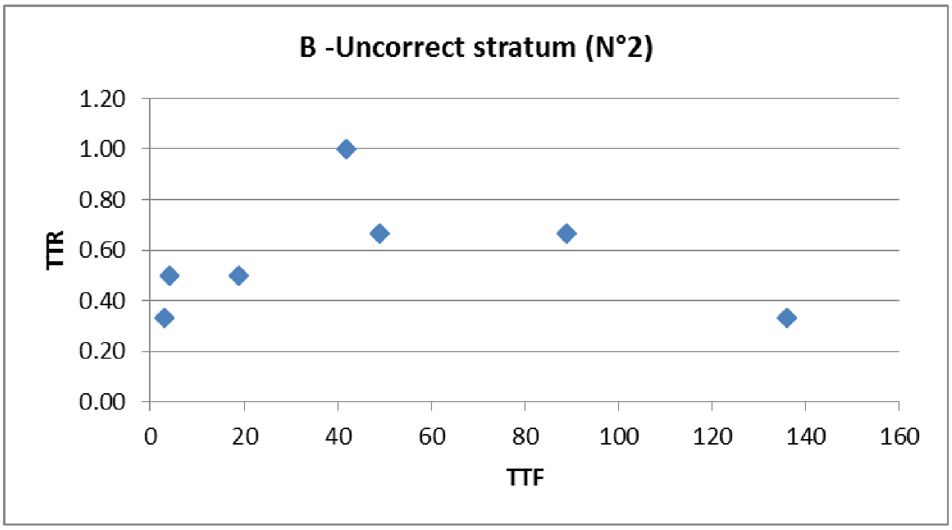

Figure 5.12 TTF-TTR Plot - Micro Downtime B

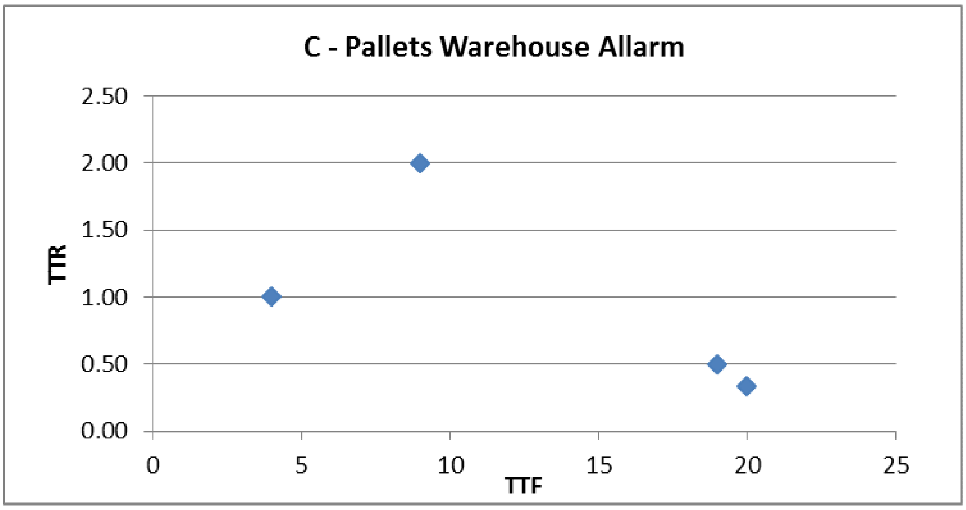

Figure 5.13 TTF-TTR Plot - Micro Downtime C

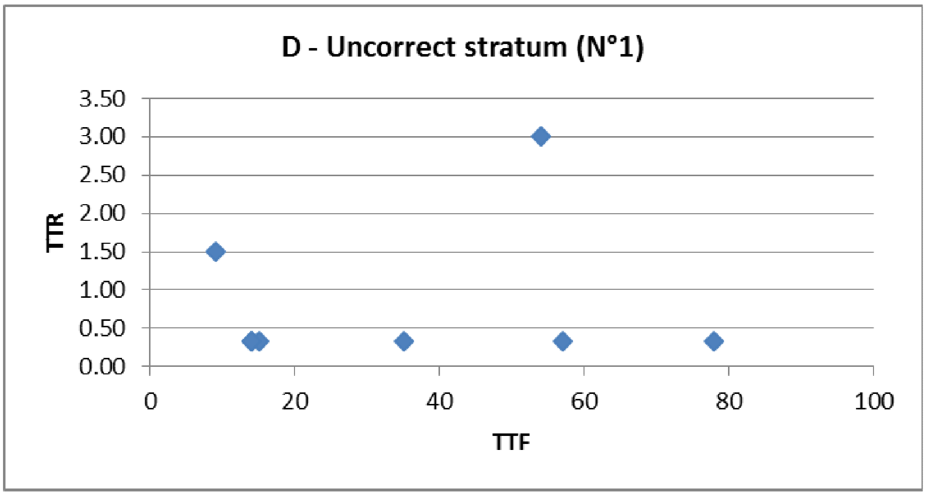

Figure 5.14 TTF-TTR Plot - Micro Downtime D

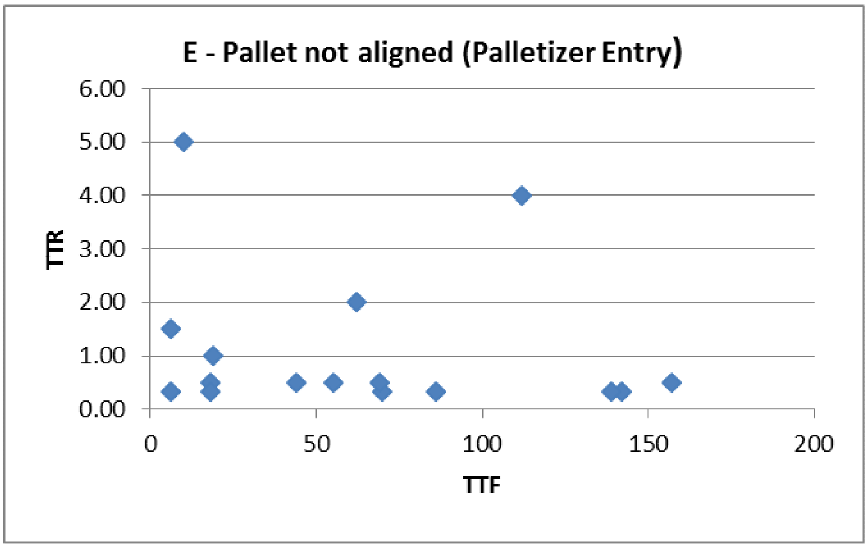

Figure 5.15 TTF-TTR Plot - Micro Downtime E

5.1.3

Other Considerations

The statistical analysis of the probability distributions of TTR and TTF of the most critical micro downtime of M1 has been carried out.

For each micro downtime of the palletizer it has been proposed the optimal TTR and TTF probability distribution, as the better distribution that fitted the collected data; moreover it has been carried out TTF-TTR graphics to highlight possible trends of micro downtime. Relationship between duration and frequency of micro downtime can give a first idea of micro downtime nature and helping the resolution of the process failure.

Anyway probability distributions of this analysis are very different and personalized, and difficult to extend to more generalized models. Moreover, data are not so considerable to give an absolute validity of the probability distributions carried out.

In order to study the reliability of the machine and to construct a simulative model of the production line, another statistical analysis is carried out assuming that TTF data follows Weibull probability distribution and TTR the normal one, as assumed in Battini et al., (2013) for the downtime of a whole machine.

5.2
Reliability Analysis

To create the basis for a relevant simulative model, reliability analysis of the previous data is carried out. In fact, the previous probability distributions were very different from each other and data were not so consistent to construct a generalized model.

As suggested by Battini et al. (2013), downtime TTF data probability distribution is well fitted by Weibull distribution, while TTR data probability one is well fitted by normal distribution. In their work, the authors suggest to apply Weibull probability distribution to downtime TTF of machines.

What is new, is that it is proposed to apply Weibull distribution for each single micro downtime, not to the whole machine. The aim is to carry out for each micro downtime a specific trend, depending on Weibull parameters (process failures that are decreasing, increasing or random).

Using MINITAB®, Weibull parameters are carried out and then applied to the simulative software (FlexSim®).

In the following sessions Weibull distribution analysis and Reliability considerations are carried out.

5.2.1
Weibull Distribution

In order to carry out micro downtime trend, it is supposed that their TTF probability distribution follow the Weibull one.

First of all, as it is assumed that data about Time To Failure follow Weibull distribution, Reliability function is defined as:

$$R(t)= e^{-(\frac{t}{\theta})^{\beta}} \quad (20)$$

Where β is the shape parameter, θ the scale parameter and t is the considered time.

In the same way, they could be defined the Probability Density function of the failure distribution and the Hazard Failure Rate as:

$$f(t) = \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} x\ e^{-(\frac{t}{\theta})^{\beta}} \quad (21)$$

$$\lambda(t)= \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} \quad (22)$$

Components lifetime is well described by the so called "bathtub" curve, that plots variation of the failure rate of a component/item with the passing of the time (Figure 5.16). Plotting the failure rate and the time, it emerges a function similar to a "bathtub", as failure rate as first decreases, then is

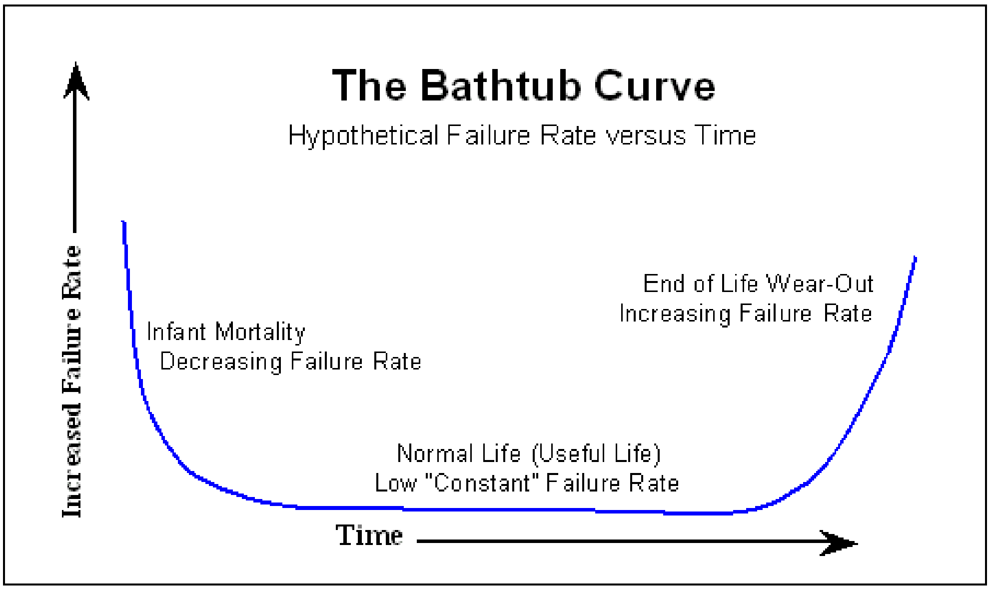

Figure 5.16 The Bath Tube Curve

costant and finally increases.

The trend of the curve can be divided into 3 parts that correspond to three parts of the item lifecycle:

- The first part, that corresponds to the setting phase, in which failure rate is decreasing;
- The central part, that corresponds to the normal life as the failure rate is constant
- The final part, that corresponds to the degradation phases the failure rate is increasing;

The analysis of the shape parameter β determines the component life position in the bathtub curve. Studying β parameter it is possible to carry out the failure rate trend (Table 5.15). When β < 1, the component is in the setting phase as the TTFs are decreasing. When β =1 the component has a random failure rate, as it is in its "normal life"; finally, when β > 1 the component is in a degradation phase as the failure rate is increasing.

Shape Parameter β	Failure rate Trend
B < 1	Setting phase (Failures decrease)
B =1	Normal life (Random Failures)
B > 1	Degradation phase (Failures increase)

Table 5.15 Meaning of the Shape Parameter β

Figure 5.17 shows Weibull curve variation based on β values and θ values.

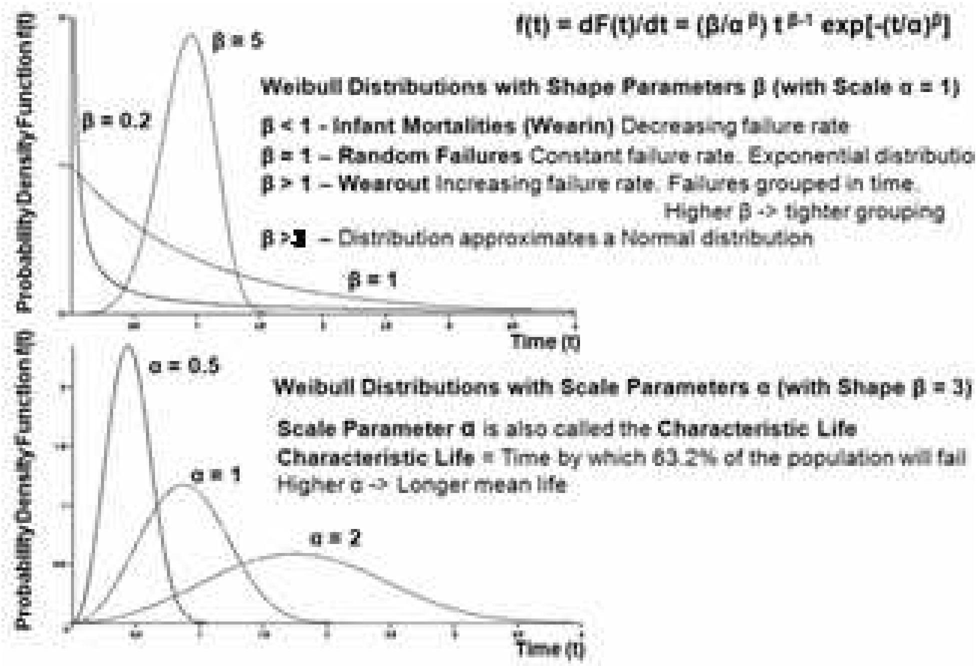

Figure 5.17 Weibull Distribution varying shape and scape parameters

5.2.2

Weibull Distribution Parameters for micro downtime

Using MINITAB® software for defining shape β and scale θ parameters, micro downtime probability distributions are carried out. Figure 5.18, Figure 5.19, Figure 5.20, Figure 5.21 and Figure 5.22 show the plotting graphics for defining the statistical parameters. It is calculated the Anderson- Darling Index (AD) and the Correlation Parameter (r) for evaluating the goodness of fit of data to Weibull Distributions; it is used the Least Squares method, with a range of 95%.

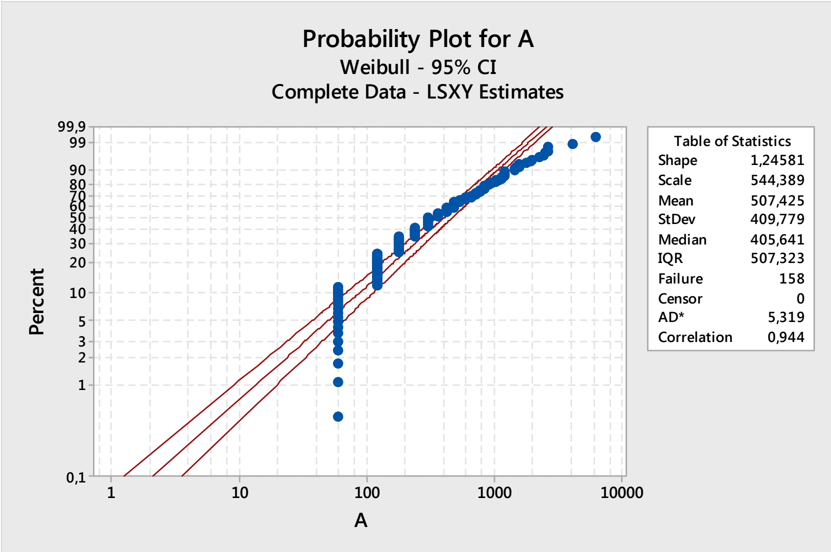

Figure 5.18 Weibull Distribution - Probability Plot for Micro Downtime A

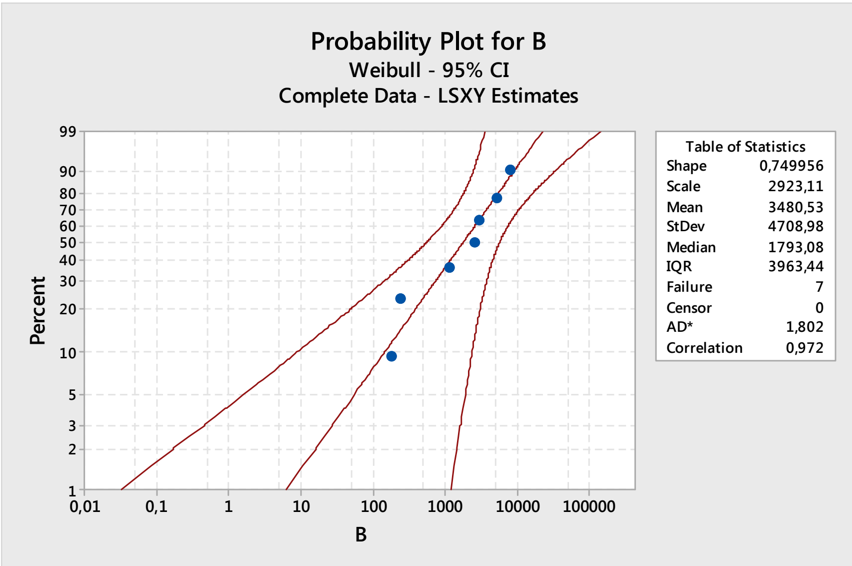

Figure 5.19 Weibull Distribution - Probability Plot for Micro Downtime B

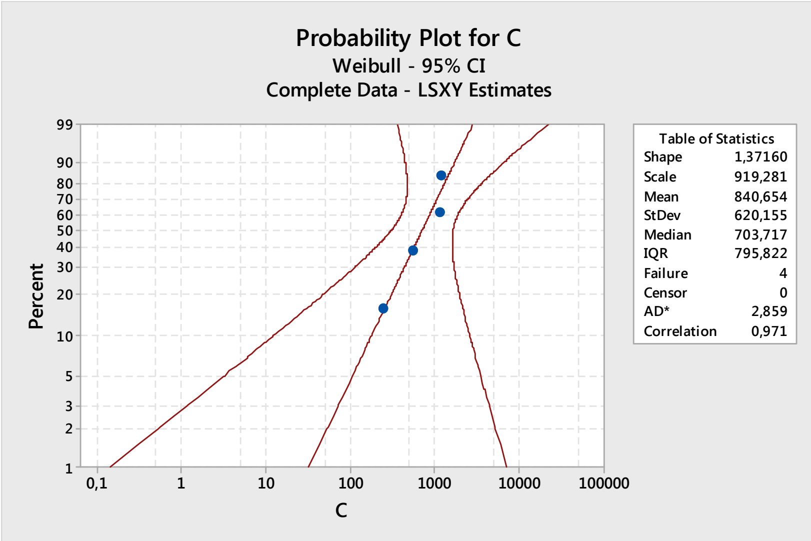

Figure 5.20 Weibull Distribution - Probability Plot for Micro Downtime C

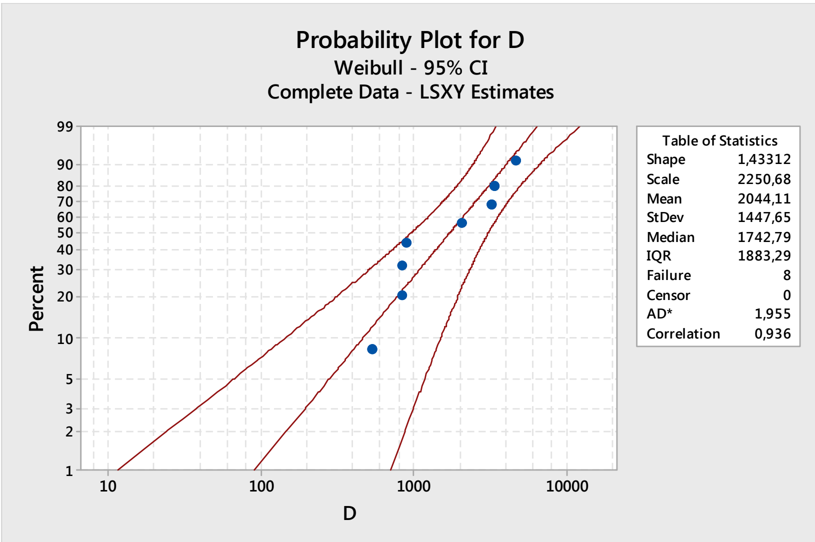

Figure 5.21 Weibull Distribution - Probability Plot for Micro Downtime D

Table 5.16 summarizes β and θ parameters for each micro downtime, and also for the palletizer as machine N°1 (Figure 5.23). The palletizer TTF probability distribution is calculated as the sum of the whole micro downtime registered, and it is compared to the single causes (Figure 5.24 and Figure 5.25). In addition it is calculated MTTR and MTTF parameter and the recoverable OEE for each micro downtime, considering the TTR time and the OEE measured in the considered period.

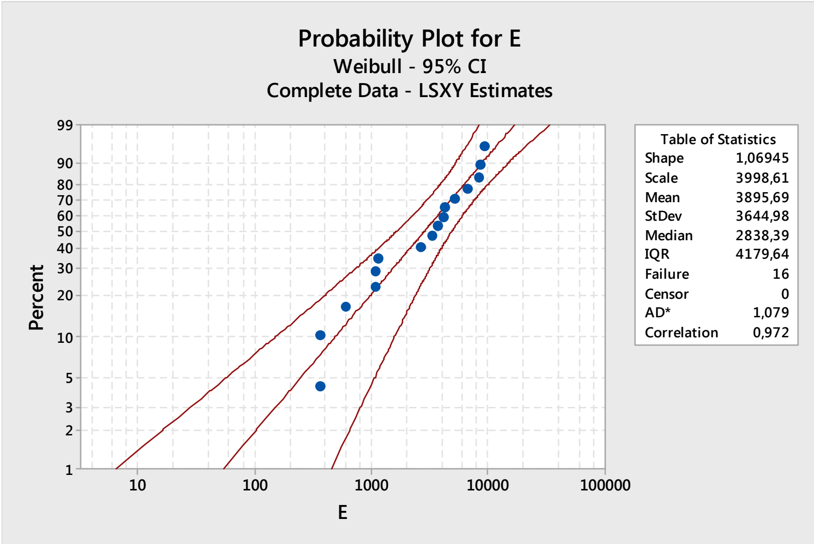

Figure 5.22 Weibull Distribution - Probability Plot for Micro Downtime E

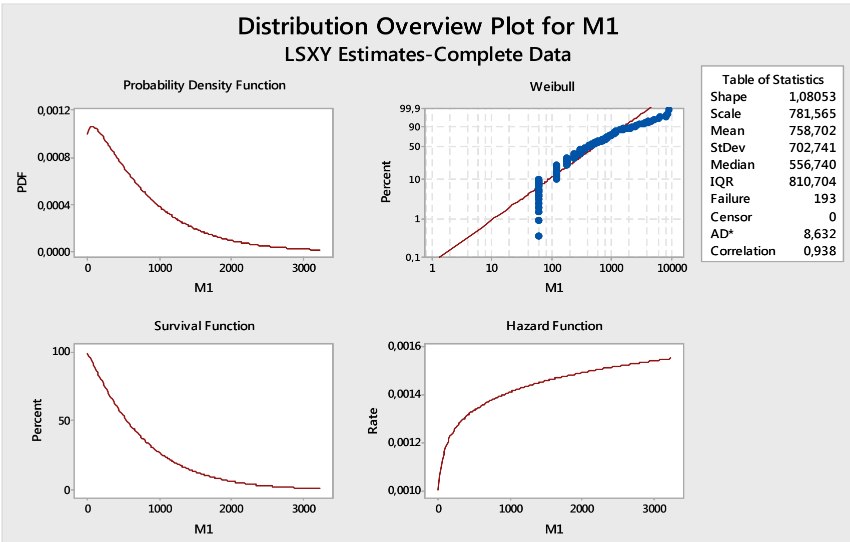

Figure 5.23 Weibull Distribution - Probability Plot for Machine 1 (Palletizer)

Figure 5.24 and Figure 5.25 about R(t) and F(t) curves of the various distributions are carried out.

From the analysis of β and θ parameters, it emerges that M1 (the palletizer) has a constant failure rate as β is very near to 1; this means that the machine is in its useful life, with random and unpredictable failures. Also micro downtime E has β near to 1 that is synonymous of a constant failure rate. Micro downtime A, C and D, instead, have a shape parameter greater than 1; this means that the hazard failure rate is increasing and components are in their degradation phase, near the end of their life. Finally micro downtime B has β smaller than 1, so the failure rate is decreasing and the component is in its setting phase, at the beginning of its life.
Looking MTTR data, micro downtime D results the higher (67.5s), followed by micro downtime B (57.5s). Micro downtime A MTTR is the lower, 17,5s, but because of its high frequency it influenced a lot M1 MTTR.
Similar considerations could be done for MTTF: micro downtime B has the higher (29.3143s), followed by D and E. Micro downtime C and A, instead, have a lower MTTR, that influences the M1 one (1.016s).

