Master thesis

Measurement and evaluation of the contribution of technical services within organizations.

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Thessaloniki

January 2015

ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ

ΠΑΝΕΠΙΣΤΗΜΙΟ ΜΑΚΕΔΟΝΙΑΣ

ΟΙΚΟΝΟΜΙΚΩΝ ΚΑΙ ΚΟΙΝΩΝΙΚΩΝ ΕΠΙΣΤΗΜΩΝ

Acknowledgements

This master thesis constitutes the final task of my master's education in management business administration at the University of Macedonia. The study was conducted at Greenfood S.A production plant in Sindos Thessaloniki, Greece.

First of all I would like to thank my supervisor at the University, Kotzamani Katerina, for being supportive and for the contribution of insights and ideas to the study. Additionally, I would like to express my appreciation for the plant manager, A D, who made this study possible and was a great source of inspiration. Furthermore, I would like to thank the staff of my department for the helpfulness and openness and in particular L.S for the engagement and interest in the study. Also many thanks are owed to N.M production manager of Greenfood s.a who helped me to collect some data from both processed and good products.

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Thessaloniki 2014

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Abstract

Purpose: The aim of this master thesis is to provide an analysis and assessment of the current methods, as these are presented and proposed in literature, to measure maintenance performance effectiveness of technical departments. Two additional objectives of the study include: a) the identification of major causes of production inefficiencies which are born from malfunctions, breakdowns and bad operation programming And b) the design and implementation of a suitable and appropriate data collection system for feedback on maintenance work (planned/unplanned), which will enhance current philosophy and operation of organizations' maintenance departments. Their potential and contribution towards operations and performance improvement will be tested based on a case study at a fresh cut produce company, namely Greenfood S.A, in Sindos Thessaloniki, Greece. The performance maintenance measurement (MPM) was estimated via (Overall Equipment Effectiveness (OEE), mean time to repair (MTTR), mean time between failure (MTBF) etc.) metrics, which are some of the many key performance indicators (KPIs') offered in literature. Furthermore, the study aims to identify causes for production inefficiencies and offers recommendations to minimize losses in operations and/or technical malfunctions.

Methodology: For the purpose of this study, the case study methodology was applied in order to analyze in depth the maintenance processes in a real context. More specifically, this research focuses on the monitoring of maintenance performance in food industries and its contribution to the overall operation of the company. Empirical research is founded on a thorough conceptual literature review to select and use suitable key performance indicators. Information acquired from interviews, records and observations is examined in relation to literature findings aiming to investigate any potential areas of improvement. Production data has been recorded and analyzed using appropriate software tools in order to identify core problems, strengths and weaknesses that are met in practice.

Findings: In the present study quantitative measurements are applied in order to detect effectiveness rates, causes for production losses, breakdowns, setup times etc. As a result, valuable information is provided concerning performance monitoring of production equipment, as well as performance measurement and evaluation of the technical department. Individual performance indicators were analyzed along with their impact on the production process, while the data collected

was used to interpret how the specific performance indicators may be used to support the evaluation of any technical department as well the operation of organizations.

Keywords: Total Productive Maintenance (TPM); Overall Equipment Effectiveness (OEE); Maintenance Performance Measurement (MPM); Key Performance Indicators (KPIs).

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Chapter 1 – Introduction

In the last few decades industries were forced to shift their business models from closed system-orientations, to more open system-orientations. This shift was brought about by drastic competitive forces, which made the customer the focus of organizational, operational and strategic practices (Simões, Gomes and Yasin, 2011). Today's industries are required to operate as open operational systems. In such systems advanced operational manufacturing and process technologies are blended with modern information and communication technologies to integrate and coordinate operational resources, processes, and activities in order to generate a stream of value-added operations aimed at capturing and sustaining a competitive advantage (Stratman, 2007). With the increasing complexity, scope, and organisational role of operational advanced industry technologies the maintenance of these technologies is becoming very critical to the ability of the organization to compete. In this context, maintenance management is taking on a broader organizational strategic role.

On the other hand, quality is a critical factor to achieve high targets and long-term profits. Organizations with successful quality improvement programmes can enjoy significant competitive advantages. In food industries quality and safety are critical. Quality has a dominant position to ensure safe and hygiene products. More and more the standards of quality assurance are stringent based on directions of international organizations. Increasing automation and mechanization production processes are shifting from workers- to machines dependent (Ben-Daya and Duffuaa, 1995). Consequently, the role of equipment maintenance in controlling quantity, quality and costs is more evident and important than ever. To succeed in this new environment, equipment must be maintained in ideal operating conditions and must run effectively. The link between quality improvement and productivity is well established (Montgomery, 1985). Quality improvement results in elimination of waste, such as scrap and rework, which increases productivity and often leads to cost reductions. Likewise quality of products affects the life of equipment and therefore the smooth operation of machines. Many times bad products create breakdowns. Under the total quality management philosophy quality can no longer be inspected into the product (Maloney, 1992). Final control inspection is being moved to the process level through adequate process control techniques. Consequently defects and variations are eliminated at their source. In particular machine performance problems are identified early on. Equipment effectiveness is no longer restricted to availability, but involves other factors, such as quality and efficiency, as well.

At this point, it is important to note that the link between maintenance and quality, although not completely missing, is not adequately addressed in the literature and therefore by the practitioners. The focus on total productive maintenance (TPM) (Nakajima,1988) is equipment management. As pointed out later, quality is a key factor in measuring equipment effectiveness. One out of six big losses of any equipment, as identified by Nakajima (1988), is directly related to quality.

Quality and performance of maintenance activities themselves are an important issue, since they affect equipment performance and consequently the quality of the final product Jacques (Trienekens, Peter Zuurbier, 2008). However, the modelling of the explicit relationship between maintenance activities and the quality of the final product has not been adequately addressed. There is a definite need for developing models which integrate maintenance, production and quality with high performance. The purpose of this master thesis is to two fold:

First of all we will provide a literature review on Maintenance Performance Measurement (MPM) system and indentify the key performance indicators (KPIs). Our discussion here aims towards the identification of major causes of production inefficiencies which are born from malfunctions, breakdowns and bad operation programming. Furthermore, our discussion will include the design and implementation of suitable and appropriate data collection systems for feedback on maintenance work (planned/unplanned),

Next the aforementioned performance indicators discussed in the first objective will be tested at a part of process equipment in Greenfood company as a case study. According to the results our objective is to draw conclusions regarding the correlation between quality, production speed and proper functioning of the equipment and how it affects the entire operation of the company. Maybe in the future there is a possibility to use this system as a tool for monitoring, control and continuous improvement of operation, maintenance and quality in this company.

Chapter 2 - Literature review

2.1. Maintenance

2.1.1 Maintenance chronology

According to Parida and Cumar (2006) « prior to the early 1900s maintenance was considered as a necessary evil. Technology was not in a state of advanced development, there was no alternative for avoiding failure, and the general attitude to maintenance was: “it costs what it costs”. With the advent of technological