	MICRO DOWNTIME					
	A	B	C	D	E	M1
β	1,24581	0,749956	1,3716	1,43312	1,06945	1,08053
θ	544,389	2923,11	919,281	2250,68	3998,61	781,565
AD	5,319	1,802	2,859	1,955	1,079	8,632
r	0,944	0,972	0,971	0,936	0,972	0,938
MTTF(s)	602,658	293143,4	780	2070	3798,75	1016,58
MTTR(s)	17,8571	34,2857	57,5	48,75	67,5	24,335
OEE	1,45%	0,78%	0,89%	0,53%	0,44%	4,09%

Table 5.16 Weibull Parameters, MTTF, MTTR and OEE Recoverable of Micro Downtime (M1)

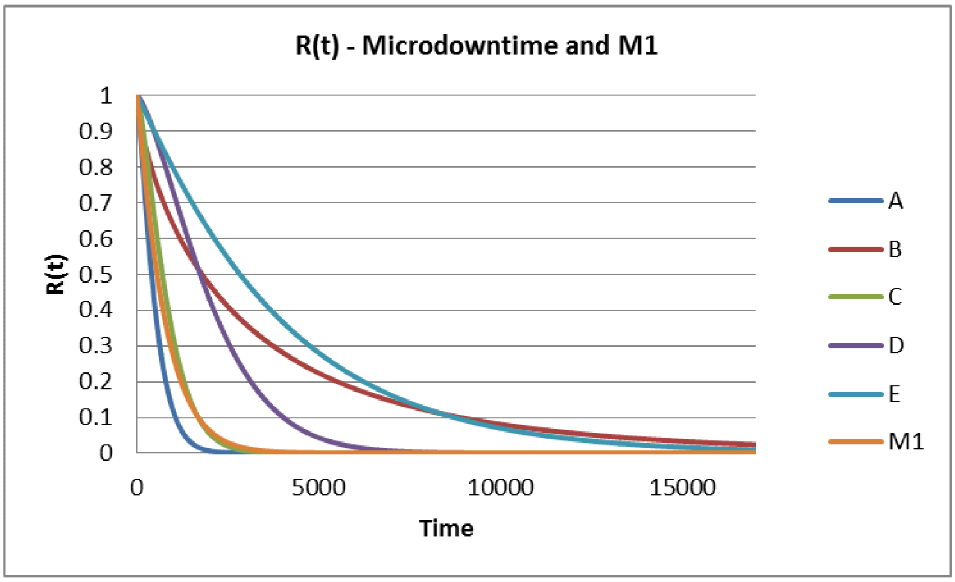

Figure 5.24 R(t) Function of M1

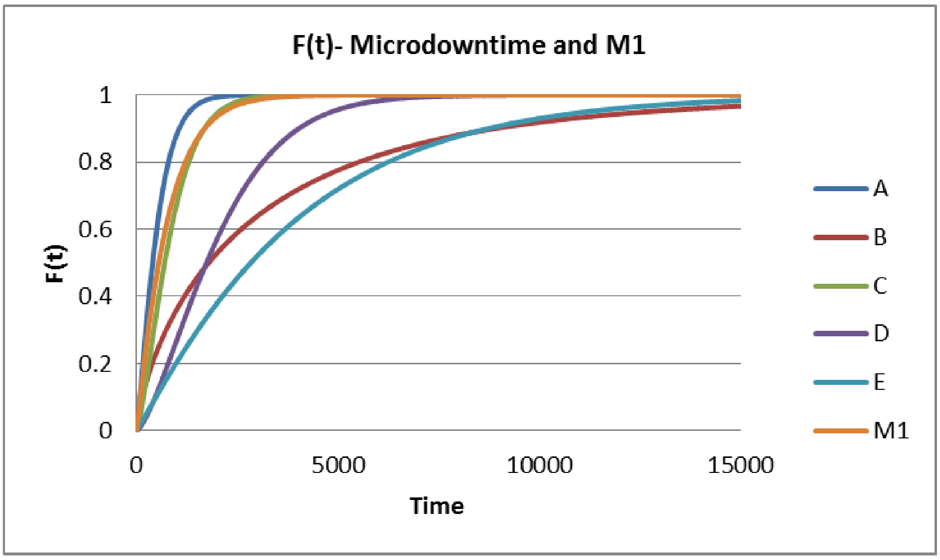

Figure 5.25 F(t) Function of M1

After this analysis a question arises: “How failure probability distribution of micro downtime A, B, C, D and E influences the failure rate of M1 ?”

To answer to this question, Reliability distribution of M1 is re-calculated without the considered micro downtime; in other words it has been recalculated β and θ parameters of M1 without TTF data about micro downtime A, then micro downtime B, and so on.

Figure 5.26, Figure 5.27, Figure 5.28, Figure 5.29, Figure 5.30 show the plotting graphics about data correlation. For example Figure 5.26 is about TTF data of the palletizer (M1) without micro downtime A (B+C+D+E).

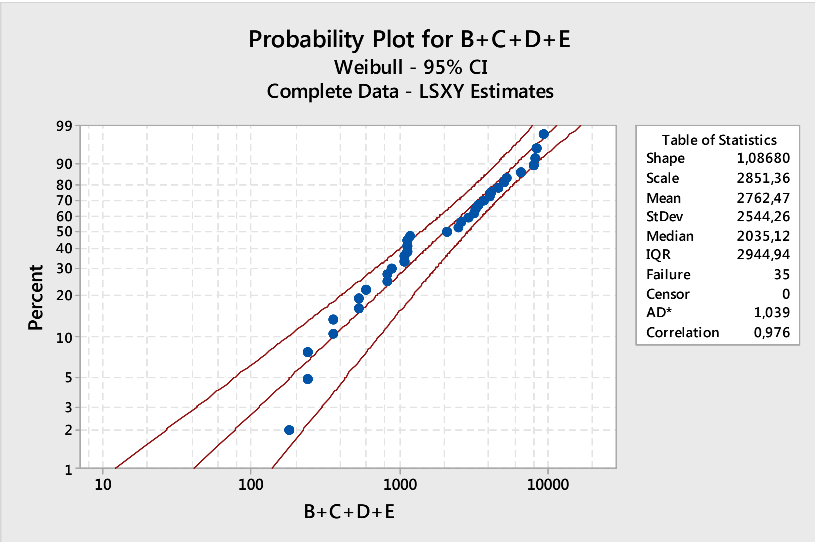

Figure 5.26 Weibull Distribution - Probability Plot for M1 without Microdowntime A

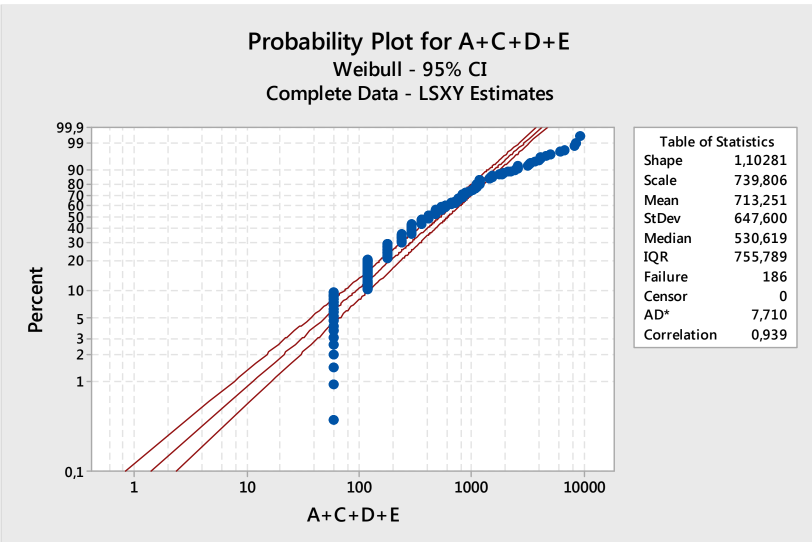

Figure 5.27 Weibull Distribution - Probability Plot for M1 without Microdowntime B

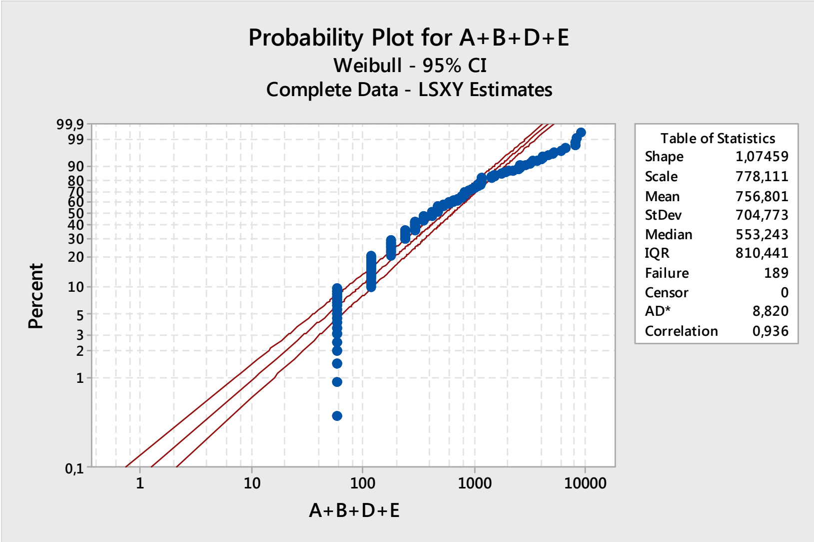

Figure 5.28 Weibull Distribution - Probability Plot for M1 without Microdowntime C

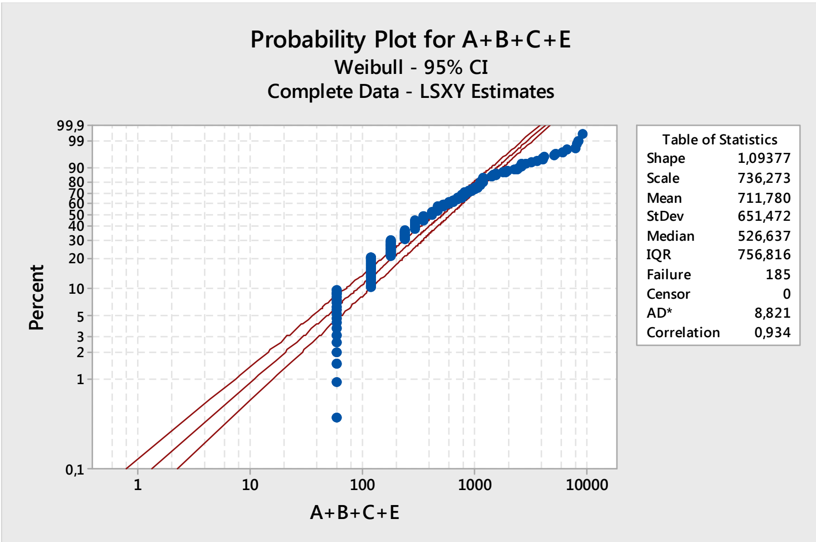

Figure 5.29 Weibull Distribution - Probability Plot for M1 without Microdowntime D

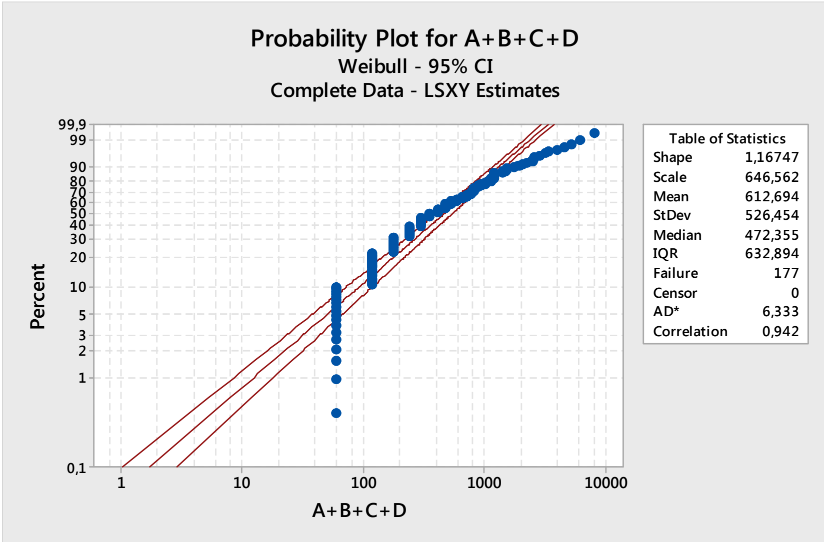

Figure 5.30 Weibull Distribution - Probability Plot for M1 without Microdowntime E

Table 5.17 summarizes the palletizer characteristics varying the presence of micro downtime. If micro downtime A, that has a shape parameter greater than 1, is eliminated, β of M1 does not change so much (1.0868s vs 1.08053s). This because βA is not so high and the machine failure rate remains constant. Anyway the MTTF is higher than before (2.885s) and the MTTR is about the double (55.4s). In fact micro downtime A has a great impact on the machine as it has high frequency and short duration, with a recoverable OEE of 1.45%. Considering the elimination of micro downtime B that has a decreasing failure rate, β of the machine increases (1.10281s); in fact the component is in a setting phase. Consequently the MTTF decreases (944.5s) as the ageing of machine increases. Also in this case the recoverable OEE is considerable (0.78%).

Deleting micro downtime C and D, there is the same effect of excluding micro downtime A on the shape parameter. β does not change so much (1.07459s and 1.09377s), also because the frequencies of these data are very low. By the way, MTTF increases in case of C elimination (1021s), and it decreases in D one (971s).

Finally, eliminating micro downtime E, the machine's failure rate increases (1.16747s) as E has a random trend of the failure rate; so the elimination of a component with a random failure rate will increase the age of machine and consequently the failure rate. MTTF and MTTR decrease (765s and 20.6s), influenced by the frequency of micro downtime E.

It is evident that Micro downtime A is the one that mostly influences the machine reliability function; it is also the one with the higher OEE improvement margin. So it is reasonable to evaluate an investment on this micro downtime to eliminate it and to increase the OEE.

	M1 RELIABILITY ANALYSIS				
	M1-A	M1-B	M1-C	M1-D	M1-E
β	1,0868	1,10281	1,07459	1,09377	1,16747
θ	2851,36	739,806	778,111	736,273	646,562
AD	1,039	7,71	8,82	8,821	6,333
r	0,976	0,939	0,936	0,934	0,942
MTTF	2885,14	944,516	1021,59	971,027	765,085
MTTR	55,42857	23,97959	23,66834	23,33	20,64171

Table 5.17 Weibull Parameters, MTTF, MTTR and OEE Recoverable of M1 varying the presence of Micro downtime

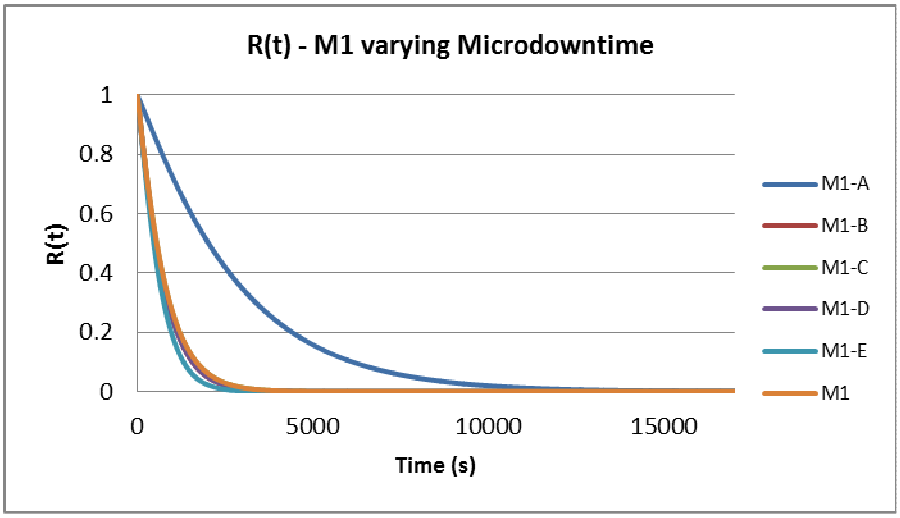

Figure 5.31 R(t) Function of M1 varying micro downtime presence

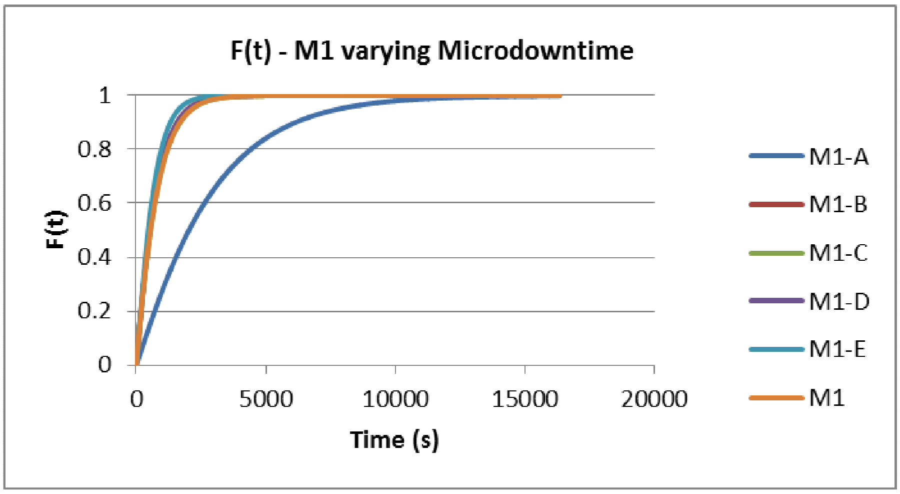

Figure 5.32 F(t) Function of M1 varying micro downtime presence

5.3

Simulative Model

After the statistical and reliability analysis of data, the simulative model is carried out. The core objective is to evaluate and to highlight benefits of buffer increasing before the palletizer, and then of the other buffer, to improve the OEE of the whole line. Moreover benefits from solution proposed in Chapter 3 are carried out in the model.

Below it is presented the software that has been used (FlexSim®), before entering in the model details.

5.3.1

FlexSim Software

Production systems simulation provides a computer-based modeling of the real system or process. It might be model all the production system reality as the process equipment, the material handling, the work in process, the

storage space and the various policies and procedures of the production process. It is useful to test various scenarios, in relation to predefined factors, as the required throughput, the wanted performances, the predefined space. Looking to an objective, it allows to find the best solutions in terms of performance optimization and costs reduction. It is based on the concept that is possible to answer to the question “what if… ? “ and evaluate results.
FlexSim is a recent simulative software, sold from USA (Utah); its core characteristic is that it is very simple and user friendly, as it do not require particular codes. It is composed by various objects; below are presented the objects used in the case study to construct the line D model.

The Source

This object is located at the beginning of the production systems as it produces items for the model. (Figure 5.33)

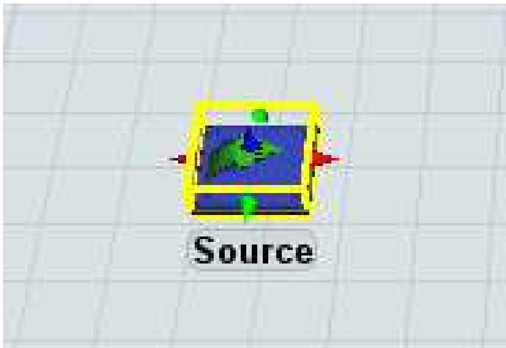

Figure 5.33 The Source

Figure 5.34 presents the source properties windows: from these two it is possible to define the Interval-Arrival Time that could be a constant period of time or can be represented by a statistical distribution. It is also possible to define the typology of item through the bottom “Flow Item Class” (for example boxes, cylinders, spheres, etc.).
Then a second list of properties is related to the flow (Figure 5.35), where it is defined the products flow after the source. In fact it is required to express the

next item, and in case more than one is available, it is necessary to define which priority the source should give.

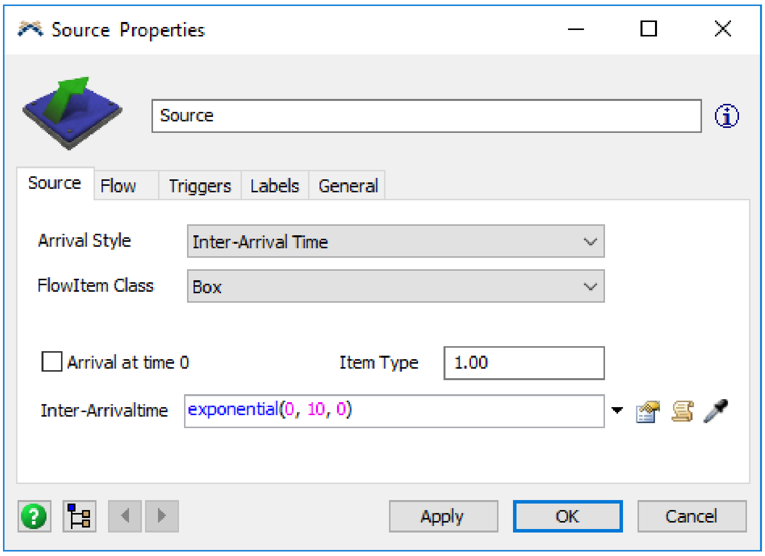

Figure 5.34 Source Properties window

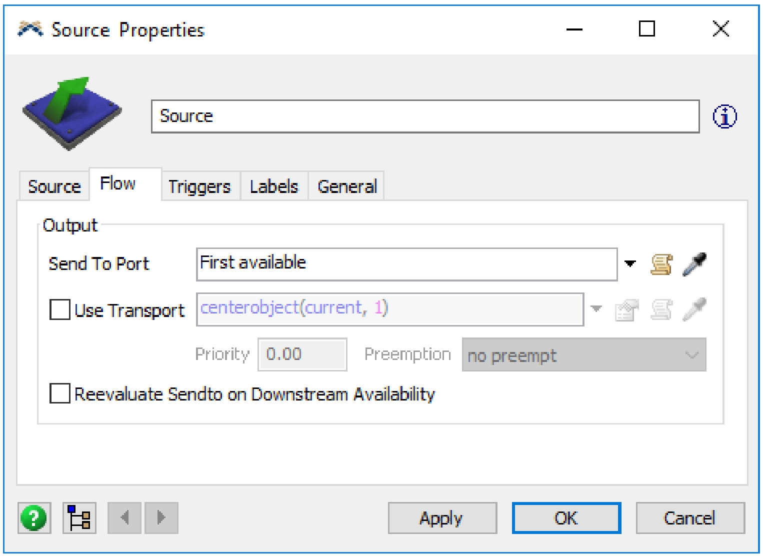

Figure 5.35 Source Properties window - Flow

The Queue

The queue can be define as that object that collects items between processors, or transport. It could be seen also as a buffer. It represents the queue of items that could be create along production process.

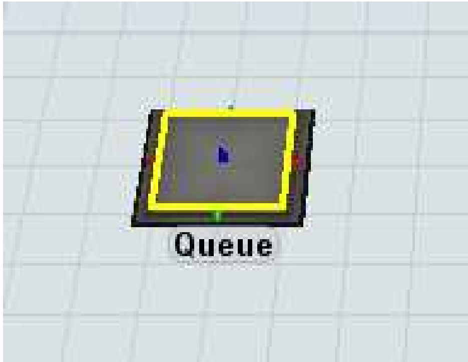

Figure 5.36 The queue

Queue properties (Figure 5.37 and Figure 5.38) defines:

- Maximum Content: It defines the maximum number of items that the queue could have;
- Lifo: If LIFO is checked, items follow Last In First Out rule for the flow, otherwise FIFO is applied (First In First Out);
- Perform Batching: if this box is checked the queue will accumulate flow items into a batch before realizing them downstream;
- Max Wait Time: It defines the maximum length of time that the queue will wait before sending the flow items downstream;
- Send to Port: it defines the rule for sending the flow items downstream;
- Use Transport: if this box is checked it is required a transport to send items downstream.

In the case study, this object is used as buffers along the line.

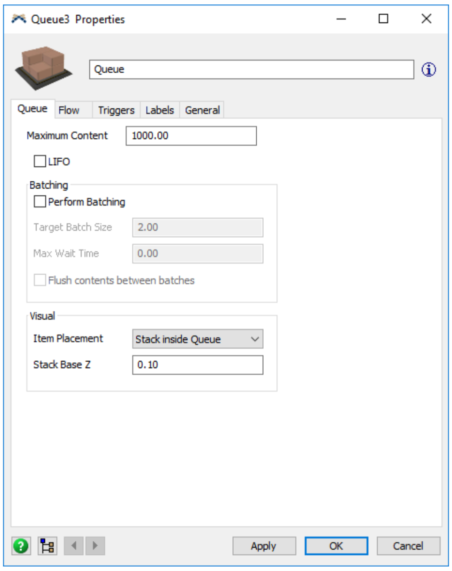

Figure 5.37 The queue property window

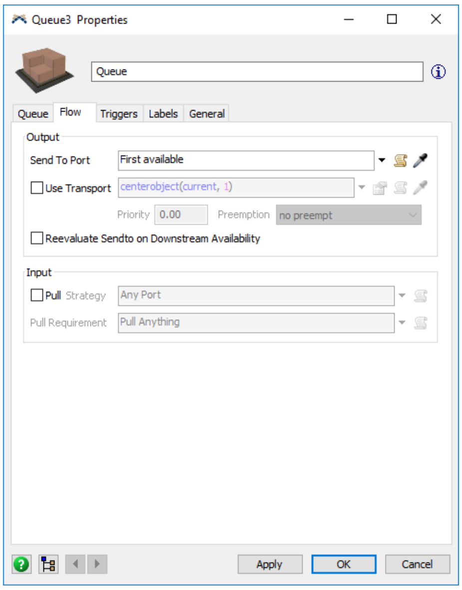

Figure 5.38 The queue property window - Flow

The Processor

The processor is the core object of the simulation. It defines the production process as it models machines along the products flow. It represents the working station in the flow and could be personalized through the properties' window.

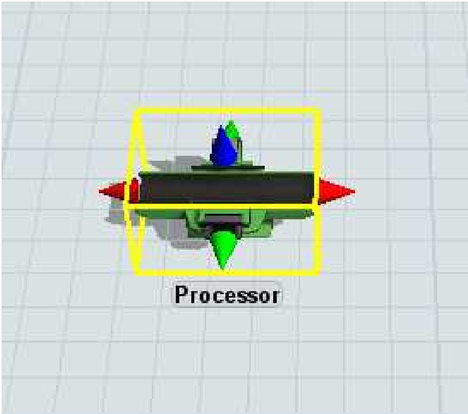

Figure 5.39 The Processor

From the properties' window it is possible to define (Figure 5.40 and Figure 5.41):

- Maximum Content: It is the maximum number of flow items that it could have in process. Usually it is equal to one.
- **Set Up Time**: It is the time dedicate to the set up operations; it could be a constant value or a statistical distribution. Moreover if the box use operator(s) is checked, it means that the action of an operator is required.
- **Process Time**: it defines the time needed to process the item; also in this case, it could be a constant value or a statistical distribution. Moreover if the box use operator(s) is checked, it means that the action of an operator is required.
- **Breakdown**: It defines the downtime of the processor depending on breakdown (idle and blocked times are intrinsic in the simulation model); it is possible to define more breakdown typologies, through the function "Add..". Then for each one it is required to define (Figure 5.42):
    - **First Failure Time**: that is the statistical distribution of the first processor failure

- **MTBF**: That is the Mean Time To Failure, corresponding to the statistical probability distribution of the time between two failures
- **MTTR**: that is the Mean Time to Repair, corresponding to the statistical probability distribution of the duration of a failure.

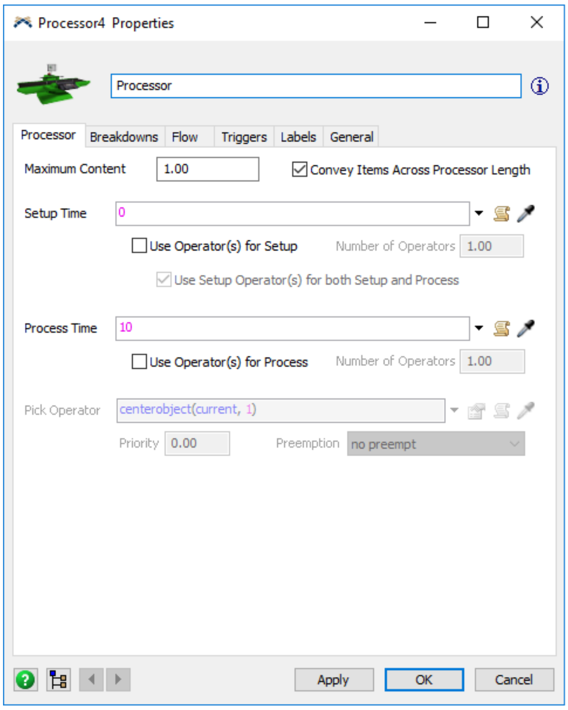

Figure 5.40 The processor property window - Flow

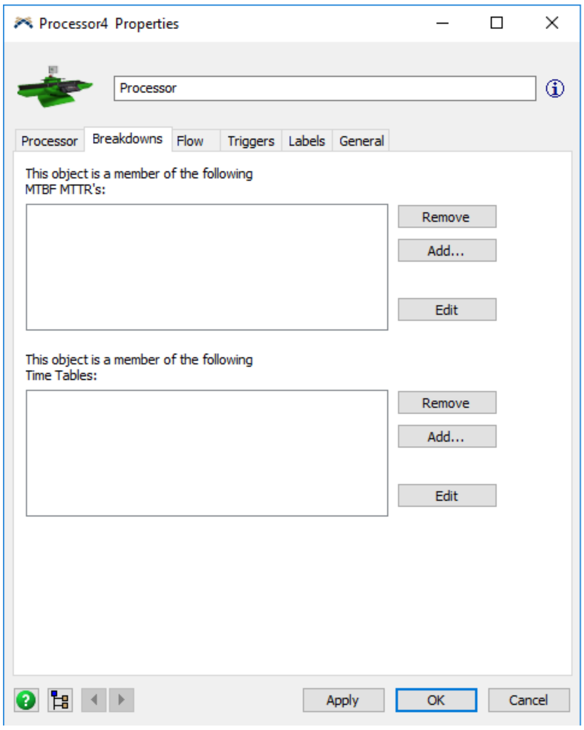

Figure 5.41 The processor property window - Breakdown

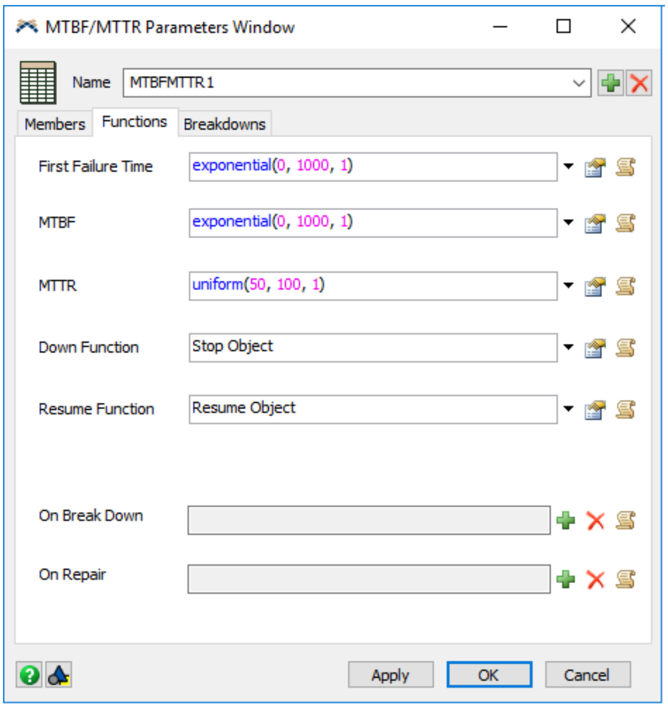

Figure 5.42 The processor property window - Breakdown Functions

The Transport

Then there is the transport that correspond to the systems that provides the material handling between machines, without the operators' support. They could be straight or curved, depending on the layout.

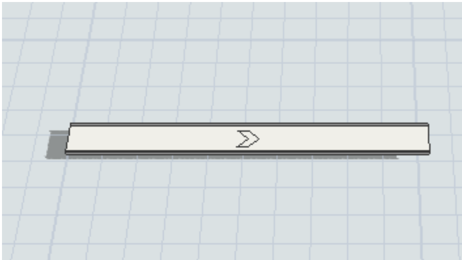

Figure 5.43 Transport System

From the properties' window it is possible to define (Figure 5.44):

- The speed
- The acceleration
- The deceleration
- The stopping space
- Etc.

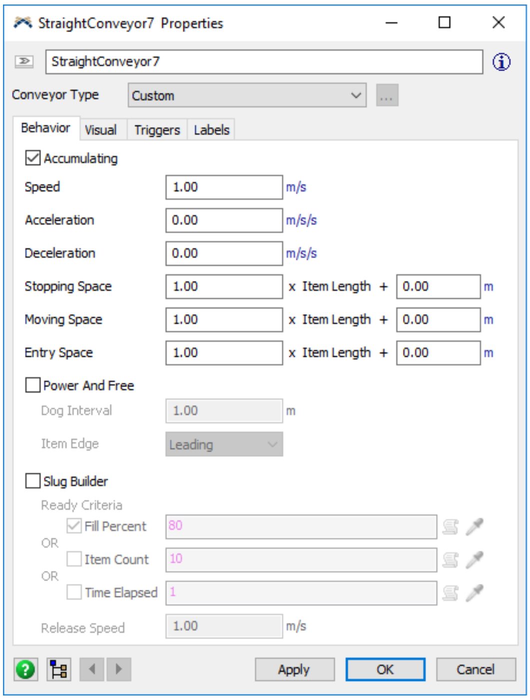

Figure 5.44 The Transport property window

The Sink

Finally, the last useful object for the project is the sink that is the end of the production process. Fundamentally it deletes the flow items. If the study of the warehouse is required, instead of the slink, there could be the warehouse model, but for the aims of the case study it is not required.

Sink's properties are related to the possibility of delete the item as "good" product or to re-work it.

Figure 5.45 The sink

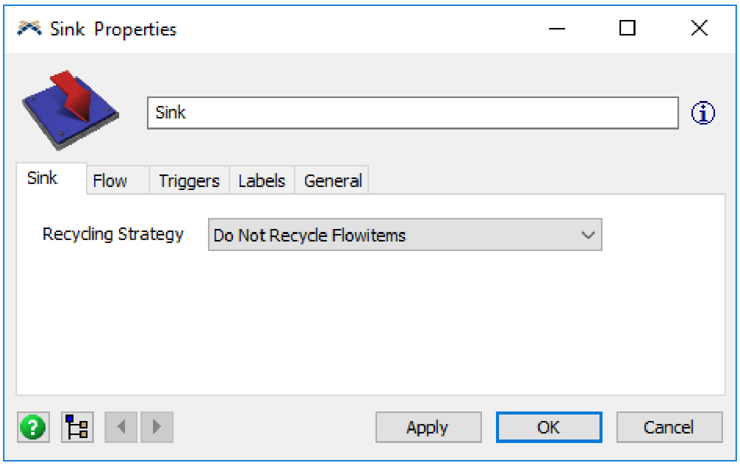

Figure 5.46 The Sink property window

Next paragraph presents data input and assumption for the construction of the model.

5.3.2

Line D model – Input data

To implement line D simulative model some assumptions are made.

The core aim of the simulation is to highlight benefits of buffer implementation to reduce micro downtime inefficiency.

Figure 5.47 presents line D model in FlexSim software. There are the source and the sink as it is required to represent the production process. The source generates the empty bottles and the sink delete them after the production process; in the reality, a systems of forks lifts directly upload the final products from the line and take them to the dedicated storage zone or inside the truck. But this process is not object of the study.

After the source a buffer named "silos" is located; it represents the accumulation transports of empty bottles before their arrival in the bottling line which is also a sort of dedicate storage container.

Then there are eight processors representing in order:

1. Positioner N° 1
2. Positioner N°2
3. Rinser – Filler – Plug Applicator (Filler Syncrobloc)
4. Labeller
5. Shrink Wrap Packer
6. Handler
7. Palletizer
8. Wrapper

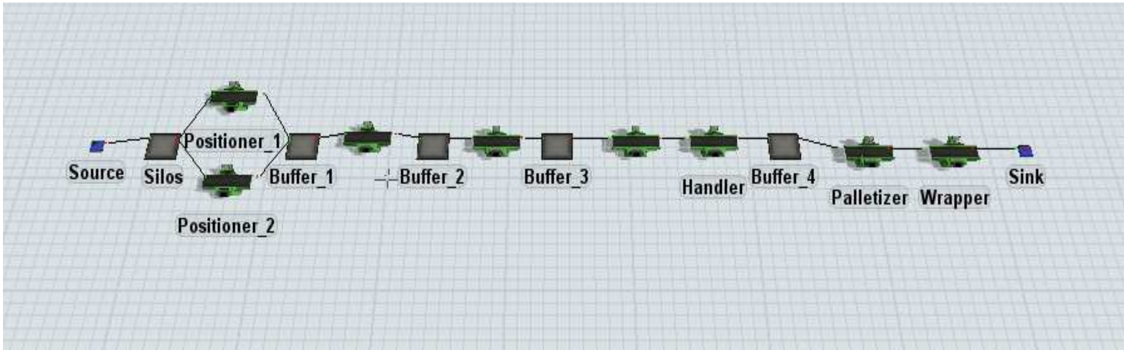

Figure 5.47 Line D Model - Working stations

The rinser, the filler and the plug applicator are considered as a unique working station as data that are used for the simulation of these ones consider them as one single machine. It is not so unrealistic to consider the three machine together as there are no transport systems between them and they are also call “Filler Syncrobloc”.

Data for the simulative model are taken from a pre-existing database that registers the production rate of each machine. Data covers a period of one month (March 2015) that corresponds to the data collection period of the chapter 3. In fact, for the work station of interest (the palletizer), micro downtime data collected are used.

Table 5.18 shows production data referred to one turn of work:

1. **Up – Time**: Seconds in which the corresponding machine is in ON state as it is reliable to work (it might be down for starving or blocked states, but it is registered as uptime for the machine);
2. **Down Time** – Allarm: Seconds in wich the referred machine is in alarm state;
3. **Mean speed**: It is the average bottles produced per hour of the referred machine;
4. **Production:** It is the number of bottles produced in one turn of work (8 hours)

	Up Time (s)	Down Time Allarm (s)	Mean Speed (items/h)	Production (N° items / 8 h)
Positioner N°1	28330	470	29029	192861
Positioner N° 2	28690	0	8683	37751
Filler Monobloc	27620	1000	29952	230550
Labeller	27290	1470	29343	229461
Shrink Wrap Packer	24340	1240	25896	229251
Handler	27090	1590	27981	228984
Palletizer	26580	2070	28583	228666
Wrapper	27810	870	28230	228666

Table 5.18 Working station data of one turn of work: Up-Time, Down-Time, Mean Speed and Production

Data are collected directly from the PLC of machines and from the photocells system along the line.

To construct the model, for each working station it is required:

- Process Time (s/item)
- First Failure Rate (s)
- MTBF (s)
- MTTR (s)

To calculate the process time, as it is known the total production and the up time in 8 hours for each machine, it has been possible to determine the real speed of each one expressed in seconds per bottle for each day. Data covering a period of one month are used (March 2015).

Then, it assumed that the process time follows the normal distribution, and so the mean and standard deviation parameters are calculated.

Table 5.19 presents data for the processing Time of the various processors (working stations).

	Processing Time (s/item)		
	Distribution	**Mean**	**St. Dv.**
Positioner_1	Normal	0.15448	0.00454
Positioner_2	Normal	1.19666	0.32771
Filler Monobloc	Normal	0.13639	0.00771
Labeller	Normal	0.13666	0.00761
Shrink-wrap Packer	Normal	0.13641	0.00751
Handler	Normal	0.13710	0.00710
Palletizer	Normal	0.13806	0,00766
Wrapper	Normal	0.13340	0.00754

Table 5.19 Machines processing time distributions

Figure 5.48 shows the data entry windows for the Filler Syncroblock.

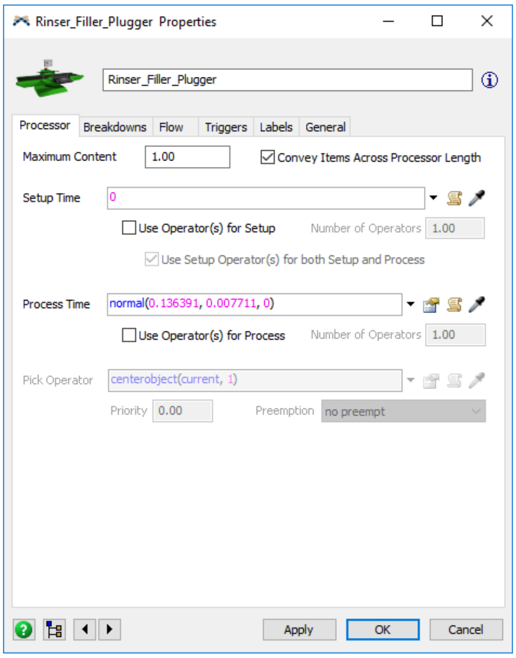

Figure 5.48 Syncrobloc Process Time Window

Other assumptions are made about the statistical distribution of downtime.

For the first failure rate it is assumed that it follows a uniform distribution with a range of two hours; that means that the first stops happens at least in the first two hours of production.

Then MTBF and MTTR of machines are assumed to be normally distributed, as proposed Battini et al. 2009.

Figure 5.49 shows the data entry windows for the Filler syncrobloc breakdown. "Rinser" is referred to the filler breakdown distribution and Figure 5.50 indicates the three parameters for the downtime distributions (First Failure Rate, MTBF and MTTR).

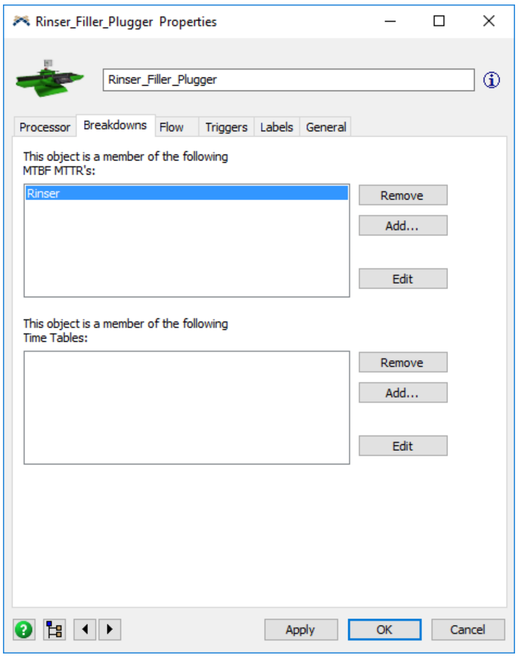

Figure 5.49 Syncrobloc Breakdown window

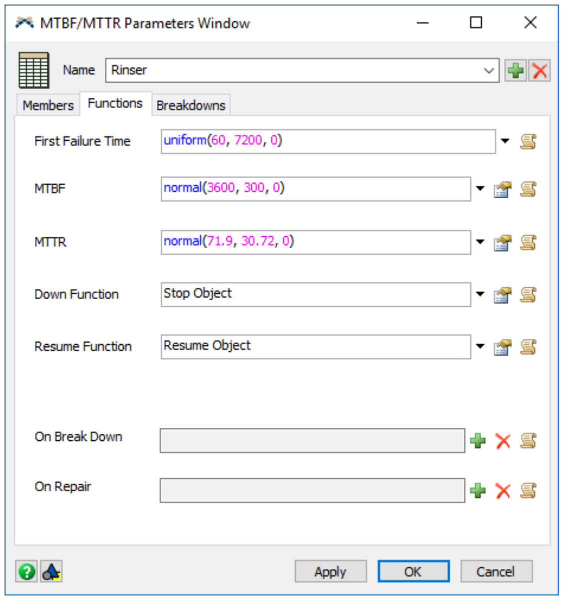

Figure 5.50 Syncrobloc Breakdown probability distribution window

Table 5.20 summarized the data used for the downtime simulation of the working stations.

	MTBF			MTTR		
	Distribution	**Mean**	**St. Dv.**	**Distribution**	**Mean**	**St. Dv.**
Positioner_1	Normal	2450	200	Normal	81,55	71,3364
Positioner_2	Normal	7960	600	Normal	81,55	71,3364
Filler Monobloc	Normal	3600	300	Normal	71,9	30,7168
Labeller	Normal	2500	160	Normal	304,35	46,4868
Shrink-wrap Packer	Normal	3300	430	Normal	79,1	50,9395
Handler	Normal	3340	150	Normal	185,25	58,5262
Wrapper	Normal	4800	360	Normal	166,95	91,5412

Table 5.20 Work stations breakdown probability distribution (MTBF, MTTR)

Only the palletizer micro downtime MTBFs are studied separately with Weibull distributions to better approximate the reality.

In fact, even if the model is about the whole line, the case study is concentrated on the Palletizer.

For the palletizer's MTBF and MTTR different distribution had been used; in fact, in accord with the aim of this research project, data about Weibull distributions are carried out. The palletizer has five breakdown distributions, corresponding to the five micro downtime of the data collection analysis. Figure 5.51 show the Palletizer window for registering micro downtime, while Figure 5.52 is referred to micro downtime A (Bundle not Aligned) distribution.

Table 5.21 summarizes data used for Palletizer micro downtime.

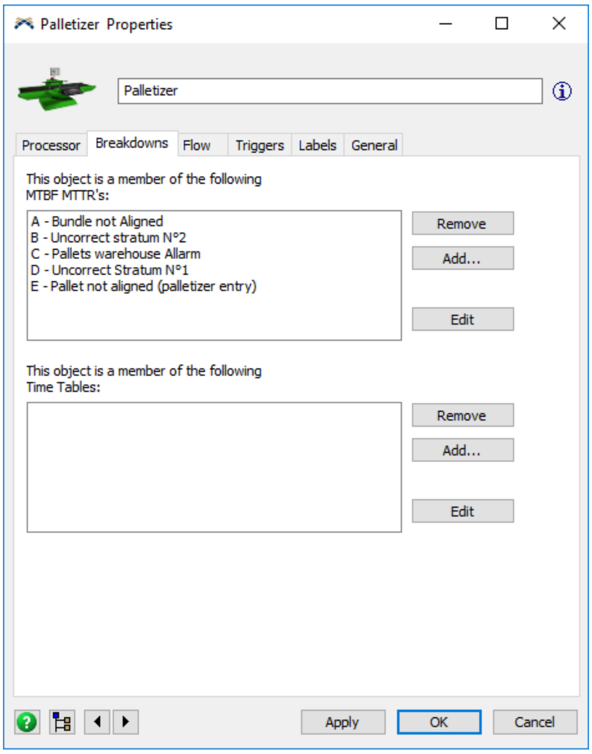

Figure 5.51 Palletizer Breakdown window

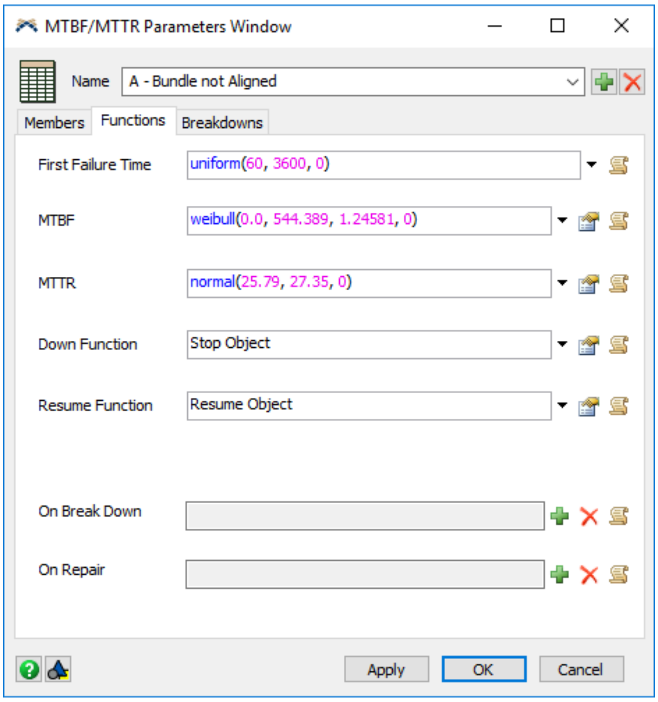

Figure 5.52 Palletizer Microdowntime A window

	MTBF			MTTR		
	Distribution	**β**	**θ**	**Distribution**	**Mean**	**St. Dv.**
Micro Downtime A	Weibull	1,24581	544,389	Normal	25,79	27,35
Micro Downtime B	Weibull	0,74996	2923,11	Normal	36,99	44,95
Micro Downtime C	Weibull	1,3716	919,281	Normal	52,85	34,51
Micro Downtime D	Weibull	1,43312	2250,68	Normal	34,35	28,75
Micro Downtime E	Weibull	1,06945	3998,61	Normal	33,71	21,71

Table 5.21 Palletizer Micro downtime probability distribution (First Failure Rate, MTBF, MTTR)

5.3.3

Line D model – Runs and Results

Once model has been constructed, it has been validated and runs are carried out. Run_1 has been validated comparing the mean real production and the mean simulative production about 10 runs with an error of 2%.

Run_1

The first run is about the actual state of the line. In other words, the starting model represents the line in a state of "AS-IS", (Figure 5.53). The run comprehends two working turns of 8 hours.

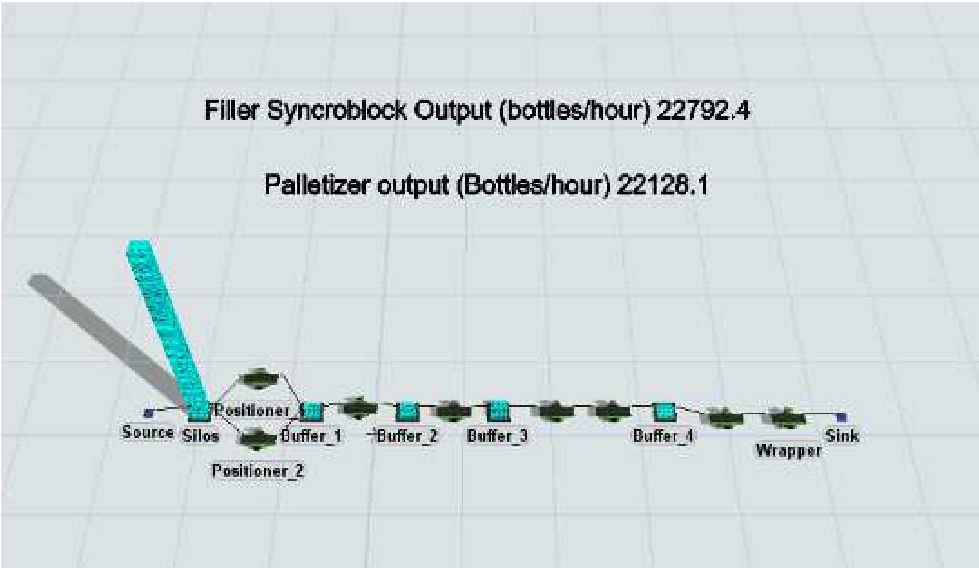

Figure 5.53 Line D model - Run 1

In this state, line performances represent the real state of the line before the improvement activities. Figure 5.54 represents the processing time % (green) of the working stations that represents in other words the Uptime (when the machine is productive). The palletizer has an uptime of about 81.9%, with a large percentage of breakdown state (11.9%); the idle time (red) instead is about the 2%, while the blocked time (yellow) is the 4.2%.

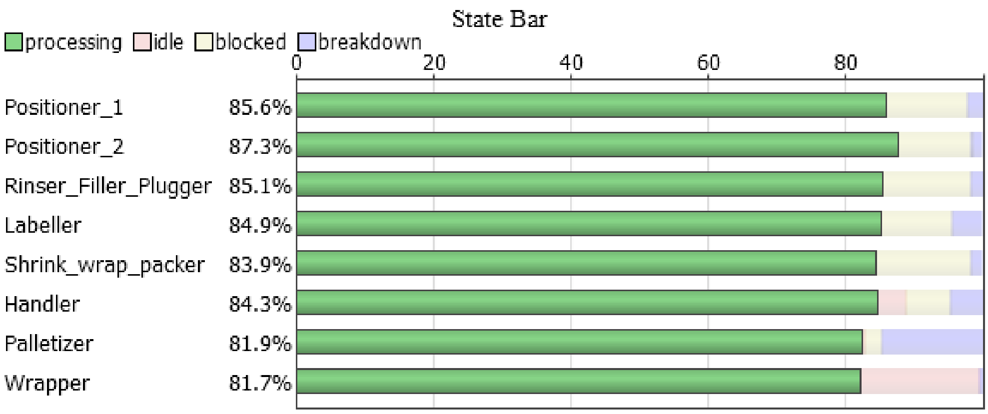

Figure 5.54 Line D working stations processing time % - Run 1

Working Station	Processing %	Idle %	Blocked %	Breakdown %
Positioner_1	85.60%	0.00%	11.80%	2.60%
Positioner_2	87.30%	0.00%	12.10%	0.60%
Syncrobloc	85.10%	0.00%	14.10%	0.80%
Labeler	84.90%	0.00%	10.90%	4.20%
Shrink Wrap Packer	83.90%	0.00%	14.20%	1.90%
Handler	84.30%	4.80%	5.60%	5.30%
Palletizer	81.90%	2.00%	4.20%	11.90%
Wrapper	81.70%	15.20%	0.00%	3.10%

Table 5.22 Working stations time % - Run 1

The Syncrobloc, instead, has a higher processing time (85.1%), and also a high blocked time caused by the downstream machines' downtime (13.80%); breakdown covers the 1.1%. The working station with the highest processing time % is the Positioner_2 (87.3%), as it works in parallel with the positioner_1, but just when it is needed. The one with the highest idle time is the wrapper (15.2%), as it is after the palletizer that has the major breakdown index. The shrink-wrap packer presents the biggest blocket tim % (14.2%) followed by the Filler Syncroblock (14.10%). Finally the palletizer results as the working station with the highest breakdown % (11.90%), as it was expected, followed by the handler (5.30%) and the Labeller (4.20%). In the data collection of Chapter 2, Handler micro downtime are included in the Shrink-wrap packer.
Table 5.22 summarize working stations' parameters %.

Figure 5.55, instead, represents the buffer capability variation along the passing time. It is evident that buffer 4 often reach its maximum capability, making the working stations before waiting for space in exit. Also the other buffers might be improved, for example buffer 2, but the idle time of the working station interested is low.

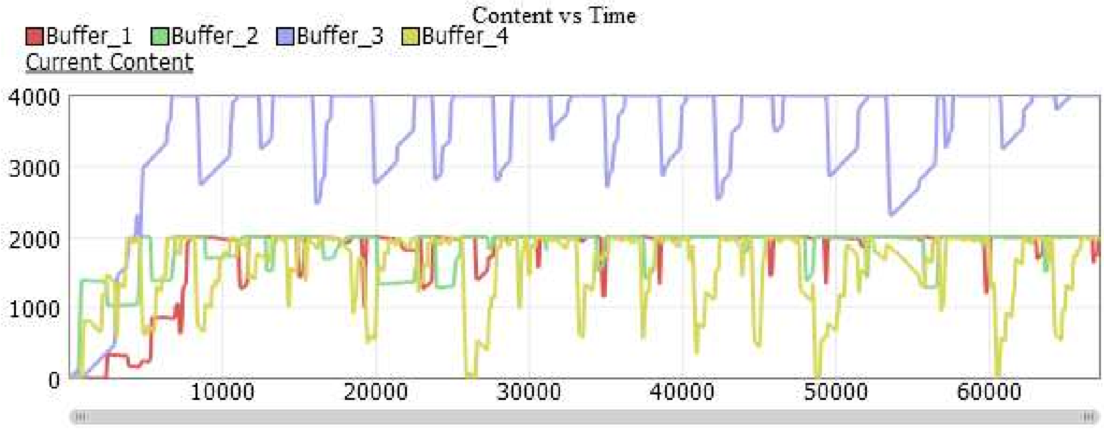

Figure 5.55 Buffer capability variation - Run 1

Finally, Figure 5.56 shows the average output per hour per working station. Positioner N° 2 has a low production as it works in parallel with positioner 1, but just in predefined sequence of production time. The Filler Syncrobloc, as it is the bottle neck, has the highest output per hour (22,400 bottles/hour), while the Palletizer has a speed of 21,900 bottles/hour.

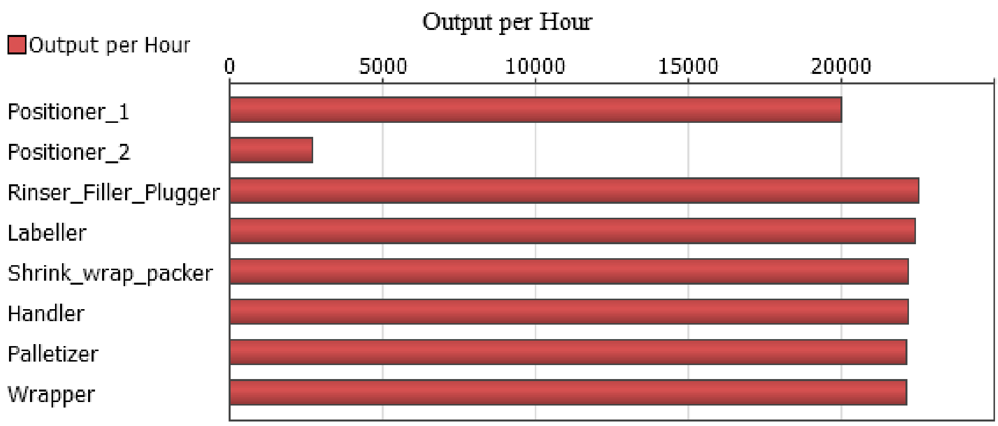

Figure 5.56 Line D - Output per hour of the various working sations – Run 1

Run_2

In the second run, two improvement has been done in conclusion:

1. The elimination of micro downtime A, as the investment has been carried out
2. The implementation of buffer 4, from 2000 bottles to 4000 bottles.

Figure 5.57 represent the model of Line D in the second run.

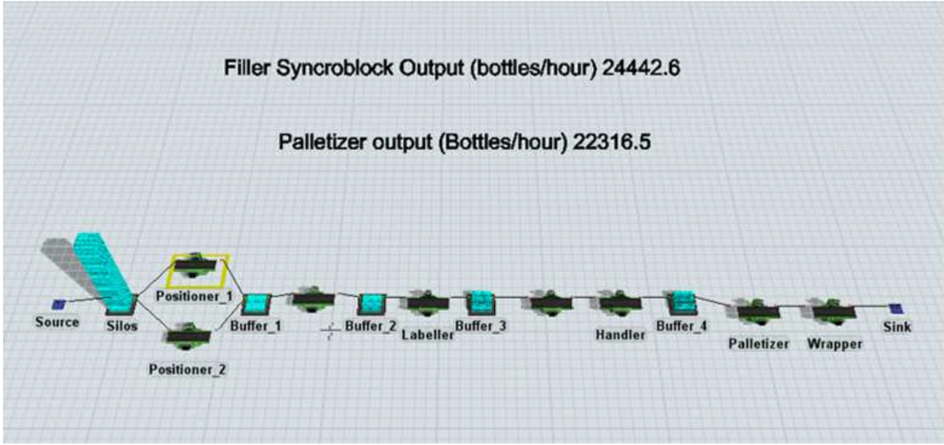

Figure 5.57 Line D model - Run 2

Looking at the state bar of the working station of this configuration (run 2), it is evident that the improvement is tangible (Figure 5.58). The Filler Syncrobloc improves its processing time of 4.3%, reducing the blocked time percentage, from 14.10% to 8.4%. The Palletizer, as the core critical machine, improves its processing time % to 86.5%, reducing the breakdown % of about – 2.6% and the idle time % of about -2%. In general all the working stations increase their processing time, due to the palletizer uptime increasing.

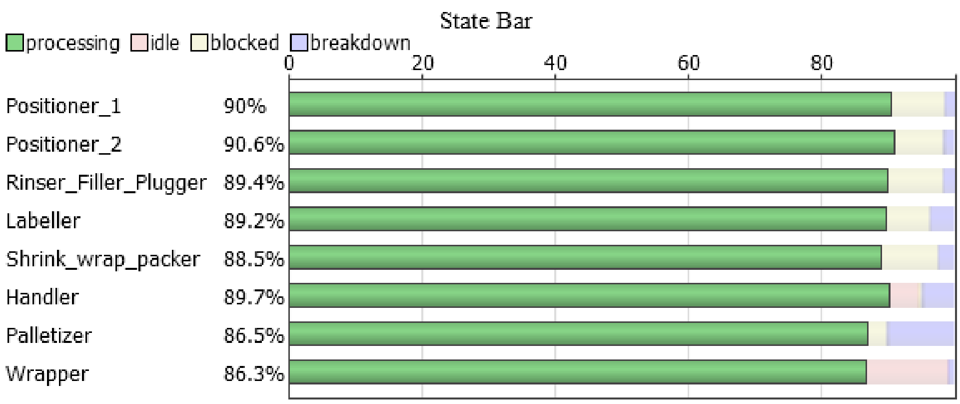

Figure 5.58 Line D working stations processing time % - Run 2

The machine with the highest increasing in processing time is the handler (+5.4%), has it was deeply influenced by the blocked phenomena cause by the palletizer. The wrapper, instead, has the highest improvement in terms of idle time %, from 15.2% to 11.6%.

Table 5.23 summarize the data registered in the second configuration of Line D, while Table 5.24 shows the differences between the two configurations in terms of % of processing time, idle time, blocked time and breakdown, highlighting in green the improvement and in red the worsening factors.

Working Station	Processing %	Idle %	Blocked %	Breakdown %
Positioner_1	90.00%	0.00%	7.90%	2.10%
Positioner_2	90.60%	0.00%	8.40%	1.00%
Syncrobloc	89.40%	0.00%	9.80%	0.80%
Labeler	89.20%	0.00%	6.10%	4.70%
Shrink Wrap Packer	88.50%	0.00%	9.60%	1.90%
Handler	89.70%	5.20%	0.00%	5.10%
Palletizer	86.50%	0.00%	4.20%	9.30%
Wrapper	86.30%	11.60%	0.00%	2.10%

Table 5.23 Working stations time % - Run 2

Working Station	Processing %	Idle %	Blocked %	Breakdown %
Positioner_1	**4.40%**	0.00%	**-3.90%**	**-0.50%**
Positioner_2	**3.30%**	0.00%	**-3.70%**	**0.40%**
Syncrobloc	**4.30%**	0.00%	**-4.30%**	0.00%
Labeler	**4.30%**	0.00%	**-4.80%**	**0.50%**
Shrink Wrap Packer	**4.60%**	0.00%	**-4.60%**	0.00%
Handler	**5.40%**	**0.40%**	**-5.60%**	**-0.20%**
Palletizer	**4.60%**	**-2.00%**	0.00%	**-2.60%**
Wrapper	**4.60%**	**-3.60%**	0.00%	**-1.00%**

Table 5.24 Working stations time % - Run 1 vs Run 2

Finally Figure 5.59 and Figure 5.60 show respectively the buffers capacity variation along the time and the output per hour of each working station. The Palletizer output increases of about 1400 bottles/hour; the Filler Syncrobloc one of about 1300 bottles/hour, that correspond to the real improvement of the production of the whole line

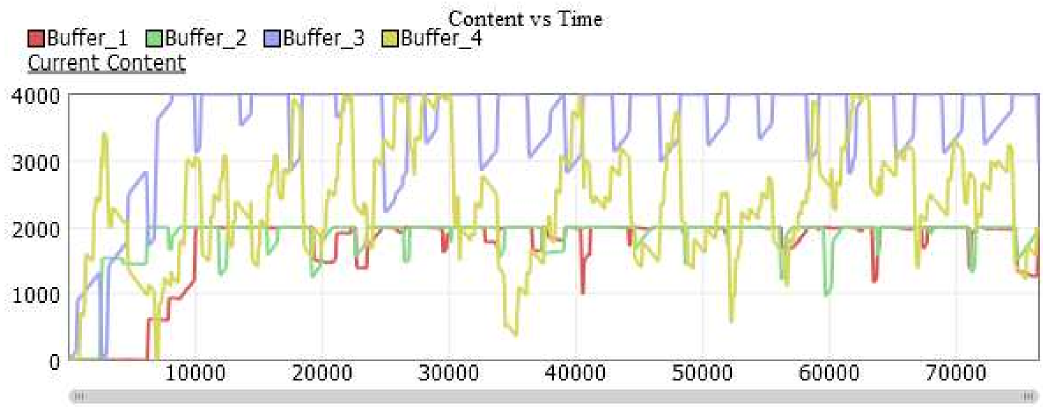

Figure 5.59 Buffer capability variation - Run 2

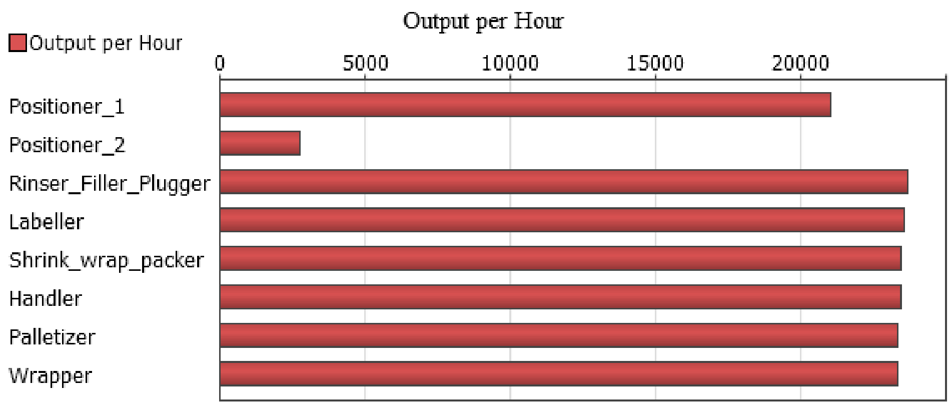

Figure 5.60 Line D - Output per hour of the various working stations – Run 2

5.4
Cost Benefit Analysis

Finally, as in Chapter 3, a cost-benefit analysis is carried out, knowing the production increase per year. From the data of the simulative model, it is calculated the production increase per year (2,288,000 bottles/year). Then, as in Chapter 3, it is calculated the contribution margin per year (CM) of 1° level

	CM n°1	CM n°2	CM n°3	CM n°4	CM n°5	CM n°6
Investment Cost [€]	€ 60,000.00	€ 60,000.00	€ 60,000.00	€ 60,000.00	€ 60,000.00	€ 60,000.00
Labor Cost (Project)[€]	€ 10,000.00	€ 10,000.00	€ 10,000.00	€ 10,000.00	€ 10,000.00	€ 10,000.00
Total [€]	€ 70,000.00	€ 70,000.00	€ 70,000.00	€ 70,000.00	€ 70,000.00	€ 70,000.00
CM 1° Level [€/pz]	**€ 0.01**	**€ 0.02**	**€ 0.03**	**€ 0.05**	**€ 0.10**	**€ 0.15**
Increase in Production [pz/year]	2,288,000.00	2,288,000.00	2,288,000.00	2,288,000.00	2,288,000.00	2,288,000.00
CM 1° Level [€]	**€ 22,880.00**	**€ 45,760.00**	**€ 68,640.00**	**€ 114,400.00**	**€ 228,800.00**	**€ 343,200.00**
Fixed Costs [€]	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00	€ 12,000.00
CM 2° Level [€]	**€ 10,880.00**	**€ 33,760.00**	**€ 56,640.00**	**€ 102,400.00**	**€ 216,800.00**	**€ 331,200.00**

Table 5.25 Cost of the investment with Variable Contribution Margin

(without fixed costs) and of 2° Level (considering fixed costs) varying the unitary contribution margin. (Table 5.25).

Then, with NPV formula, it is calculated the pay back period, varying the unitary contribution margin. (Figure 5.61 and Table 5.26)

	2° Level Cash Flow					
YEAR	**0,01 € CM**	**0,02 € CM**	**0,03 € CM**	**0,05 € CM**	**0,10 € CM**	**0,15 € CM**
0	-€ 70,000.00	-€ 70,000.00	-€ 70,000.00	-€ 70,000.00	-€ 70,000.00	-€ 70,000.00
1	-€ 59,638.10	-€ 37,847.62	-€ 16,057.14	€ 27,523.81	€ 136,476.19	€ 245,428.57
2	-€ 49,769.61	-€ 7,226.30	€ 35,317.01	€ 120,403.63	€ 333,120.18	€ 545,836.73
3	-€ 40,371.06	€ 21,936.85	€ 84,244.77	€ 208,860.60	€ 520,400.17	€ 831,939.75
4	-€ 31,420.06	€ 49,711.29	€ 130,842.64	€ 293,105.33	€ 698,762.07	€ 1,104,418.81
5	-€ 22,895.29	€ 76,163.13	€ 175,221.56	€ 373,338.41	€ 868,630.54	€ 1,363,922.67
6	-€ 14,776.47	€ 101,355.36	€ 217,487.20	€ 449,750.87	€ 1,030,410.04	€ 1,611,069.21
7	-€ 7,044.26	€ 125,347.97	€ 257,740.19	€ 522,524.64	€ 1,184,485.75	€ 1,846,446.87
8	€ 319.75	€ 148,198.06	€ 296,076.37	€ 591,832.99	€ 1,331,224.53	€ 2,070,616.07
9	€ 7,333.10	€ 169,960.06	€ 332,587.02	€ 657,840.94	€ 1,470,975.74	€ 2,284,110.54
10	€ 14,012.48	€ 190,685.77	€ 367,359.07	€ 720,705.66	€ 1,604,072.13	€ 2,487,438.61

Table 5.26 Pay back period of buffer implementation varying CM

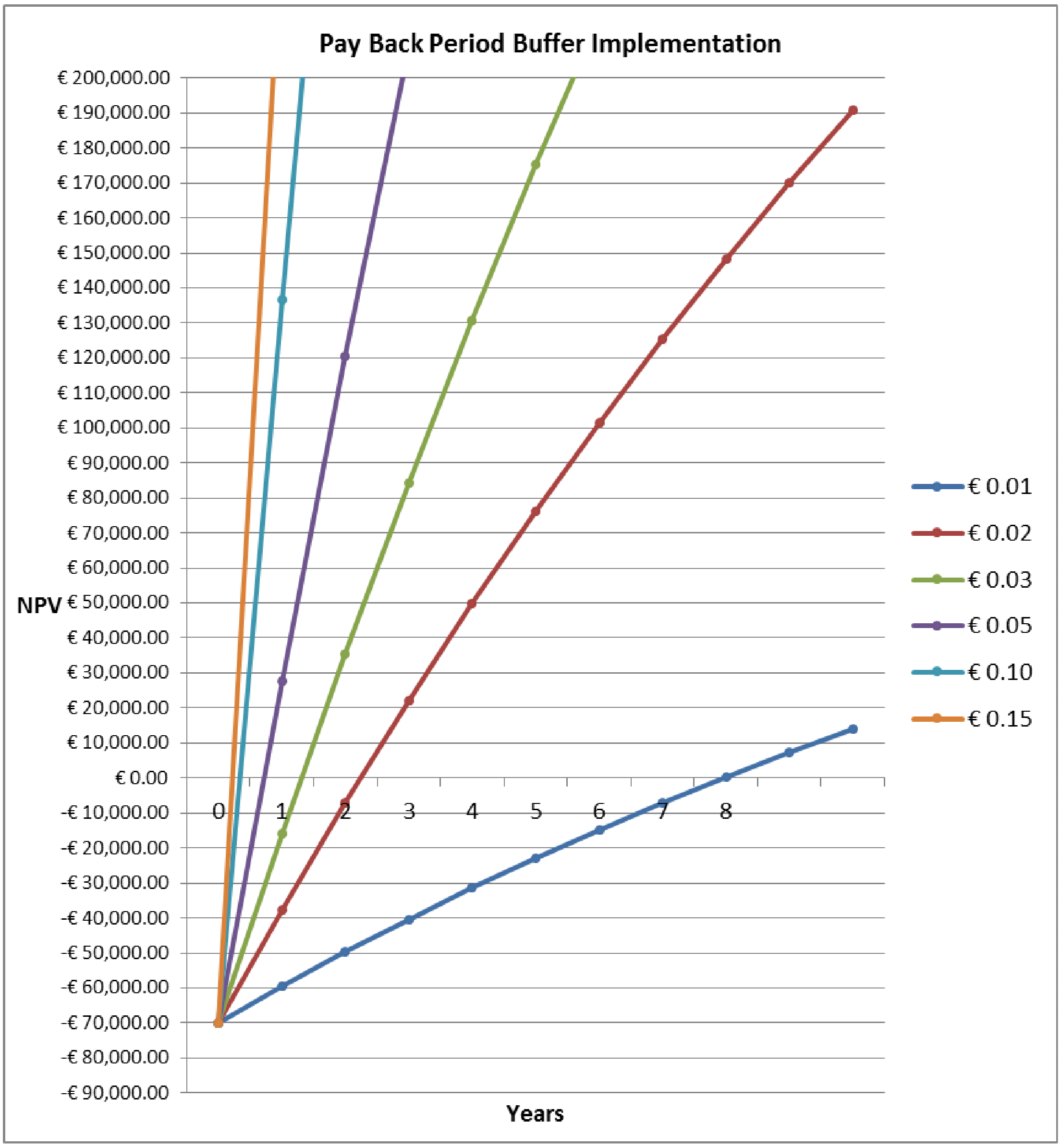

Figure 5.61 Pay back period of buffer implementation varying CM

5.5

Final Considerations

The core aim of this second part of the case study is to carry out a strategic model to improve production effectiveness by decreasing micro downtime of the equipment. Micro downtime are common causes of inefficiency in automatic production flow lines, and their origin might be technical or related to the normal functioning of the machines. In the first case is possible to consider technical solutions, as changing in the design of the machine; chapter 2 proposed the construction of a CPI to evaluate the benefits of eliminate or reduce micro downtime.

When micro downtime does not presents technical solutions or they are not convenient, buffer sizing could be a solution to decrease this problem. This chapter proposes the construction of a simulative model that assumes that TTF probability distribution of micro downtime is well fitted by Weibull Distribution.

Results from the case study confirm the model, and it has been applied to the reality to propose the improvement of the buffer.

5.6
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6

Conclusion

" TPM is not a maintenance program. Rather, TPM was a company-wide program for improving equipment effectiveness—something that maintenance alone could not do. When TPM came to America, we realized we probably made a mistake calling it Total Productive Maintenance. Probably should have been Total Productive Manufacturing. "

[Nakajima, 1988].

6.1
Results and final Considerations

The aim of this work is to present an innovative framework for TPM Implementation in Food and Beverage Industry that focused on highlight benefits and results of this paradigm. Chapter 2 presents the analysis of various case studies of TPM Implementation in automatic production systems; influential factors and drivers about the success of its implementation are carried out. Moreover a deep study of food industry peculiarities is proposed. Matching all together, it is carried out a new TPM framework that focused on criticalities solutions to make TPM benefits arise.

In Chapter 3 the framework is applied to a bottling plant reality; it is carried out the pilot line as the one with the lowest OEE and an analysis of its inefficiency is presented. Micro downtime arise as the core cause of inefficiency that is a common reality in automatic production systems. A deep data collection has been organized on the most critical machines, the Palletizer, the Shrink-wrap packer and the Labeller. Most critical micro downtime for each machine are individuated and study in deep. For each one is presented:

- OEE recoverable per month
- Bottles recoverable per month
- Production hours recoverable per month

Through problem solving techniques and fishbone diagrams, solutions as maintenance activities or investments in new technologies are carried out. To highlight benefits of these solutions an innovative index is proposed, the Cost Performance Indicator, that compares the cost of the investment (€) with the OEE improvement related to that activity. The lower this index is, the better, as it individuates activities with low costs and high OEE improvements.

Chapter 4 presents a review of downtime analysis in automatic flow line production systems; it is highlighted the lack of a focused micro downtime analysis, especially in Food industry. It is presented the Buffer Allocation Problem (BAP) as solution to micro downtime, focusing on three different approaches: the graphical approach, the simulative model, and the one applied by the company of the case study, based on experience and historical data.

Last Chapter presents the second part of the case study, in which a deep micro downtime analysis is carried out. It is proposed a new simulative model to evaluate the optimal buffer size, as the maximum throughput registered between two working stations. What is different from the models presented in chapter 4 is that each TTF probability distribution of its micro downtime individuated is fitted by Weibul distribution, to maximize the reality of the model.

Results carried out benefits of buffer implementation and of micro downtime A delete. Table 6.1 summarizes the OEE improvement margin varying the focus of the improvement, from the Line D till Micro downtime A of the Palletizer. Table 6.2, instead, summarized the two solutions proposed in the case study. The first, the modification of the transport in ingress of the Palletizer has already been done and results are shown below. Buffer Implementation, instead, is going to be discuss from the company management.

Microdowntime	OEE Improvement Margin
Line D	16.20%
Palletizer	6.30%
Microdowntime A, B, C, D and E (Palletizer)	4.10%
Microdowntime A	1.44%

Table 6.1 OEE Improvement Margin Classification

Solution Proposed	Method	OEE Recoverable	State
Transport in Ingress Modification	CPI	1,44%	Done
Buffer Implementation	Simulative Model	4,1%	In itinere

Table 6.2 Solutions proposed summary - Acqua Minerale San Benedetto S.p.A. Study

Solution to micro downtime A of M1 proposed in Chapter 3 are applied to line D: Figure 6.1 shows micro downtime trend of line D that is decreasing. Moreover Figure 6.2 shows OEE trend of Line D, that is increasing since investment is carried out in January 2016.

Finally, last graphic Figure 6.3 is about the trend of Line D OEE along the various years; the violet curve represents the OEE trend of this year that is clearly increasing.

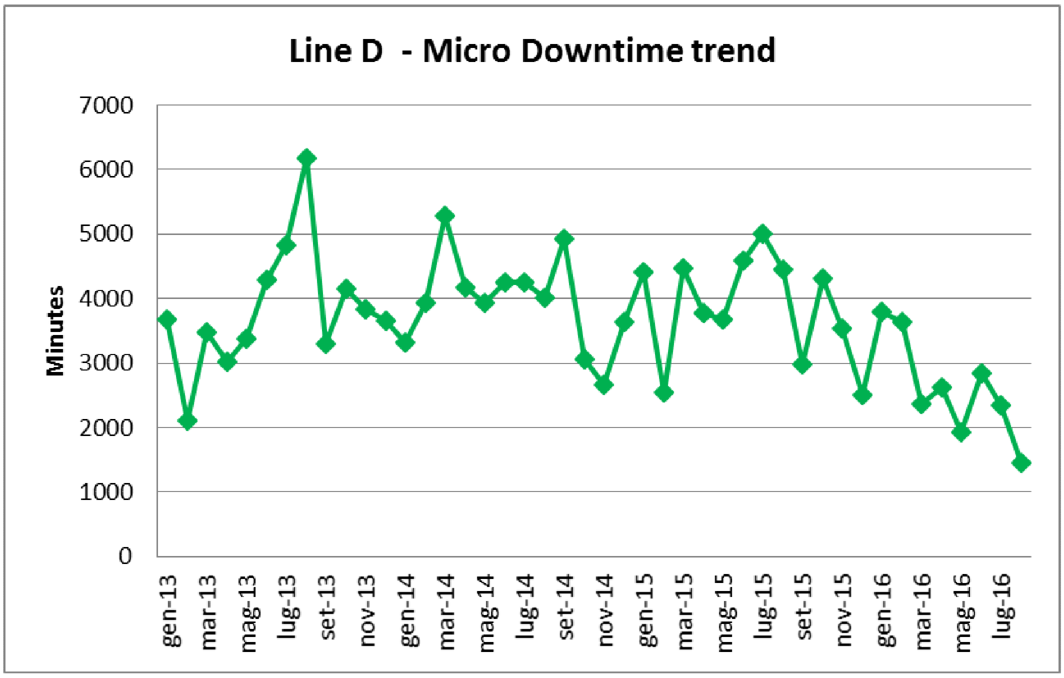

Figure 6.1 Line D - micro downtime trend

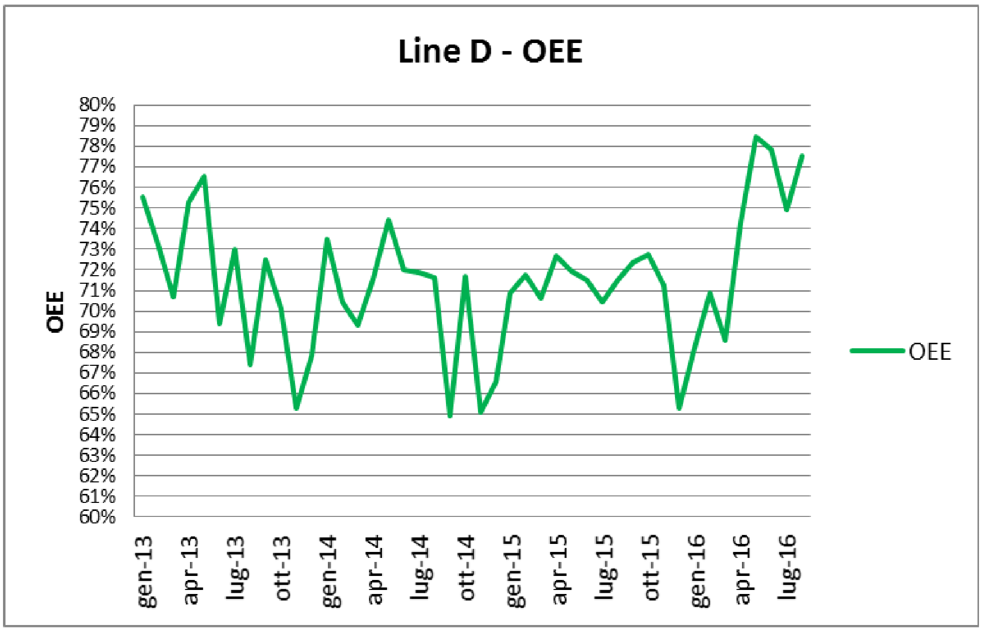

Figure 6.2 Line D - OEE trend

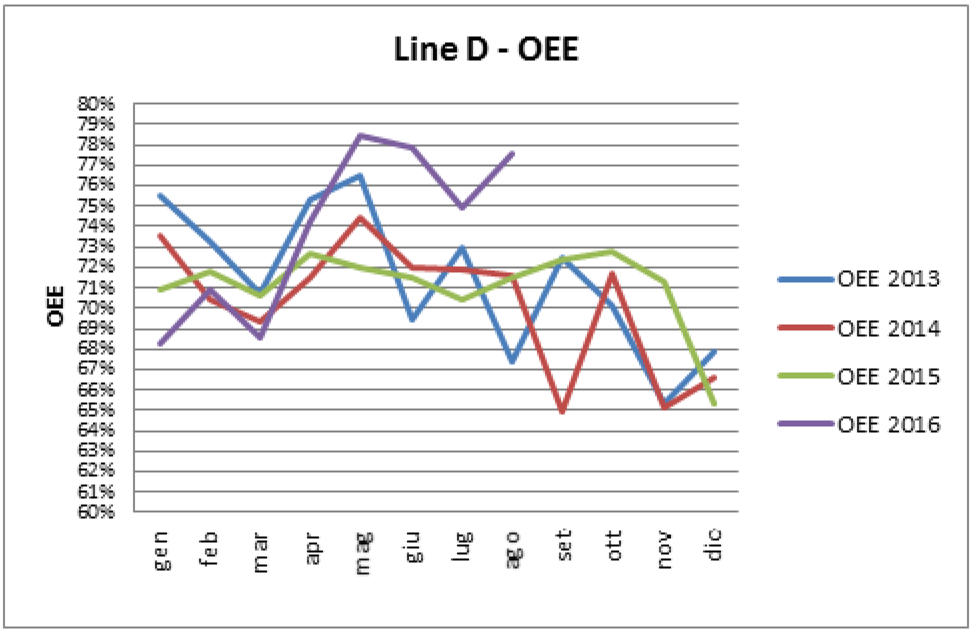

Figure 6.3 Line D - OEE trend per year

This work has been carried out with a strong collaboration with Acqua Minerale San Benedetto S.p.A., that allows to apply and analysed methods and tools proposed. Economic data in this essay are totally fictions, for privacy reasons, but proportionate to reality to do not alter scientific results.

It is demonstrated the effectiveness of the Innovative TPM Implementation model proposed, through its application and its results proposed in this chapter. The framework proposed results as a useful industrial tool, to implement maintenance techniques and involve employee in maintaining efficient the production systems. The focus on criticalities allowed to carry out benefits in a faster way and to highlight benefits.
Moreover the simulative model proposed is useful to compare other industrial realities and evaluate improvement activities.

Figure 6.4 presents the core outline of this thesis.

Finally more researches can be carried out applying the framework to other industrial realities and optimizing it. Moreover, the application of the model to other realities might improve its effectiveness on representing various industrial scenarios.

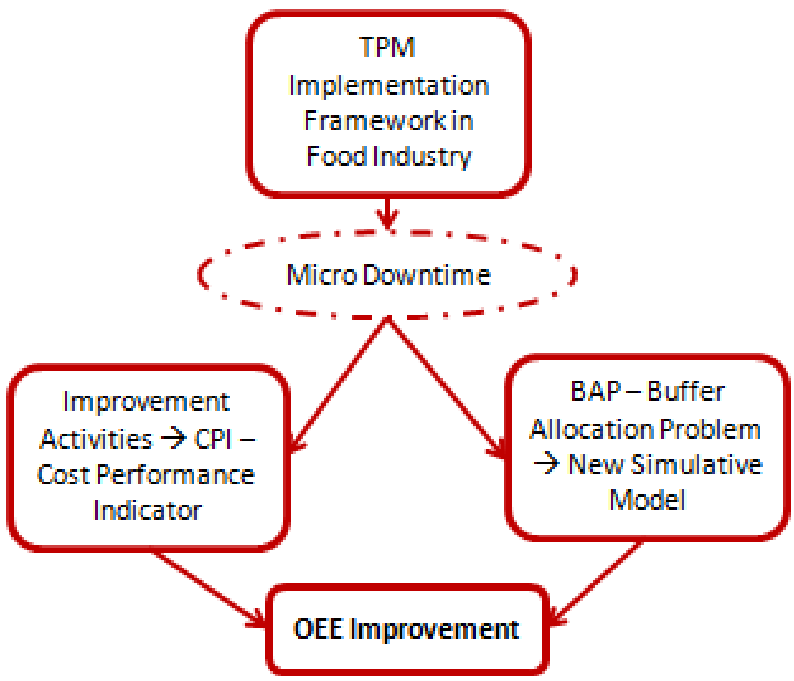

Figure 6.4 Thesis Outline

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ATTACHMENTS

Reliability Analysis based on field Microdowntime data: A bottle production plant case study

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Keywords: Reliability analysis, OEE, Weibull Distribution, TTF, TTR, downtime.

Abstract

Reliability analysis based on field downtime data is carried out in a bottle production plant. The main objective is to individuate the core inefficiency causes of the worst production line in terms of OEE; the analysis pointed out that the main cause is represented by "microdowntime", that are short production stops not directly related to mechanical/electric failure. A focused downtime analysis is carried out about the most critical machine of the pilot line; its microdowntime causes are individuated and measured on field in terms of TTF and TTR data. A statistical analysis is carried out on TTF of principal microdowntime to describe both the machine and the microdowntime reliability function with Weibull distribution. Moreover it is showed how each microdowntime influences the machine Reliability function, by recalculating it without the microdowntime influence.
Finally it is individuated the recoverable OEE from each microdowntime (the most critical is 1,45% OEE).

1. Introduction

Nowadays automatic production systems are very diffused in industrial reality, to produce goods with the required quality and quantity. Production systems are measured mostly with the Overall Equipment Effectiveness index (OEE), that is the combination of three parameters as Availability, Performance and Quality. To increase and to maintain high this index is the aim of production staff, to guarantee the effectiveness of production and reliability of machines.
Reliability analysis techniques play an important role to optimize the operational management of the production process [11]. When a failure occurs, maintenance costs increase, production is stopped, quality decreased and there are delays in the delivery of final products. For this reasons to reduce the probability of failures and to increase reliability of production systems is one the main objective of production management.
Tsarouhas et al. affirm that to ensure an adequate reliability level is of great importance for industrial applications on food production lines, as there are numerous interlocking variables to be taken into account [15]. Food industry is characterized not only by the quality of products, but also by safety and hygienic rules. Moreover there are also sustainability aspects that should be taken in consideration. It takes a long time for a company to establish a reputation for reliability but only a short time for its reputation to be ruined [3].
Tsarouhas reviewed reliability, availability and maintainability analysis in the food industries, and he identified the critical points of the production systems that should improve the operational performance and the maintenance effectiveness[13]. The available literature referring to the food industry is quite limited. He developed reliability and maintainability analysis for strudel and feta cheese production line at machine, workstation and entire line level [11]. Wang et al. studied the buffer capacity in a dairy filling and packaging lines [16]. Tsarouhas et al. also presents a case study in a peach-canning production line and they showed how failures data follow the logistic distribution whereas the repair data follow the Weibull one [12]. Finally Tsarouhas presented a reliability analysis in a limoncello production line by applying statistical techniques on field failure data [14].
The paper proposes the reliability analysis of a bottle production line, focusing on the most critical machine. What is new is the study not only of the reliability function of the single machine, but also the statistical distribution of its microdowntime causes. It is at first considered the OEE of the production line to individuate the core inefficiency, that results microdowntime; they could be considered as short stops of few minutes (less than 15 minutes) that cannot be called failures. Once it has been individuated most critical workstation affected by this inefficiency, it is analysed in deep through TTR and TTF data collection and analysis. It is studied how each one influences the reliability of the work station and the OEE of the whole line.

The paper is divided in five sessions; session 2 presents methods and tools follows to carry out the case study. Session 3 presents the case study and session 4 presents results and discussion. Finally session 5 presents conclusions.

2. Tools and Methods

The core objective of the project is to increase OEE of a production system through the analysis of its effectiveness. As the core inefficiency is represented by short stops (microdowntime), a focused downtime analysis is carried out, based on methods and tools used in literature. To identify the core inefficiency of a production line and to analyse it, the project follows five phases:

PH1: Identification of the worst production line in terms of lower OEE.
OEE is the main efficiency production index used in industries; to make results arise, the focus was centered on the worst production line. Moreover, as the final objective is to improve OEE, an initial analysis of this index is necessary.

PH 2: Identification of the core inefficiency of the line.
Once the project line is individuated, it is necessary to identify which inefficiency mostly affects it. As OEE is composed by three parameters (Availability, Performance and Quality), it is possible to divide OEE into the six big losses as: failures, set-up, speed reduction, micro downtime, defects and scraps and individuate which one is more incisive on OEE. In the case study the core inefficiency is represented by microdowntime (downtime shorter than 15 minutes).

PH 3: Individuation of the critical machine.
This step provides to analyse which work station is more affected by the core inefficiency. In the case study, microdowntime of the whole line are collected and divided per work station. Palletizer (M1) results as the critical one.

PH 4: Data Collection
This step provides a focused data collection centered on the most critical machine. In the paper is presented the study and data collection of stops of the machine n°1 (M1); in particular data about TTR and TTF of the downtime and microdowntime causes are collected.

PH 5:Data Analysis
With data collected, a statistical analysis is constructed. With Pareto diagrams about frequency and duration of TTR, most critical microdowntime causes are individuated. TTF data are used to construct reliability functions of M1 with Weibull Distribution. Finally, with TTR data, the recoverable OEE is measured.

3. Case Study

The company is situated in beverage world market and presents the biggest plant of Europe. Its core business is centred in mineral water and beverage, of its property and for third parts. It has 1800 employees, 6 plants in Italy (and others around the world), and a turnover of 720 million (2013).
The project is situated in the core factory in Italy, that has 23 production lines: glass, PET and aseptic lines with numerous formats (0.25L, 0.5L, 1L, 1.5L, etc.). Moreover the company not only provide to bottling their products, but it produces the bottles, the plugs and the stamps for doing these ones from itself.

PH 1: Identification of the worst production line in terms of lower OEE.
Line D, after various factors evaluation, was chosen as the pilot line for the project.

PH 2: Identification of the core inefficiency of the line.
Line D produces mineral water in 1.5L format; it produces in media 15.000.000 bottles per month, with a speed of 26.000 bottles per hour in media. It is composed by 8 principal machines: the positioner, that takes the bottles in a correct order, the rinser machine, that washes them, the filler machine, that fills the bottles, the bottle sealing, to close them, the labeller machine, the shrink-wrap packer, to make the first packaging, the palletizer and the wrapper machine, to close the final product. Figure 1 presents the production flow diagram of the line.

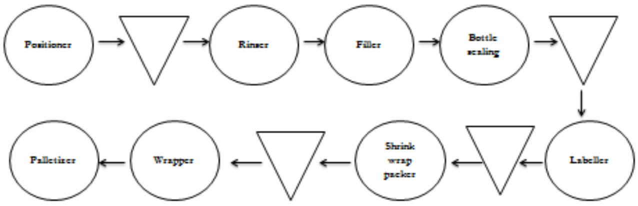

Figure 1 Line D – Production Flow diagram

Data about OEE were analysed and Figure 2 shows how the inefficiency of the line is divided in terms of failures, set-up, materials, defects, microdowntime and others. It is evident that these short process failures represent the core inefficiency as they cover the 57% of the total ineffciency.
Moreover Figure 3 shows the OEE recoverable from each

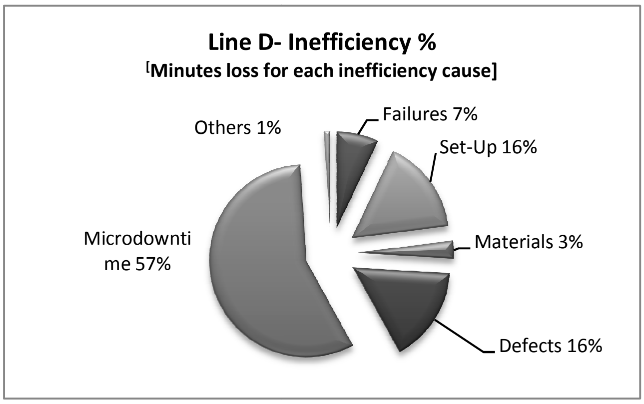

Figure 2 – Line D Inefficiency %

inefficiency, and the micro downtime improvement margin results the higher (16.20%).

OEE	OEE+ Loss Time	Improvement Margin
OEE (Start)	71.57 %	-
OEE + Time loss for Microdowtime	**87.78%**	**16.20%**
OEE + Time loss for Defects	76.01%	4.44%
OEE + Time loss for Set-Ups	76.01%	4.44%
OEE + Time loss for Failures	73.55%	1.98%
OEE + Time loss for Materials Lack	72.29%	0.72%

Figure 3 OEE Improvement Margin per Inefficiency

PH 3: Individuation of the critical machine.

The study is now centered on microdowntime analysis. Microdowntime in the paper are considered as process stops shorter that 15 minutes; for this reason they are not proper failures but "process failures". As the objective is to study in deep the primary causes of inefficiency, it is decided to focus the analysis on the worst machine.The aim is to analyse in deep a single machine and to apply statistical analysis to its downtime data (TTR and TTF). Microdowntime of the whole line are divided by each work station; Figure 5 shows microdowntime percentage referred to one year divided per machine, and the worst results the Palletizer (M1).

	Machines Names
M1	Palletizer
M2	Shrink wrap packer
M3	Labeller
M4	Trasport 1
M5	Handler Machine
M6	Data Machine
M7	Trasport 2
M8	Strap Applicator
M9	Filler
M10	Wrapper
M11	Posistioner

Figure 4 Machines Names

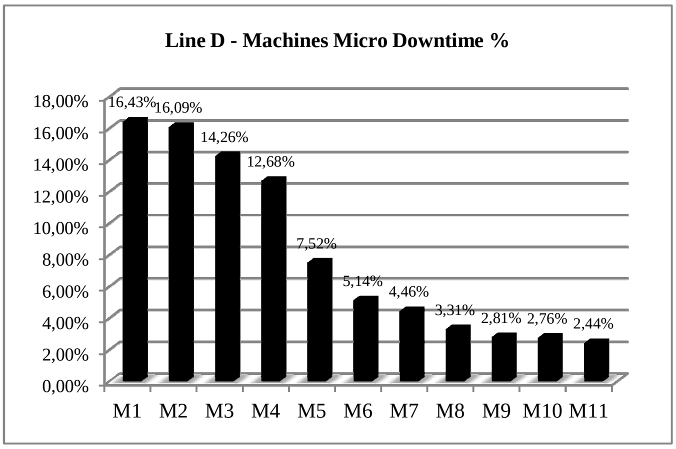

Figure 5 - Line D Micro Downtime % for each machine

PH 4: Data Collection

In this step, data about microdowntime are collected directly from the production system, in particular TTF and TTR data. An *Ad Hoc* paper shit is prepared, collaborating with production staff, to individuate the main process failure causes. The collection covered a period of two months, 8 hours per day, while the line was working in two turns per day.

PH 5:Data Analysis

In this step is described the data analysis carried out.

As first a Pareto analysis about TTR is made to individuate most critical microdowntime that affected OEE.

The analysis is made considering both the frequency (Figure 6) and the duration.

Results show that both in terms of frequency and duration the first five microdowntime causes are the most critical as they cover about the 80% of the inefficiency (Figure 8 shows the cumulative percentage of microdowntime causes in terms of frequency).

Once individuated the most critical causes (A,B,C,D,E), a statistical analysis is carried out. It is assumed that when a microdowntime is "solved" the system is in a "as good as new" condition.

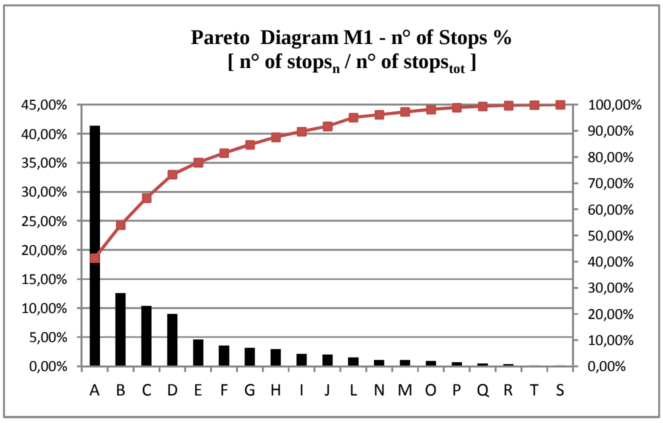

Figure 6 Pareto Diagram M1 - Frequency

It is also assumed that the probability distribution of TTF data about M1 is well fitted by Weibull Distribution, as applied in numerous studies of Tsarouhas et al. and others [2,6,7,11, 14,15].

	Microdowntime	% n° of stops	% n° of stops cum
A	Bundle not Alligned (Palletizer)	41,38%	41,38%
B	Uncorrect Stratum (N°2)	12,60%	53,98%
C	Pallets Warehouse Allarm	10,38%	64,36%
D	Uncorrect Stratum (N°1)	9,00%	73,36%
E	Pallet not Alligned (Palletizer Entry)	4,57%	**77,92%**

Figure 8 Microdowntime cumulative percentage - Frequency

Reliability R(t) is defined as the probability that a system (machine or component) will perform a required function for a given period of time T. As data follow Weibull distribution, Reliability function (1) is defined as:

$$R(t)= e^{-(\frac{t}{\theta})^{\beta}} \quad (1)$$

Where β is the shape parameter, θ the scale parameter and t is the considered time. The shape parameter β determines the component life position (setting phase, normal life and degradation phase); when $\beta < 1$, the component is in the setting phase as the TTF are decreasing. When $\beta = 1$ the component has a random failure rate, as it is in its "normal life"; finally, when $\beta > 1$ the component is in a degradation phase as the failure rate is increasing.

In the same way could be defined the Probability Density function of the failure distribution (2) and the hazard failure rate (3) as:

$$f(t) = \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} x\ e^{-(\frac{t}{\theta})^{\beta}} \quad (2)$$

$$\lambda= \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} \quad (3)$$

Table 1 shows the descriptive statistics of TTR and TTF data; for the statistical analysis of data MINITAB® software has been used.

TTF	Count	Mean	SD	CV	Min	Max
A	168	566.8	761.2	1.343	0	6240
B	7	2931	2925	0.9978	180	8160
C	4	780	467	0.5991	240	1200
D	8	2070	1546	0.7471	540	4680
E	16	3799	3082	0.8114	360	9420

Table 1 Descriptive Statistics of TTF

Fitting TTF data with Weibull Distribution it is calculated β and θ parameter of the M1 and of the single microdowntime A,B,C,D and E (Table 2).

It is calculated the Anderson- Darling Index (AD) and the Correlation Parameter (r) for evaluating the goodness of fit of data to Weibull Distribution. In addition it is calculated MTTR and MTTF parameter and the recoverable OEE for each microdowntime, considering the TTR time and the OEE measured in the considered period. Figure 9 shows the Distribution Overview Plot of TTF of M1.

	A	B	C	D	E	M1
β	1,24581	0,749956	1,3716	1,43312	1,06945	1,08053
θ	544,389	2923,11	919,281	2250,68	3998,61	781,565
AD	5,319	1,802	2,859	1,955	1,079	8,632
r	0,944	0,972	0,971	0,936	0,972	0,938
MTTF	602,658	293143,4	780	2070	3798,75	1016,58
MTTR	17,8571	34,2857	57,5	48,75	67,5	24,335
OEE	1,45%	0,78%	0,89%	0,53%	0,44%	4,09%

Table 2 Weibull Distribution parameters of microdowntime A, B, C, D, E and of the machine M1

From the analysis of β and θ parameters, it emerges that M1 has a constant failure rate as β is very near to1; this means that the machine is in its useful life, with random and unpredictable failures. Also microdowntime E has β near to 1, that is synonymous of a constant failure rate. Microdowntime A, C and D, instead, have a schape parameter greater than 1; this means that the hazard failure rate is increasing and components are in their degradation phase, near the end of their life. Finally microdowntime B has β smaller than 1, so the failure rate is decreasing and the component is in its setting phase, at the beginning of its life.

Looking MTTR data, microdowntime D results the higher (67.5s), followed by microdowntime B (57.5s).

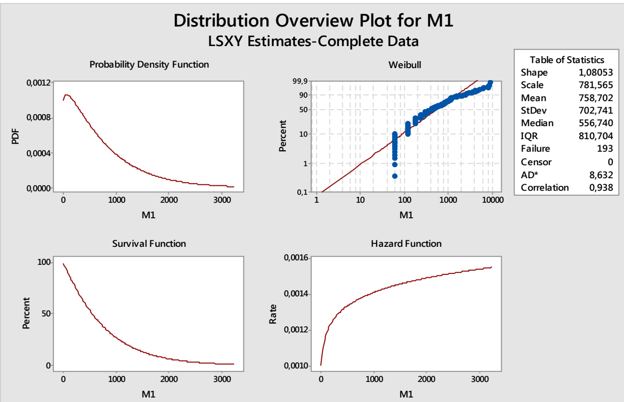

Figure 9 Distribution Overview Plot of TTF of M1

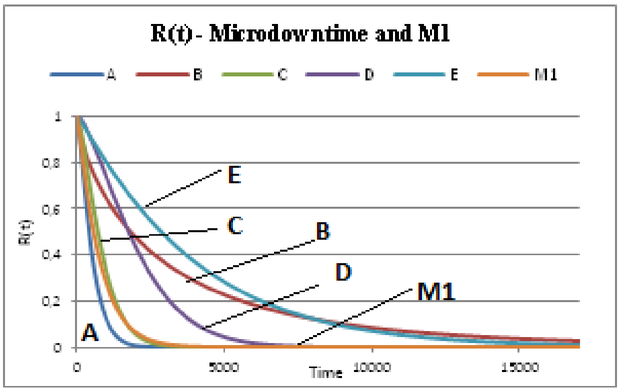

Figure 10 R(t) of microdowntime A, B, C, D, E and M1

Microdowntime A MTTR is the lower, 17,5s, but because of its high frequency it influenced a lot M1 MTTR.

Similar considerations could be done for MTTF: microdowntime B has the higher (29.3143s), followed by D and E. Microdowntime C and A, instead, have a lower MTTR, that influences the M1 one (1.016s).

Next session is about how failure probability distribution of microdowntime A, B, C, D and E influences the failure rate of M1; Figure 10 presents R(t) graphic about the single microdowntime and of M1.

4. Discussion and Results

Once individuated shape and scale parameters for microdowntimes and M1, and so defined the hazard failure rate characteristics, it is wondered how each microdowntime influences the machine. For doing this it has been recalculated β and θ parameters of M1 without TTF data about single microdowntime considered.

Table 3 summarizes M1 characteristics varying the presence of microdowntime.

If microdowntime A, that has a shape parameter greater than 1, is eliminated, β of M1 does not change so much (1.0868s vs 1.08053s). This because β_A is not so high and the machine failure rate remains constant. Anyway the MTTF is higher than before (2.885s) and the MTTR is about the double (55.4s). In fact microdowntime A has a great impact on the machine as it has high frequency and short duration, with a recoverable OEE of 1.45%.

	M1-A	M1-B	M1-C	M1-D	M1-E
β	1,0868	1,10281	1,07459	1,09377	1,16747
θ	2851,36	739,806	778,111	736,273	646,562
AD	1,039	7,71	8,82	8,821	6,333
r	0,976	0,939	0,936	0,934	0,942
MTTF	2885,14	944,516	1021,59	971,027	765,085
MTTR	55,42857	23,97959	23,66834	23,33	20,64171

Table 3 Weibull Distribution parametrs for M1 without Microdowntime A, B, C, D and E

Considering the elimination of microdowntime B, that has a decreasing failure rate, β of the machine increases (1.10281s); in fact the component is in a setting phase. Consequently the

MTTF decreases (944.5s) as the ageing of machine increases. Also in this case the recoverable OEE is considerable (0.78%). Deleting microdowntime C and D, there is the same effect of excluding microdowntime A on the shape parameter. β does not change so much (1.07459s and 1.09377s), also because the frequencies of these data are very low. By the way, MTTF increases in case of C elimination (1021s), and it decreases in D one (971s).
Finally, eliminating microdowntime E, the machine's failure rate increases (1.16747s) as E has a random trend of the failure rate; so the elimination of a component with a random failure rate will increase the age of machine and consequently the failure rate. MTTF and MTTR decrease (765s and 20.6s), influenced by the frequency of microdowntime E.
It is evident that Microdowntime A is the one that mostly influences the machine reliability function; it is also the one with the higher OEE improvement margin. So it is reasonable to evaluate an investment on this microdowntime to eliminate it and to increase the OEE.

5. Conclusions

Results carried out how each microdowntime cause has an effect on the reliability of the machine. Microdowntime influence the failure rate of the machine, depending on the shape parameter β and scale parameter θ of microdowntime and the frequency of its data. Consequently also MTTR and MTTF depended from it.
Finally and mostly important, it is evaluated the economical benefits that each microdowntime solution could give in terms of production efficiency. This part is fundamental for management to decide where and when an investment is convenient, considering not only the reliability of machines, but also its effectiveness (OEE) and consequently the production increase.
The main research finding is the relation between these short process failures and the failure rate probability distribution of the machine; results can be extended to the whole production line, and studies about reliability variation of single machines can be carried out.

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Technical Study

When Micro Downtime Counts

Automated flow line manufacturing systems are becoming more and more relevant, especially in the food and beverage sector. Their efficiency is most companies' core objective to succeed. TPM (Total Productive Maintenance) is a useful industrial tool to improve production plant effectiveness, measured by the OEE index

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Downtime analysis carried out by Acqua Minerale San Benedetto S.p.A., with the collaboration of the University of Padua

Acqua Minerale San Benedetto S.p.A. is situated in the beverage market and it is the biggest plant in Europe. Its core business is mineral water and beverage. It has 1800 employees, 6 plants in Italy (and others around the world), and a turnover of 720 million euro (2013).

The project has started in Italy's headquarters, that has 23 production lines: glass, PET and aseptic lines with numerous formats (0.25L, 0.5L, 1L, 1,5L, etc.). Moreover, the company not only takes care of the bottling process, but it produces bottles, plugs and stamps for self-manufactured bottles.

The project aims to analyse in depth an automated production line, focusing on downtime and micro downtime (stops lower than 15 minutes) to improve the OEE of the equipment. It was applied a TPM approach and, in order to make results arise, Figure 1 shows the steps implemented.

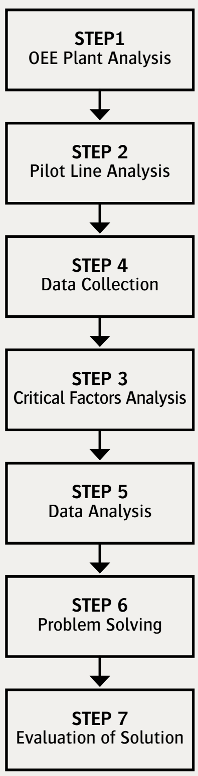

Figure 1. Project Steps.

OEE ANALYSIS OF THE PLANT

The project started with the efficiency analysis of the production equipment of all the production plant in terms of OEE. Data about OEE plant referred to one year were analyzed. Line D was chosen as the Pilot Line of the project since it is the one with the lowest OEE.

OEE ANALYSIS OF THE PILOT LINE

Line D produces mineral water in 1.5L format; it produces on average 15.000.000 bottles per month, with a speed of 26.000 bottles per hour on average. It comes with 8 main machines. In this step OEE was analysed by dividing it in each parameter that influenced it (Figure 2).

In Figure 2 it is shown which are the main inefficiency causes that affect the pilot line OEE, gathered in the following categories:

- Failures
- Set-Ups
- Materials lack
- Micro Downtime
- Defects

The graphic shows in % which were the principal factors that affect the line efficiency; it was evident that the principal cause was micro downtime, with a percentage of the 57% on average.

Moreover, it was calculated the impact of each factor in terms of OEE% and points recoverable from each one. Results showed that if no micro downtimes were occurred, OEE could have been of 87.76%, with an improvement margin of 16.2%; For this reason, the company decided to invest more resources in micro downtime study (micro downtime are considered in the project as short stops of few minutes, related to "process failures", with high frequency).

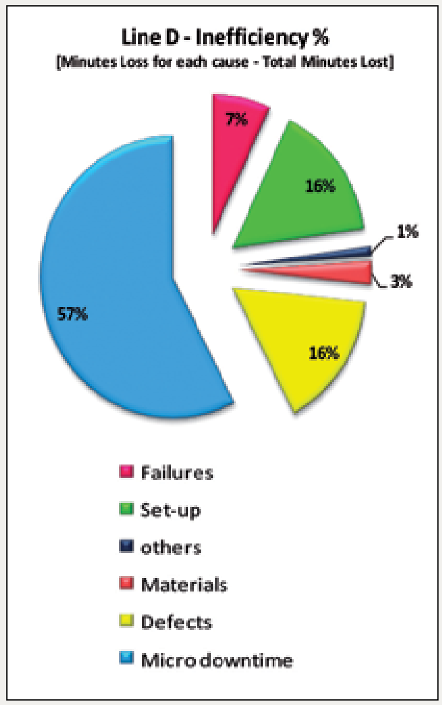

Figure 2. Inefficiency of Line D %.

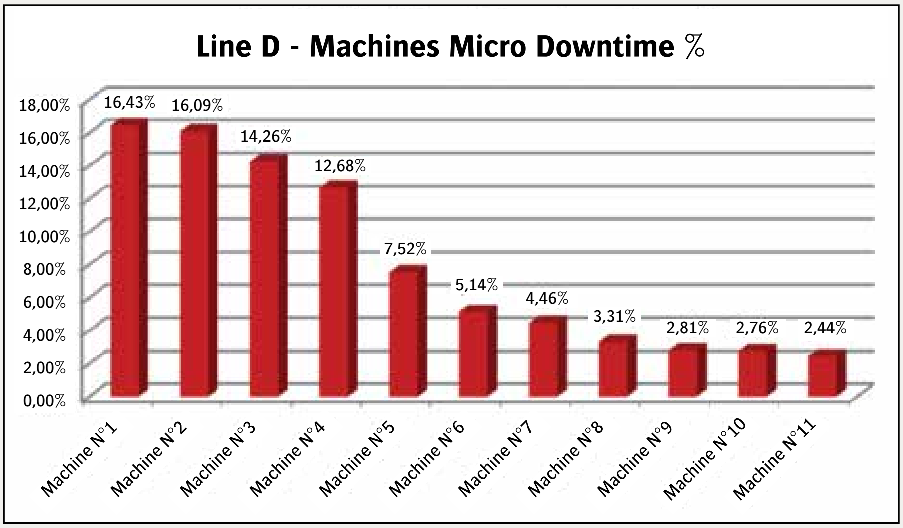

Figure 3. Microdowntime per Work Station (Machine).

CRITICAL FACTOR ANALYSIS

In this step the analysis was focused on micro downtime to individuate the most critical machines affected by this inefficiency. Figure 3 shows in order the machines that result more affected by micro downtime: The Palletizer (M1), the Shrink-wrap packer (M2) and the Labeller (M3). Once critical machines were individuated, an ad hoc data collection and analysis was conducted.

TABLE1. Microdowntime % - Frequency

	Micro Downtime	% n° of stops	% n° of stops cum
A	Bundle not Alligned (Palletizer)	41,38%	41,38%
B	Uncorrect Stratum (N°2)	12,60%	53,98%
C	Pallets Warehouse Allarm	10,38%	64,36%
D	Uncorrect Stratum (N°1)	9,00%	73,36%
E	Pallet not Alligned (Palletizer Entry)	4,57%	77,92%
F	Fallen Bundle (Palletizer)	3,60%	81,52%

DATA ANALYSIS

Pareto Analysis

After evaluating the effectiveness of micro downtime impact on OEE, machine micro downtime causes have been analysed in depth.

The main causes are the same both in terms of frequency and time loss. The first 6 causes cover 80% of the time loss for micro downtime, as supposed by the Pareto principle; in particular, 81.52% in terms of frequency (Table 1) and 77.94% in terms of time.

After the individuation of the most critical micro downtime causes for the machine N°1, the TTF and TTR of these ones were studied to understand if these factors affected OEE in a random way or in a chronic way. It resulted from the TTR-TTF correlation of the main palletizer micro downtime cause (A) that "Bundle not Aligned" was a chronic factor, that could be analysed and solved.

OTHER ANALYSIS - CONSIDERATIONS

Once principal micro downtime causes were identified and studied, it was calculated the possible recovered OEE for each one per month to individuate the most critical problem. "Bundle not aligned" results are the most critical issue in terms of OEE incisiveness, as they affect OEE of 1,44 point % per month.

SOLUTION - COST-BENEFIT ANALYSIS

Finally, the last step is about the cost-benefit analysis to evaluate the solutions proposed. It was proposed the analysis of the new Spiral Transport System as a solution for Microdowntime A. The cost of the investment and the recoverable OEE have been calculated and compared; Moreover, the payback period was taken into account.

CONCLUSION

Nowadays, improving the OEE is most companies' core objective, to try to maximize machinery utilization and minimize costs. The study commissioned by Acqua Minerale San Benedetto reveals the importance and incisiveness of short process downtime in automated production systems in terms of OEE reduction.
The Bottle Line Downtime Analysis shows that the 57% of inefficiency is caused by little process failures called micro downtime; the analysis carried out the following results:

- Working on three machines, it is possible to recognize the strongest micro downtime cause, that covers the 80% of micro downtime of the line;
- The TTF and TTR analysis reveals if micro downtime is random or related to specific causes, or furthermore to the ageing of machinery;
- The most incisive causes has a recoverable OEE of 1.44%;
- Through the VAN calculation and the Contribution Margin it is possible to individuate the payback period of investments.

TPM Implementation in automated flow line manufacturing systems: criticalities and key factors to support a faster implementation

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Abstract

Total Productive Maintenance (TPM) is a very diffused industrial tool used to improve and guarantee efficiency of industrial plants. . Significant financial savings are achieved by TPM, thanks to the involvement of all staff, from management till production operators, through all functions. It requires time and resources to be successfully implemented as a deep transformation in conventional production mind it is needed, from productive to proactive. Nowadays the economical situation of the industries makes management reluctant about investing in projects that require long time to be implemented without showing rapid and evident results, by an economic point of view. In this context, the paper aims to discuss the critical factors about implementing TPM in automated flow line manufacturing systems, by describing the main success points to make the TPM paradigm a factory reality. The focus of the study is on beverage and food sector. The main purpose is to identify a new methodological framework to support a successful and faster TPM implementation in these specific sectors. It proposes a first step of research that aims to identify ad hoc procedures capable of achieving results faster than traditional ways. Finally, the paper aims to investigate those activities which provide a clear economical and productive benefit in order to increase people trust in TPM paradigm.

Key words: TPM; Fast Implementation; Influential Key Factor; Framework

1. Introduction

The rapid evolution of technologies, the transformation of human role in automated production systems, and the increasing need to reduce wastefulness to improve factories efficiency have introduced a deep cultural transformation in industries.

In this period of economical crisis, a company that aims to be world class manufacturing (WCM) needs to reduce production loss and maximize the utilization of its resources, by increasing machinery effectiveness and developing multi-skills operators. In this context, TPM (Total Productive Maintenance) is a useful industrial tool, designed primarily to maximize the effectiveness of equipment throughout its entire life by the participation and motivation of the entire workforce (Nakajima, 1988). Strategic investments in the upholding function can show to improved presentation of manufacturing arrangement and amplify the competitive market position of the organization (Jonsson and Lesshammar, 1999). Nakajima (1988) identified three main meanings for the word total, as:

1.Total Effectiveness that indicates the TPM aim of maximize economic efficiency or profitability.

2.Total Maintenance System that indicates the total involvement of maintenance prevention, maintainability improvement and preventive maintenance.

3.Total Participation that indicates the importance of the involvement of all staff in TPM philosophy, especially a deep collaboration between maintenance and production, through autonomous maintenance.

TPM paradigm include several objectives, as:

- Maximize equipment effectiveness.
- Establish a total Preventive Maintenance (PM) system for all the machinery, through prevention, preventive actions and improvements.
- It requires the participation of all staff, especially of equipment designers, equipment operators and maintenance workers.
- It involves every single employee, from the production operators till the top managers.
- It is based on the promotion of autonomous small group activities.

Companies that adopt TPM are seeing 50% reduction in breakdown labour rates, 70% in lost production, 50% - 90% reduction in setup, and 60% reduction in costs per maintenance unit (Koelsch, 1993). By the way, nowadays the management is reluctant about investing in projects that require long time to be implemented, considerable economical resources and deep cultural transformations, without showing rapid and evident results. The paper is set in automated flow line manufacturing systems in food & beverage sector. The company of the case study is leader in its sector and has many factories in all Europe. Maintenance in this area is very critical and incisive, and often, in a wrong way, it is view as a secondary function. For privacy reasons, the company of which it is referred in the paper is called Alpha S.p.A..

The paper is divided into three sections. There is a first part in which typical critical aspects of the food & beverage sector are explained, and principal success key factors and obstacles to TPM implementation are described. The second section proposes a methodological framework about TPM implementation in the company, focusing on activities that arise faster results and increase employee involvement. Finally, in the last section, the first results of the framework are discussed.

2. Food and beverage - Success key factors and obstacles

Food and beverage sector, that is characterized by high automated production systems, presents critical factors related to health, safety, quality and delivery of products, over the common criticalities related to automated production. Typically products of this sector have short life time, with low possibility to stock, and requires specified characteristics of quality, related to security regulations. Roth et al. (2008) studied 6 principal aspects that characterized food & beverage sector, called "6Ts", as:

- *Traceability*, that is the ability to track a product's flow. Behind traceability there are security, safety and quality reasons, regarding both the company and the customers.
- *Transparency*, regarding the product and process information, like ingredients, treatments and packaging.
- *Testability*, that is the possibility to verify a characteristic of the product, like freshness, contamination test, quality; often this tests are destructive.
- *Time*, that is the duration of a process (production, delivery, etc.).
- *Trust*, that is the relationship between partners in the supply chain, the expected information flow; this aspect is important for the efficiency and quality of the supply chain.
- *Training*, that is the continuous developing of skills, knowledge and attitudes regarding international standards of quality and food safety.

These aspects deeply influence food and beverage production, increasing controls and hygienic regulations, that makes maintenance activities more critical and important. Moreover, the short lifetime of products and the changeableness of the demand make TPM an essential strategy to prevent equipment downtime and to increase the product quality (Heymans B.).
By the way, TPM implementation it is not easy and fluent, as it requires specific attention to some critical aspects that can make the project fail. In general the failure of TPM implementation is due to lack of a support system to facilitate learning and transform learning into effective diffusion of the practices of TPM (Ahuja and Khamba, 2008). The failure of an organization to successfully implement a TPM program has been attributed to various obstacles including lack of management support and understanding, lack of sufficient training, failure to allow sufficient time for the evolution (Bakerjan, 1994). Cigolini e Turco (1997) studied several Italian industries to individuate influential aspects in TPM implementation, related both to external and internal context; they identified three factors as the firm size, the manager's commitment to the project and the program promoter.

Figure 1: The 6 Ts

In food and beverage sector all this aspects should be considered in relation to the 6 Ts, as they influence TPM and its implementation. Now it is described the major influential factors in TPM implementation.

1. Management Support
Management staff is the first division who embraces TPM philosophy, it is the promoter and principal supporter of the project. Its support is fundamental to the success of the project, both for financial and economical sustain, and as example of communication and synergy between departments. Structural and culture transformation take place from management, so its support is an important success key factor, as it is argued in various case studies (Chan F.T.S. et al. 2003, Darabi M. et al. 2013, Hansson J. et al. 2002).

2. Sufficient Time
Time for implementation is a basic aspect to consider; as TPM is a cultural change, it requires time and time to be implemented, and often results are not immediate. After a step gets start, it needs time to be implemented and improved. Companies that does not gives TPM enough time to evolve, often fails in its implementation (Bakerjan, 1994; Davis, 1997). Also Rodrigues and Hatakeyama (2006) affirmed that TPM implementation in a quick way, omitting some consolidation steps, is a failure influence factor. This aspect is the most critical in the company, since they need immediate results

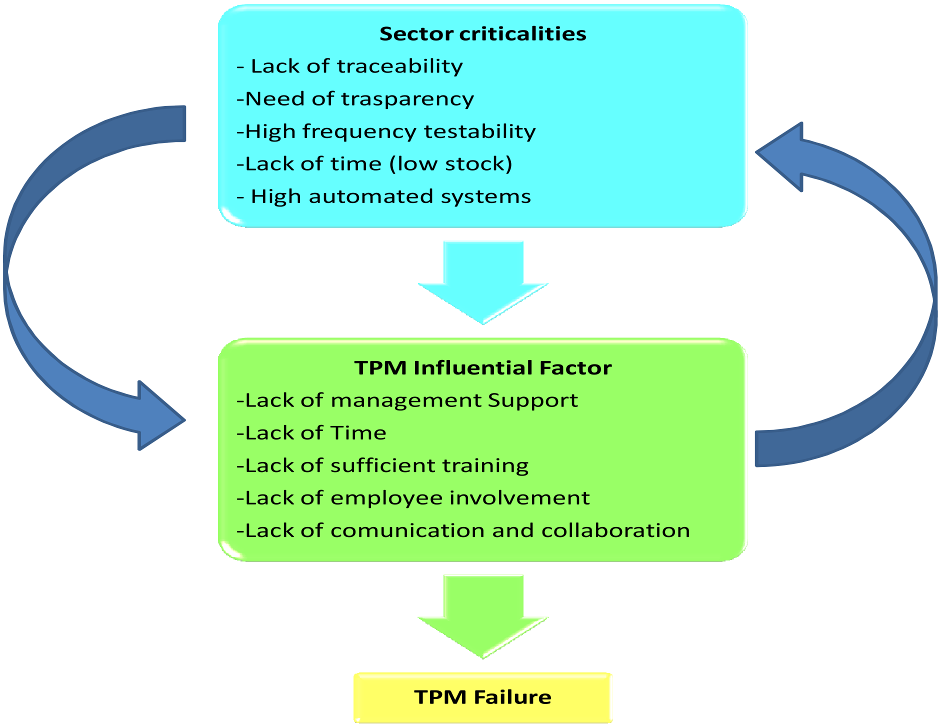

Figure 2 Factors related to TPM failure

3. Employee Involvement

Management support is a success prerequisite as employee involvement and participation. Operators as first have to change their mindset from productive to proactive, embrace the project, and improve their control of the machines. Total employee involvement is indeed a pre-requite to successful TPM implementation and can be ensured by enhancing the competencies of employees towards the jobs, evolving the environment of the equipment and system ownership by the employees (Ahuja et al, 2008). Moreover TPM is a total cultural transformation, that must comprehend all the staff to success.

4. Training and education

TPM needs focused training and education sections for all the company's staff, from management till production department. Management needs training to deep understand TPM paradigm, how to manage and improve its development through the company; operators needs training both for the new cultural mindset and to achieve the required technical skills. This key factors it is not only discussed in various case studies, but it is a proper TPM pillar.

5. Communication and cooperation (team work)

Team work is the basis of TPM, in which maintenance and production functions have to cooperate and communicate to win. Production needs maintenance to reach its performance objectives, and have to communicate with it to improve its output. Operators and maintenance staff should work in team to follow the win-win strategy; in fact operators should be multi-skills staff and maintenance staff should trust in them and delegate basic maintenance activities.

6. Integration and visibility of TPM goals

TPM is a paradigm, a cultural transformation, of which boundaries are hard to define. Define goals and measure TPM results is important to control and underline the project progress. Management needs TPM goals to check their investment and to manage future improvement; on the other side staff need to know the development of their actions, to improve motivation and gratification. TPM purpose and objectives necessitate to be entirely incorporated into the designed and commerce plans of the organizations, since TPM have an effect on the entire association, and is not restricted to manufacture (Darabi et al., 2014)

In figure 2 it is shown the whole influential factors related both to the specified context of food and beverage and to TPM Implementation, that could make the project fail.

3. TPM Framework - Case study

The company Alpha S.p.A. has 23 automated production lines; each line is composed by 15-20 machines, related by internal transport systems, and for each line there are 3-4 operators, that supervise a group of machines. Operators

Key factor	Company situation
1-Management Support	• Adequate investment - budget • Establishment of Maintenance Engineering department • Management periodic meetings
2-Sufficient Time	• Necessity of immediate results
3-Employee Involvement	• Synergy between various departments as production, maintenance, purchase and tooling • project sharing • maintenance engineering periodic meeting
4-Training and Education	• Periodic training for production staff • Improving operators skills • Improving maintenance workers responsibility
5-Communication and Cooperation	• Maintenance and production operators work together • Line Team composed by both maintenance and production staff • Cooperation between maintenance and production department to plan production stops
6-Integration and Visibility of TPM goals	• OEE index • Output

Figure 3 Key Factors - Case Study

are few and often do not have ownership of the machinery. The big maintenance activities are made during a specified period of 2 weeks, by a maintenance equipment, while, in the rest of the year, machines have to work with no stops. In fact this sector is characterized by a high seasonality and machines cannot stop in high period, while in the lower one a period of two weeks is the

maximum allowed (the whole maintenance actions, usually, keep more than 2 weeks). In the figure 3 it is shown the company position respect the major key influential factors related to TPM. The management established an adequate budget to support TPM Implementation and a Maintenance Engineering Team. The company promotes synergy and collaboration between departments, in particular between production and maintenance; weekly meetings are planned between maintenance engineering staff to share the projects development. For the training and education key aspect, the company established periodic TPM training sections and placed production operators to support maintenance staff to improve their skills. Finally the company decided to measure TPM with two fundamental indexes, as the produced pieces and the OEE (Overall Equipment Effectiveness).

As first, the maintenance structure has been reviewed, as shown in the figure 4; principally it had been introduced a maintenance engineering team and a TPM technicians team. The maintenance engineering team is composed by the TPM Project Manager, the Maintenance Planner and other TPM collaborators that provide to follow the project implementation. TPM technicians are three: there is the line technicians, responsible of the efficiency of the line, the Mechanic and the Electric technicians that provide to more specific maintenance actions of the line; all three are supported by operators.

The project of the paper is a part of the TPM implementation, that goes on all the factory. It aims to accelerate TPM results, to arise its benefits and to implement a more quickly diffusion of its culture.

As it is shown in the framework (figure 5), there are several project steps. As first, it was required an analysis of all the factory's production lines, based on the principal efficiency index (OEE - Overall Equipment Effectiveness), to individuate the pilot line. The pilot line was the one who has the lower OEE index. Improvement actions on the pilot line will be more visible and effective, as it was the worst one, and this should increment TPM diffusion in the company. Then a study of the line is necessary to find the most critical machines and/or mechanical parts. With the support of the analysis, the maintenance engineering team and the TPM technicians team work together to implement three action

Maintenance Engineering	TPM Technicians	Other departments
TPM Project Manager	Line Technician	Purchase department
Maintenance planner	Mechanic Technician	Spare parts warehouse
TPM collaborators	Electric Technician	Tooling department

Figure 4 Company TPM Organization

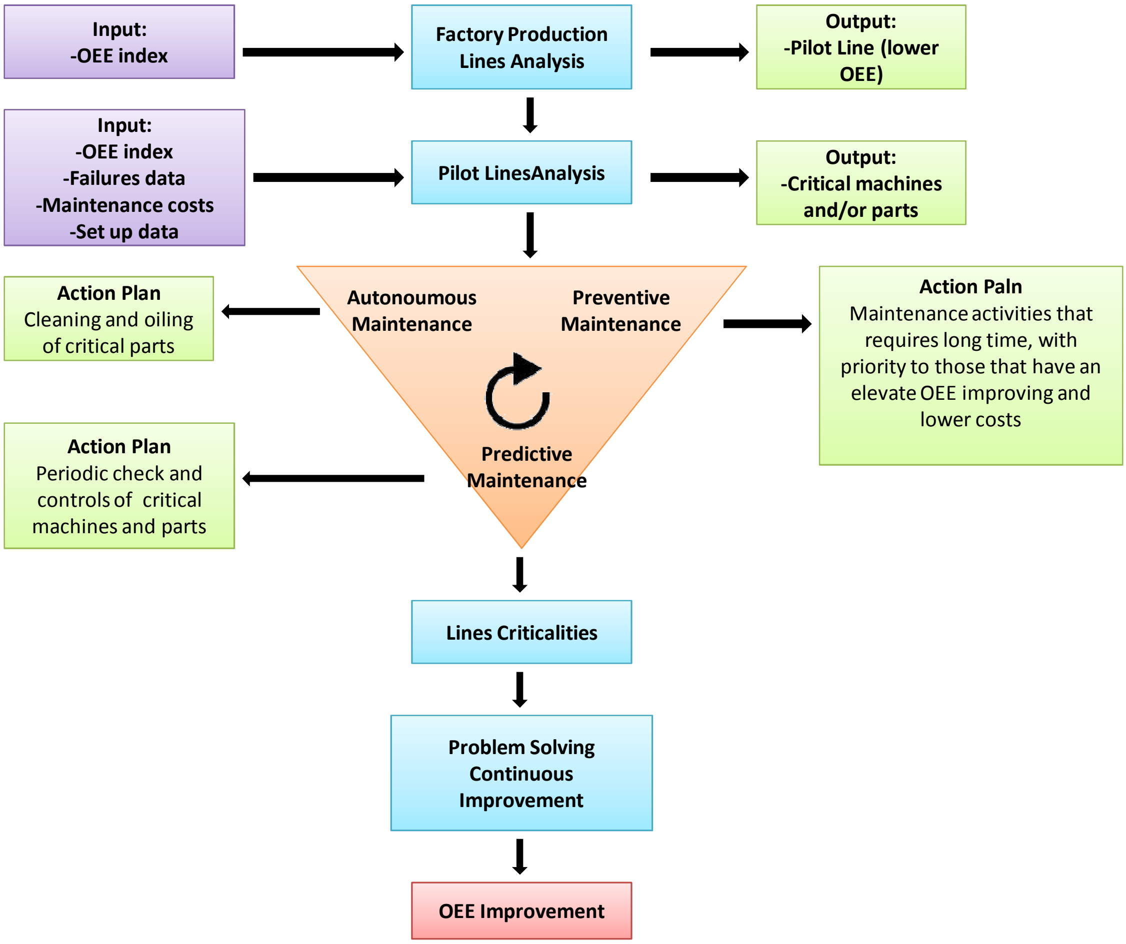

Figure 5 TPM Framework

plans, based on three different maintenance approaches:

1. *Preventive Maintenance*: Maintenance activities that require more than two days, or related to quality and security factors. Activities with low costs that gave a remarkable OEE increment have higher priority.

2. *Predictive Maintenance*: Checks and controls of critical machines and particularities, to plan needed maintenance actions.

3. Autonomous Maintenance: Cleaning and oiling activities, made by the production staff, to implement their ownership of the machines and to make critical zone emerge.

This part of the project required a strong collaboration between all staff, to plan activities, resources, spare parts and to schedule all the data. This step has no end, it is in continuous evolution and improvement.
After this step it is expected that some criticalities raised, as lack of information regarding correct spare parts, correct appropriate scheduling time and resources. Moreover, with the analysis support and staff experience, the spare part warehouse will be involved to improve the right stock level of critical parts.
After the first implementation, it will be necessary a periodic analysis of results, to focus on critical parts and activities, to solve problems emerged and to achieve new information.
An increment of OEE index is expected.

Conclusions

The project is underdeveloped and clear results are not seen yet, especially from autonomous maintenance. The analysis of the line showed the most critical machines and zones, and, with production staff involvement, it had been possible to implement the action plans. The preventive action plan had been implemented and improved, while the predictive and the autonomous one are under development. The OEE index has grow up of one point, but the high season had not started yet. Some visible benefits had been seen, as the awareness of the line problems by the staff and the reorder of all correct spare parts and needed activities. As first it is expected an improvement of OEE and a complete involvement of all production staff, that should change its mindset from productive to proactive. After the high season, a new analysis session will begin to better improve the first implementation.

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Downtime Analysis as a tool to improve efficiency in automated production lines: A bottle plant case study

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Abstract:

Automated flow line manufacturing systems are becoming more and more relevant in our industries, especially in food and beverage sector. Safety, Quality and Sustainability are the main aspects that characterize this sector, but production efficiency remains the core objective of the entire system. In this context TPM (Total Productive Maintenance) is a useful tool to improve production plant effectiveness, through the utilization of OEE (Overall Equipment Effectiveness) index. One of the factor that considerably affects OEE in automated lines, is downtime, in particular micro downtimes of equipment, that are production minutes lost with low duration and high frequency that could not be define as failures. In this context micro downtimes are defined as short stops (few minutes) that are not related to failure, but, for example, to buffer capacity, layout parameters, production and product characteristics and other aspects. The paper presents the downtime analysis of a bottle production plant, from the OEE of the plant, the individuation of the most critical line, its global analysis, till the micro downtimes collection data and analysis. The aim of the paper is to present the initial studying and analysis of a TPM approach in food and beverage industry. It presents a framework for the individuation of the line criticalities, in relation to failures and OEE. The project aims to simulate the production system with a software and individuate suggestions and solutions to improve OEE with a cost-benefit analysis.

Keywords: Micro downtime, TPM, food & beverage, OEE, downtime analysis.

1. Introduction

Automated manufacturing systems are now being deeply influenced by the changing in market requests. A growing multitude of variants and an increasing product differentiation, due to various factors as more customization, shorter product lifecycles, uncertainty in demand, have to go along with an increase in effectiveness, to rise in the market competition [Mourtzis et al., 2012]. As the increasing of personalization of products, mix variability, requirement of short time to market and risk of products obsolescence, the need of continuous flow and JIT solutions forces the industries to achieve constant improvements in terms of product quality, operation efficiency and production capacity utilization [Battini et al. 2006].

Nowadays food and beverage sector is characterized by automated flow line manufacturing systems, that are several machines working in sequence, related to various transport systems. Automation, in general, has the core aim of reduce human participation in production systems, introducing machines for doing repetitive and/or complex actions, transforming production more continuous as possible. With this kind of production systems are required few operators that work as controller and supervisor of the process, and operate when is extremely necessary (for example during set ups). Food and Beverage sector, in addition to automation peculiarities, is characterized by Safety, Quality and Sustainability aspects that collocated and identified the company in the market. A food company has to respect strict legislations and procedures to be accepted in the market, as safety of customers is the major priority. Quality and sustainability, on the other hand, have become pilot parameters to reach success. In this context automated equipment need complex systems and tools of control, as fix parameters and procedures well defined, certification, like ISO 22000, or tools like Hazard Analysis Critical Control Point system (*HACCP*), or others.

Production systems effectiveness, anyway, remain the principal aim of each industry, to be competitive and get success.

In this context Total Productive Maintenance (TPM) is a useful industrial tool to improve plants productivity and operation efficiency. It is designed primarily to maximize the effectiveness of equipment throughout its entire life by the participation and motivation of the entire workforce [Nakajima, 1988]. To measure effectiveness of production plants, TPM uses OEE index (*Overall Equipment Effectiveness*), that is the core metric to measure the success of TPM implementation program; it is the combination of three parameters as availability, performance and quality.

The paper focused in micro downtime analysis, as it arises as a very relevant parameter that influence OEE in automated flow line manufacturing systems. In fact, in accord with TPM framework, with an effective maintenance action plan, most of downtimes related to failures can be controlled and reduced; anyway micro downtimes remain a relevant cause of inefficiency, that needs a focused analysis. Micro downtimes could be considered as production line stops of few minutes but with high frequency. They are not related to failures, or to particular problems that requires maintenance staff intervention; they could be manage and solve by production operators. Micro downtimes could be named "process failures" and underestimate micro downtimes could be a big error in achieving OEE improvement. These stops are low in duration, but their high frequency makes them more incisive then a failure, sometimes.

The paper presents a bottle production plant case study, characterized by automated flow line manufacturing systems; the first section is dedicated to OEE index, as the principal TPM tool to measure improvements. Then the second one provides the description of the method and tools followed in the project. The third part is dedicated to the company profile and the data collection and analysis. Finally the last section regards the conclusions and further research.

2. Overall Equipment Effectiveness (OEE)

The Overall Equipment Effectiveness is the traditional evaluation index of Total Productive Maintenance that has to be maximized; it compares the operating level with the ideal potential of the plant performance [Lanza et al., 2013].
As it aims to measure the effectiveness of plant machinery, it summarizes the three main factors that affect it, as:

1. *Availability*, time for production;
2. *Performance*, time in which machines run;
3. *Quality*, final output.

These parameters are related to the six big wastes, as set-up, failures, micro downtimes, speed loss, reworks and scraps. Availability measures the time for the production of the equipment, and is related to big time losses, as set-ups and failures. Performance is related production efficiency, in terms of micro downtimes and speed losses, and measures the speed of the production system. Finally the rate of quality measures the effective production, through counting how many produced pieces can be considered final products, in accord with market standards.
The target of TPM is to improve OEE percentage, to maximize plant productivity, to secure the equipment failure zero, defects and rework zero and industrial accident zero [Shirose et al., 1989].
"Studies carry out worldwide have revealed that the average OEE in producing companies is at about 60%" [Ryll et al., 2010]; in this context, to reach at least an index of 85% could be a proper objective, in addiction to economic and productivity benefits that OEE make risen.

3.Methods and Tools

The study aims to analyse in deep an automated production line, to construct the basis for a cost-benefit analysis to improve the OEE of the equipment.

To achieve this, the methodology followed is:

1. Collecting historical data of downtime of the equipment;
2. Collecting downtime data directly from the production system;
3. Implementing a Downtime Analysis (MTTF, MTTR, MTBF, etc.)
4. Implementing a Cost Analysis for each improvement action
5. Modelling and simulating the production system
6. Calculating a CPI Index (Cost Performance Indicator)
7. Individuating priority on investing activities to improve OEE;

Figure 1 presents the whole framework followed in the study. The paper presents the first part till downtime analysis.

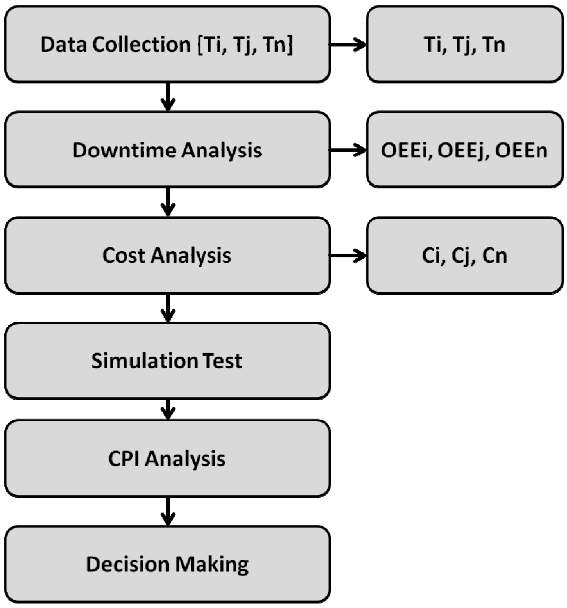


Figure 1: Framework of the project

3.1 Data Collection and Downtime Analysis

Downtime data are collected both from historical database and directly from the production system. For each stop is signed the duration, the time and the nature (failure, set-up, micro downtime, etc.). Data are necessary to calculate:

- TTF (Time to failure)
- MTTF (Mean time to failure)
- MTTR (Mean time to repair)
- MTBF(Mean time between failure)

These parameters are useful to study and construct the production line work reality. Moreover, through the data collection, the analysis allows to calculate for each cause of downtime the OEE loss; in this way it is possible to quantify the OEE recoverable, and it is useful for the cost-benefit analysis.

3.2 Cost Analysis

Cost Analysis is provided to calculate the impact from an economic point of view for each investment/action carried out from the downtime analysis. It is necessary for evaluating the priority of each activity in relation to OEE improvement..

3.3 CPI calculation

The Cost Performance Indicator aims to assign a priority to each improvement/maintenance activity.
The index provides to compare the cost of the downtime, in terms of production loss, the cost of the activity and the OEE incisiveness.

To construct it, firstly it is defined:

- i chronic downtimes (i=1,2...n)
- j random micro downtimes (j=1,2...m)
- k machine failures (k=1,2...p)

For each type of downtime, it will be discuss, through problem solving techniques and brain storming meetings, possible solutions, investment and maintenance activities to eliminate the time loss. After that, for each equipment improvement, it will be calculated the cost and compared with the OEE improvement.
The CPI will be constructed as:

$$\text{CPI} = \frac{Cost\ Equipment\ Improvement[€]}{OEE\ Improvement\ [\%]}$$

The lower the CPI is, more suitable the investment, as it means low costs and high OEE improvement.

4. The company and the OEE analysis

The company is situated in beverage world market and presents the biggest plant of Europe. Its core business is centred in mineral water and beverage, of its property and for third parts. It has 1800 employees, 6 plants in Italy (and others around the world), and a turnover of 720 million (2013).
The project is situated in the core factory in Italy, that has 23 production lines: glass, PET and aseptic lines with numerous formats (0.25L, 0.5L, 1L, 1,5L, etc.). Moreover the company not only provide to bottling their products, but it produces the bottles, the plugs and the stamps for doing these ones from itself.
Because of increased competency levels and demand of quality products at lower costs, companies needs a comprehensive system to achieve optimum output from the equipment [Dogrà et al., 2011].
The company reaches a high maturity level, as it was founded in 1956; because of its complexity, it requires a considerable maintenance system. In fact the company implemented a maintenance engineering department to maintain the plant in order to produce the required output; it comprehends maintenance technicians (mechanics, electricians and plumbers), production line technicians, a maintenance planner, improvement technicians, and a maintenance engineering team leader.
The company decided to implement TPM paradigm in 2013, to improve efficiency and effectiveness of the equipment. In order to do that, a first step of “make order” was applied to all the factory. Spare parts, activities, resources and all information related to maintenance were collected in order to have a clear situation of the AS-IS statement. This step took times and resources, but results were not immediately visible by an economic point of view.
This philosophy requires a "drastic change" in production mindset and maintenance approaches [Fredendall et al., 1997]. In fact TPM is a useful tool, but it is a process that requires time and time to be well implemented and shows results, as at first it requires a deep mind change.
For these reasons, a “faster” TPM project on a pilot line has been implemented; it aims to show more rapidly TPM benefits, to increase people trust in the project.
The paper presents the pilot line selection as the one with the lowest OEE, to make results rise more and more, and its downtime analysis.

This part of the project is divided in the following steps:

1. OEE plant analysis
2. Individuation of the pilot line
3. Pilot line OEE analysis
4. Problem solving – individuation of the lower parameter
5. Solutions and results

4.1 OEE Plant Analysis

As first it has been studied the efficiency of the production equipment of all the production plant in terms of OEE. The company calculates the OEE from years, to measure the efficiency of the production plant; data collection is made by the production personnel, day by day, in a common database following specific procedures.
For each day it is signed:

1. time loss for machines downtime, distinguishing between failures and micro downtimes;
2. time loss for set ups;
3. time loss for law material lack;
4. time loss for preventive maintenance (Planned downtime)
5. time loss for resources lack
6. planned and final output

It has been analysed the data about OEE plant referred to one year (2013), as it can been seen in Figure 2.
From the graphic the worst line is A, but it was going to be disused; furthermore line B and C were quite new (the low OEE was justified).

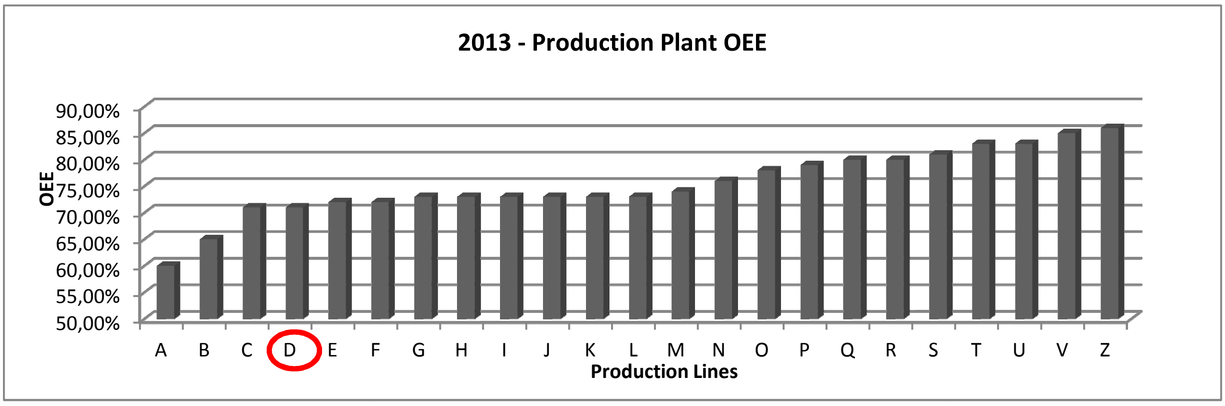


Figure 2: OEE Plant Analysis

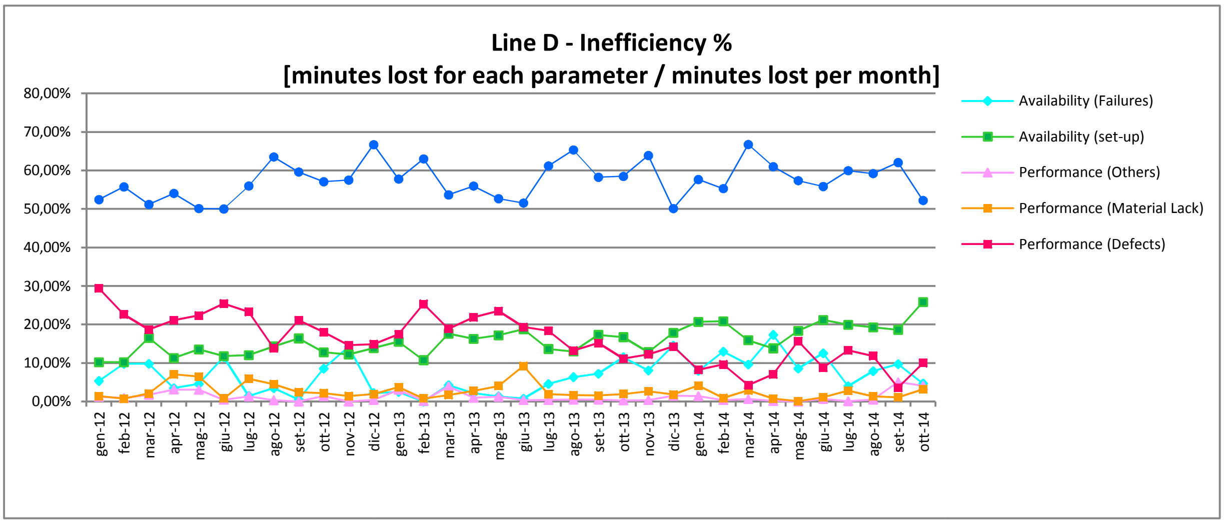
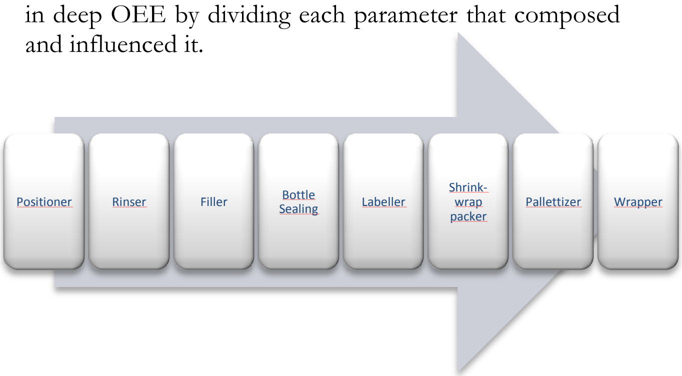


Figure 3: Line D Inefficiency Analysis: Principal Causes

For these reasons line D was chosen as the Pilot Line of the project.

4.2 OEE Pilot Line Analysis

Line D produces mineral water in 1.5L format; it is composed by 8 principal machines (Figure 4): the positioner, that takes the bottle in a correct order, the rinser machine, that washes them, the filler machine, that fills the bottles, the bottle sealing, to close them, the labeller machine, the shrink-wrap packer, to make the first packaging, the palletizer and the wrapper machine, to close the final product.
The OEE analysis of the specific line aims to understand which are the principal factors and causes that more affected production efficiency; in other words, it is study in deep OEE by dividing each parameter that composed and influenced it.



In the Figure 3 it is shown as OEE characteristics are divided and how this parameters affected OEE; the parameters are:

- Failures (Availability)
- Set-Ups (Availability)

Figure 4: Production Line Scheme

- Materials lack (Performance)
- Micro Downtime (Performance)
- Defects (Quality)

The graphic shows in % which are the principal factors that affect the line efficiency per month; it is evident that the principal cause is micro downtimes, with a percentage of the 60% in media. This means that the line inefficiency (in terms of minutes of production lost) is caused by micro downtimes for 60% of the time.
After that, it has been calculated the impact of each factor in terms of OEE% and the points recoverable from each one (Table 1).

OEE-actual	71,57%	Improvement Margin
+ OEE-materials lack	72,29%	0,72%
+ OEE-defects	76,01%	4,44%
+ OEE-set-ups	76,01%	4,44%
+ OEE-micro downtime	87,78%	16,20%
+ OEE-failures	73,55%	1,98%

Table 1: OEE Improvement Margin- Line D

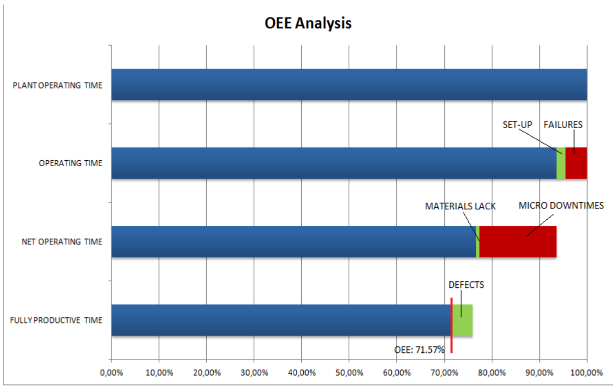


Figure 5: OEE Analysis-Causes identification

In the same way, figure 5 shows OEE division for each cause. Plant operating time correspond to an OEE of 100%, considering all the time that theoretically is planned for production. Then there is the Operating time that represents the time loss for failures and set-ups; the net operating time is influenced by the performance of the production systems, in terms of materials lack and micro downtimes. Finally the fully productive time represents the quality loss in production.

The figure well expose the great impact of micro downtime on OEE index, with the red area in the net operating time.

The line presents an OEE of 71.57%; without micro downtimes the OEE could be 87.78%. This 16% of margin represents a great potential for improvements.

For these reasons the analysis is concentred from here on micro downtimes.

As first it has been analysed micro downtimes data about

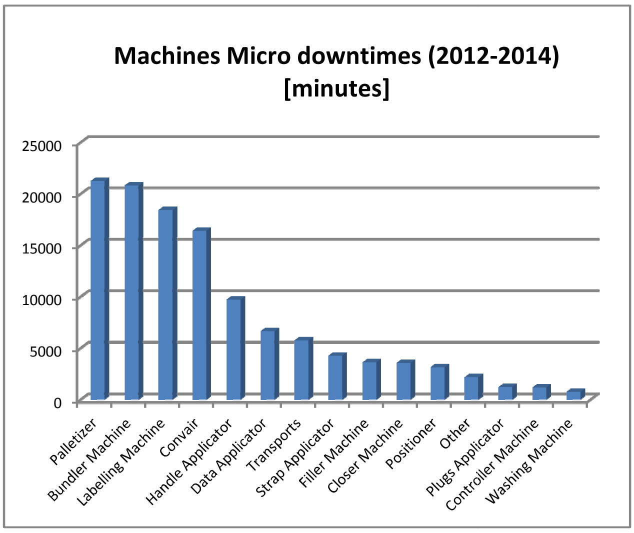


Figure 6: Micro Downtime Analysis per Machine - Line D

last years, to individuate most critical machines in the line.

Figure 6 shows the machines that result more affected by micro downtimes: the pallettizer, the shrink-wrap packer and the labeller.

In the second part of the analysis, it has been collected micro downtime data about these three machines.

4.3 Micro Downtimes Analysis

This step includes to study in deep micro downtimes of these three machines. Micro downtimes are considered in the paper as short stops of few minutes, related to "process failures", with high frequency.

For each machine, principal micro downtimes have been identified, speaking with both production and maintenance staff. Data have been collected by production operators and by the supervisor of the project, for a period of two months, in random production turns and days.

Figure 7 presents the micro downtimes pareto analysis of the palletizer (the most critical machine).

It shows the impact of each process failure in terms of frequency (number of stops); Figure 8 presents the same analysis but showing the impact in terms of time (minutes).

Anyway, the main causes are the same both in terms of frequency and time. The first 5 causes cover the 80% of the time loss for micro downtimes of the palletizer (Table 2).

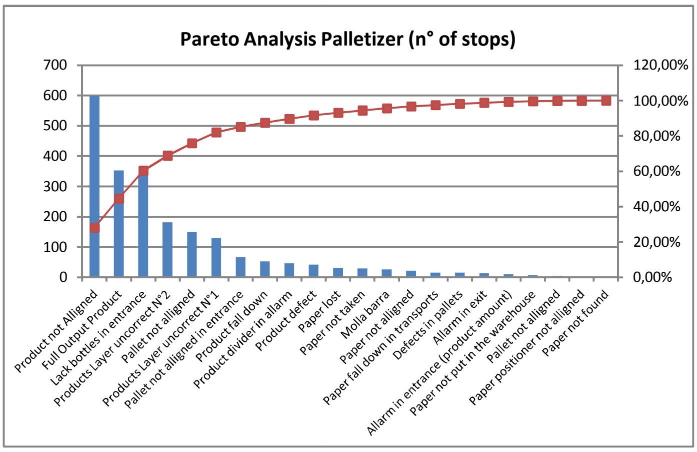


Figure 7: Palletizer - Micro downtime Pareto Analysis [Frequency]

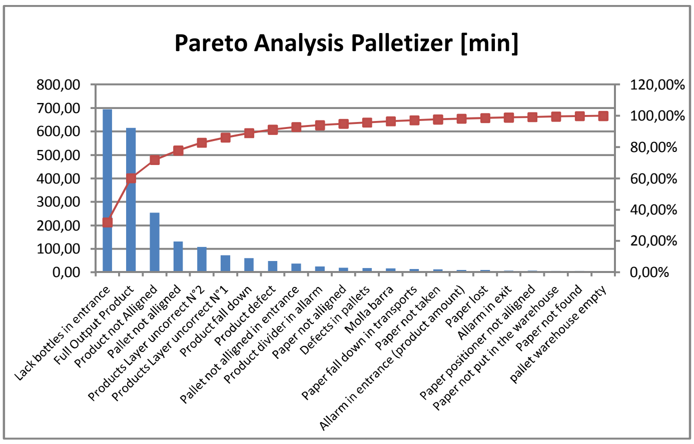


Figure 8: Palletizer - Micro downtime Pareto Analysis [minutes]

Palletizer	Total Time loss [min]	% time loss	% accumulate
Lack bottles in entrance	694,38	32,46%	32,46%
Output Transports full	615,10	28,75%	61,21%
Bottles not aligned in entrance	218,67	10,22%	71,43%
Pallet not alligned	130,58	6,10%	77,53%
Products layer uncorrect	108,00	5,05%	82,58%

Table 2: Palletizer - Principal Micro Downtimes

The same analysis has been done also for the shrink-wrap packer and the labeller .
Main micro "process failures" have been individuated and studied in deep for the three critical machines.

Once principal micro downtimes have been identified and studied, it has been calculated the possible recovered OEE for each one per month (Figure 9). Palletizer micro downtimes, as the most critical machine, covered the three first positions. This graphic points out the principal criticalities of the line, based on OEE index. It is an important tool for management to measure possible saving from further investments.
On the other hand, it is necessary to measure incisiveness in terms of OEE of all micro downtimes, to highlight the improvement margin, and to support a cost-benefit analysis.
Figure 10 and Figure 11 show the OEE areas during the data collection per day: blue area represents the real OEE, while the red one represents the possible OEE without micro downtimes of the three critical machines. It is evident that OEE improvement margin is considerable, both in March and in April.

Table 3 represents OEE improvement margin per month, summarizing data from the spider graphics.
As the data have been collected for 8 hours per day and the line produces for 16 hours per day, it has been

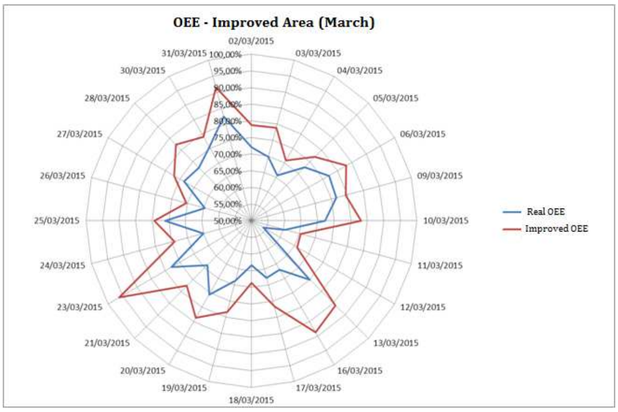


Figure 10: OEE Improvement Area - March [Line D]

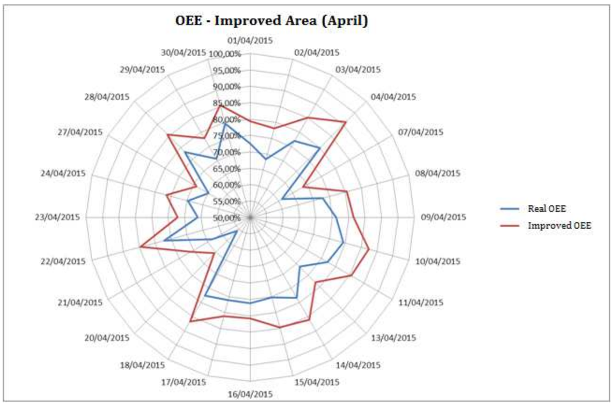


Figure 11: OEE Improvement Area - March [Line D]

assumed that micro downtimes measured, during the eight hours were approximately half of the entire production time. So the startling hypothesis is that the micro downtimes in the whole production are the double respected the measured ones. In this way it has been calculated the possible OEE without micro downtimes.
The OEE improvement margin is in media 7 point (%) per month.

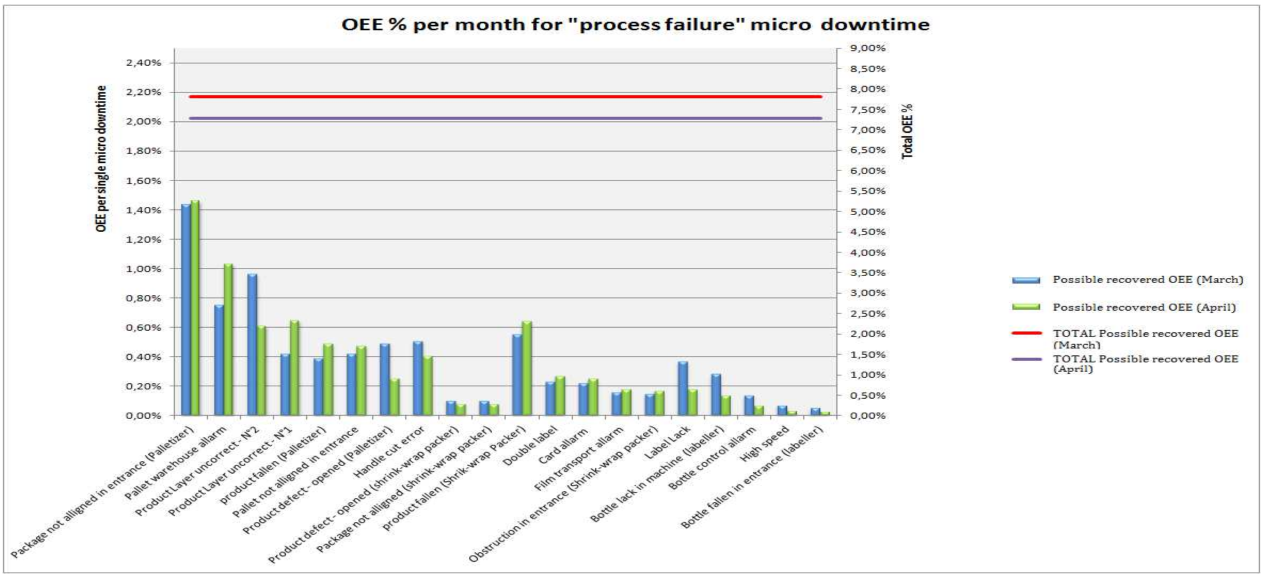


Figure 9: Line-D: OEE improvement per Micro Downtimes per Month

	March	April
Original OEE	**70,62%**	**72,68%**
New OEE	**78,42%**	**79,95%**
Δ OEE	**7,80%**	**7,28%**
Productin loss [bottles]	**1 016 509**	**921 264**
Production time loss (Hours)	**33,88**	**30,71**

Table 3: OEE Improvement Margin per Month

5. Conclusion and further research

The analysis shows as little production problems could have a great impact in terms of production efficiency. Often big failures are overestimated, hiding big losses as micro downtimes.
The case study presented in the paper is just the first part of the research project.
Table 4 summarizes steps done till today, as the data collection and the Downtime Analysis.
Next step will provide to study each critical micro downtime cause in deep. It will be necessary to understand if it is chronic or casual. Then it will be necessary to evaluate a solution (lay-out improvements, changing machine, etc.) with a cost-benefit analysis. To better understand the line criticalities and dynamics, and to validate the problems emerged a line model could be constructed with a simulator program. After that, through the calculation of the CPI, the analysis will be support a decision making step.

Step	Objective	Result
1. OEE plant analysis	Individuation of the pilot line	Line D
2. Pilot Line Analysis (OEE)	Individuation of the most critical parameter	Micro Downtimes
3.Micro downtime Analysis	Individuation of critical machines	• Palletizer, • Shrink-wrap packer • labeller
4.Machine Analysis	Individuation of critical microdowntimes	Principal process failure for each machine
5. Analysis of principal Process Failure	Calculation of OEE improvement	+7% per month

Table 4: Case Study Steps, Objectives and Results

In conclusion, to improve OEE is the core objective of most companies nowadays, through maximizing machinery utilization and minimizing costs. The paper presents the OEE analysis of an automated production plant, aiming to show the possible implications and benefits of it. It reveal importance and incisively of short process downtimes in automated production systems. It proposes how to identify the most critical aspects and how they could impact OEE. Finally it is presented a framework to reach a cost-benefit analysis based on downtime and OEE analysis.

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Buffer Allocation Problem (BAP) related to Micro Downtime in Automatic Production Lines A bottling plant case study

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Abstract: Buffer Allocation Problem (BAP) aims to find optimal buffer sizes to allocate in production systems to achieve an objective; the goal could be to maximize the production rate, to minimize the buffer size or to minimize the work in process inventory. The BAP is an important research topic and many authors discussed about that, finding various methods and solution approaches, focusing on different objectives.
The paper is collocated in automated flow production lines that are deeply influenced by micro downtime (little stops of few minutes); buffers between working stations could provide to reduce micro downtime inefficiency and so to increase production line performance. In fact this short downtime is often related to the physiological working operations of machines and could not be eliminated. machines have different speeds and working states and buffers in this typology of lines are considers as a "lung" for the production.
The paper presents some of most common methods use for BAP (graphic, simulation, empirical data approaches), and focused in particular on Buffer Design for Availability (BDFA) approach; it presents a case study in a bottling production plant, where a buffer size of a critical machine is discussed in order to reduce micro downtime (downtime of low duration). What is new is that micro downtime are studied in deep and data about those one are collected in an ad hoc datasheet; each micro downtime has been analyzed and a proper statistical distribution has been assigned through a statistical analysis (MINITAB®). Finally the buffer size is studied through simulation approach and a comparison with the company solution is proposed.

Keywords: Buffer Allocation Problem; Micro downtime, Simulation; Automatic Production Lines.

1.Introduction

Automatic flow line manufacturing systems consist in a set of machines working in sequence, related to transport systems. Material handling not only has the primary function of carrying products from a machine to another one, but also has a buffer function as it stores materials and let a work station keep running while the upstream or downstream one is down. In fact if machines were totally reliable, transports should not work as buffer, and the line will produce at the core work station rate; since automatic systems have an intrinsic reliability, buffers are important critical factors on line performance. Industrial experience demonstrates that this kind of automatic production is not only affected by relevant breakdown, that could be controlled by good preventive and predictive maintenance plans, but their performance is also affected by physiological process speed losses caused by blocked and starved states, jammed materials and so on. In particular these systems are used to be influenced by two phenomena:

- *Blocked Machine*: a machine that could not work because the downstream one is off (no more space for materials in exit);
- *Starved Machine*: a machine that could not work because the upstream one in off (no materials in ingress)

Buffers are strategic products accumulation that decrease this inefficiency; by the way buffers have a cost, as they require floor space and capital investment. Their size optimization is critical to achieve business goals, balancing production performance and costs.

BAP focused primary on three different aspects: production line maximization, total buffer size minimization and average work-in-process minimization. In literature generative and evaluative methods are used to reach buffers optimization goals; usually these methods are based on production ratios of machines, without considering machines availability. For this reasons the paper aims to investigate the relationship between machines availability and buffer size; Battini et al. (2009) proposed a Buffer Design For Availability Approach (BDFA), considering for micro downtime of machine a normal distribution. The paper, in addiction, aims to associate to each micro downtime a specific cause and an ad hoc statistical distribution, through on field data collection and statistical analysis. Then data are analyzed through a simulation approach and results are discussed.

The paper is divided in three sections: section 2 presents a comparison of three different approach for buffer size optimization (the empiric one, the software simulation and the one used from the company); section 3 presents the case study and simulation results. Finally Section 4 discusses and further researches.

2.Literature review

Buffer design is one of the most important theme in production line sizing and literature discussed and proposed solution approaches since years. Buffers are strategically located and sized to allow sequential workstations to produce more independently as possible.

In this section three methods to allocate buffers are presented:

1. Method 1 - Graphical Approach, based on machines production performance;
2. Method 2 – Simulation Approach, based on field data about machines performance
3. Method 3 – Company Approach, based on experience and historical data.

2.1 Method N°1 - Graphical Approach

This method aims to define the optimal buffer size between two machines through production performance analysis. It is a very easy and direct method, that requires only production machines rate data; the biggest lack of this method is that it does not consider inventory costs, but just machine availability and production maximization.
Two machines working in sequence are considered; the production rate of these ones are registered during an adequate interval of time.
Figure 1 shows the graphic that is registered from the machines of the case study: blue line is the production speed of machine N°1 and red line is the production speed of the second one. This graphic can also been constructed knowing data if an *ad hoc* software is not available.. The maximum distance between the two lines represents the buffer size.

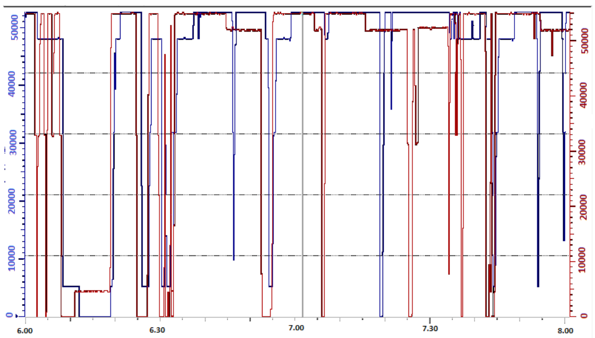

Figure 1 Comparison of Production speed of Machine 1 vs Machine 2

2.2 Method N°2 - Simulation Approach

This method is focused on simulation approach to optimize buffer size; it needs *ad hoc* data and a software for simulation to better fit production reality.
Battini at al. (2009) proposed a BDFA approach based on simulation, focused on machines availability and inventory costs. Each machine is supposed to be a reparable system, with a deterministic and constant production rate; time to failure and time to repair (TTF and TTR) are normally distributed. This method is focused on micro downtime inefficiency; it is based on G index, that is the maximum MTTR between two machines in sequence.

G = MTTRmax = max (MTTR (M1); (MTTR (M2))

Where M1 and M2 are two machines working in series in an automatic line.
The approach reveals a strong correlation between the maximum capacity buffer level and this new index.

Since micro downtime and MTTR were normally distributed, the paper proposed the application of this method with different micro downtime statistical distributions deducted from on field data; in particular Weibull parameters are deducted from data with the utilization of MINITAB® software. Finally solutions (TO-BE) are compared to the method used by the company (AS-IS state).

2.3 Method N°3 - Company Approach

Finally it is presented the method used by the company to define the optimal buffer size. As first it is considered the nominal production speed two machines, to evaluate the minimum transport system size needed. Then, from an empirical table, based on historic data and experience, it is know the recommended time that should be provided as "accumulation time" between two machines. Knowing the product size (depending on the format) and machines speeds, transport system size is evaluated. The company uses this method as they are pioneer in its market and were the first that construct machines by themselves. Figure 2 shows how is divided the transports between two machines in a production line:

- The blue and the yellow area are respectively the minimum exit and minimum ingress area of the two machines;
- The grey area is the normally transport system between the machines as they were completely reliable.
- Finally red area represents the buffer accumulation area.

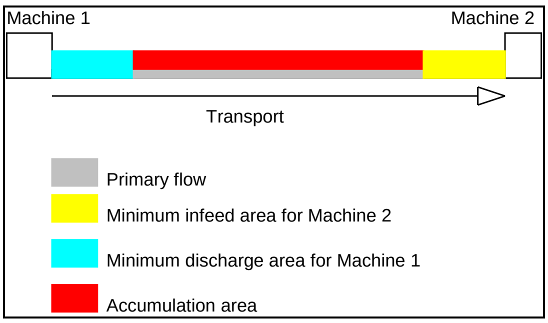

Figure 2 Transport subdivision in production lines

Table 1 summarize advantages and disadvantages of the three approaches presented.

Method	Advantages	Disadvantages
N°1	- Direct - Easy to apply	- No costs consideration - Consider just a defined period of work
N°2	- Optimal estimation -Consider a long period of work	- Need of ad hoc data - Need of a simulator
N°3	- Easy and direct to apply	- Need of experience - Not always correct

Table 1 Advantages and Disadvantages of the presented approaches

3.Case Study

The company operates in beverage world market and has one of the biggest plant in Europe. Its core business is own brand and third party mineral water and beverages. It has 1800 employees and 6 plants in Italy with others around the world and an annual turnover of €720 million (2013).
The project was situated at the lead factory in Italy. This one has 23 bottling lines: glass, PET and aseptic lines with numerous formats including 0.25L, 0.5L, 1L and 1,5L. The company not only bottles the products but also manufactures the bottles, tops and labels.
The case study data are from Line D. Line D produces mineral water in 1.5L format. It produces on average 15 million bottles per month, with at an average rate of 26.000 bottles per hour. It is composed of 8 main machines: the positioner, which takes the bottles in a correct order; the rinser, which washes them; the filler, which fills the bottles; the bottle sealer, to close them; the labelling machine, the apply the shrink-wrap inner layer of packaging; the palletizer; and the wrapper machine, to pack the final product.

The case study aims to evaluate the buffer size between two machines with the simulation approach, through the collection of ad hoc data of micro downtime and the analysis of their specific statistical distribution. In particular, micro downtime data collected about TTF and TTR (Time to Failure and Time to Repair) are approximate to Weibull Statistical Distribution, and each micro downtime type has a different scale and shape parameters.
For each machine principal causes of micro downtime have been identified through interviews of both production and maintenance staff. Working with them, a data collection form was produced and data collected with their support.
The paper presents the buffer size evaluation between the shrink wrap packer and the palletizer (the most critical machine). Table 2 summarized the causes of micro downtime for Machine N° 1 (the palletizer). For each cause the frequency and the duration were recorded. Data was collected by production operators and by the supervisor of the project for a period of two months (March and April) for 8 hours per day with random production turns.

Micro downtime of Machine N° 1	
MD A	Bundle not Alligned
MD B	Uncorrect Stratum (N°2)
MD C	Pallets Warehouse Allarm
MD D	Uncorrect Stratum (N°1)
MD E	Pallet not Alligned

Table 2 Micro downtime of the Palletizer

TTR	Count	Mean	SD	CV	Min	Max
A	598	25.79	27.35	1.0604	5	300
B	182	36.99	44.95	1.2153	10	480
C	150	52.85	34.51	0.653	10	184
D	130	34.35	28.75	0.8371	10	180
E	66	33.71	21.71	0.6439	10	120

Table 3 TTR Statistical Analysis of collected data

TTF	Count	Mean	SD	CV	Min	Max
A	168	566.8	761.2	1.343	0	6240
B	7	2931	2925	0.9978	180	8160
C	4	780	467	0.5991	240	1200
D	8	2070	1546	0.7471	540	4680
E	16	3799	3082	0.8114	360	9420

Table 4 TTF Statistical Analysis of collected data

Tables 3 and 4 summarize statistical parameters of collected data (TTR and TTF) about palletizer micro downtime (A, B, C, D, E).
It is supposed that micro downtime TTF distribution is well approximate by Weibull Distribution, while TTR data are considered normally distributed with an average time corresponding to MTTR. What is important is to define reliability of machines to better define the needed buffer area.
Reliability R(t) is the probability that a production system (machine or component) will perform a required function for a given period of time T. As data is hypnotized to follow Weibull distribution, Reliability function (1) is define as:

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \quad (1)$$

Where β is the shape parameter, θ the scale parameter

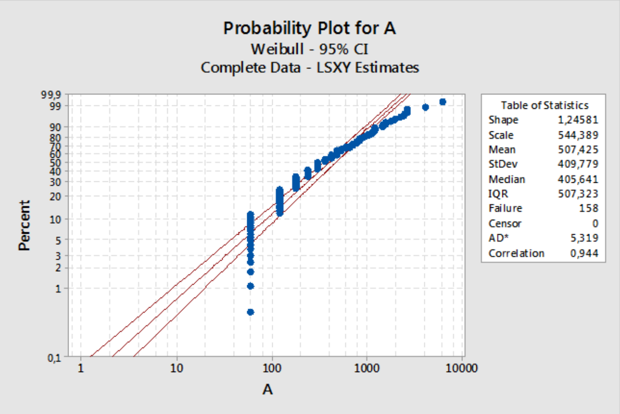

Figure 3 Micro downtime A Probability Plot for Weibull parameters definition

and t is the considered time. The shape parameter β defines component life position (setting period, normal life and degradation period); when $\beta < 1$, the component is in the setting stage as the TTF are decreasing. When β is equal to 1 the component has a random failure rate, and so it is in its "normal life"; finally, when $\beta > 1$ the component is in a degradation part as the failure
rate is increasing.
In the same way could be define the Probability Density function of the failure distribution (2) and the hazard failure rate (3) as:

$$f(t) = \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} x\ e^{-(\frac{t}{\theta})^{\beta}} \quad (2)$$

$$\lambda = \frac{\beta}{\theta} x (\frac{t}{\theta})^{\beta-1} \quad (3)$$

Data has been analyzed with MINITAB® software to estimate Weibull parameters of each micro downtime. Figure 3 presents the parameters estimation of micro downtime A.
Table 5 summarizes statistical parameters recovered from Minitab Analysis of Machine 1 Micro Downtimes.
For each Micro Downtime is estimated the scale and the shape parameter, the Anderson-Darling (AD) index and the correlation index (r). Then it has been calculated the MTTR and the MTTF parameters.
With this analysis is possible to construct the simulation of the functioning of the two machines considered. It is known the average speed (bottles per hour) of the two machines and micro downtime distribution and incisiveness. Big breakdown are not considered for buffer design; in fact buffer can be helpful to solve speed reduction inefficiency, but not breakdown one. Inefficiency caused by big failures could be reduced through preventive and predictive maintenance actions.

	A	B	C	D	E
β	1,24581	0,749956	1,3716	1,43312	1,06945
θ	544,389	2923,11	919,281	2250,68	3998,61
AD	5,319	1,802	2,859	1,955	1,079
r	0,944	0,972	0,971	0,936	0,972
MTTF	602,658	293143,4	780	2070	3798,75
MTTR	17,8571	34,2857	57,5	48,75	67,5

Table 2 Weibull parameters for each micro downtime

With the simulation approach, the aim is to define the optimal buffer area between the palletizer and the shrink wrap packer based on the availability of these work stations.
Figure 4 shows the simulation of the project; it is used FLEXIM® software. Simulation runs for one working week, 8 hours per turn, two turns per day: Table 6 summarizes Production parameters used in the simulation, in addiction to micro downtime Weibull Distributions. Buffer capacity is supposed to be infinite to measure the maximum size needed to satisfied the production request.

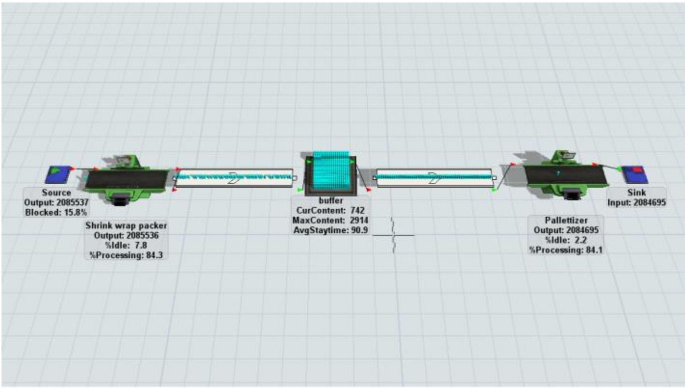

Figure 4 Work Station Simulation

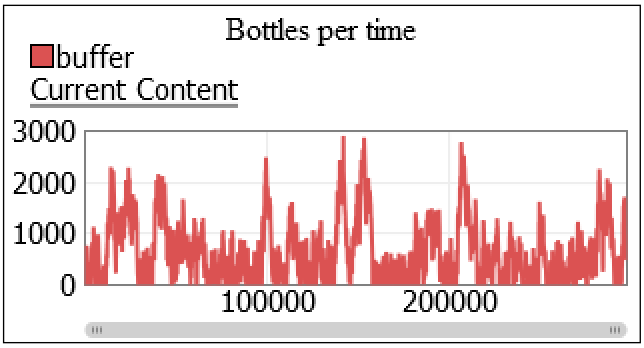

Figure 5 Buffer Capacity per Time

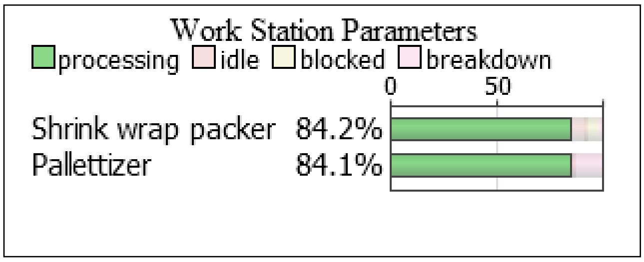

Figure 6 Work Station production parameters

Graphics, instead, are about:

- <u>Buffer Capacity Variation</u> during the considered time; it is well shown the variation of bottles presence in transports systems during production (Figure 5). The higher buffer capacity registered indicates the suitable buffer size (2914 bottles).
- <u>Workstations Production Parameters</u>, as working time, micro downtime stops (starving and blocked states) and idle time (Figure 6). It indicates the % of usage of machines.

Palletizer Speed	27.000 bottles/h
Shrink wrap packer Speed	27.500 bottles/h
Buffer capacity	Infinite Capacity

Table 3 Simulation Parameters

Leaving simulator runs, it is possible to determinate the buffer capacity size, as the maximum bottles content in the buffer. Results shows that buffer capacity needed between the two machines is about of 2.900 bottles, to guarantee an availability performance higher than 85%. The actual buffer is about of 1.500 bottles, and this explains why line performances are deeply influenced by micro downtime.

Now engineer and management staff are evaluating transport modifications to implement buffer capacity.

To justify the investment it was also calculate the OEE recoverable from the reduction of micro downtime of these two machines; the OEE (Overall Equipment Effectiveness) is the efficiency index used to measure production performance in the company. It is the combination of three parameters : Availability, Performance and Quality. Micro downtime deeply influences Performance parameter. From data collected, it is calculated the new OEE without micro downtime; the increment could be of about 5%.

4.Conclusions

This study carried out advantages of simulation approach in buffer design in the specific case of automatic production flow lines. It highlights the relevance of speed reduction, related to physiological processing functioning of machines on production efficiency (starving and blocking phenomena). Buffer capacity not only permit the normal and independent functioning of workstations, but, if adequately placed, it is also represents a solution for micro downtime inefficiency.

Moreover the study shows how it is possible to apply simulation to reality with a focused data collection; they are used ad hoc Weibull distribution for each micro downtime to better fit the reality.

Results will be used to support management decision making analysis. Then, with buffer modifications. it will be possible to measure the effectiveness of the simulation approach. The project is applied between two working stations, but it could be extend to all the line and used for more further researches.

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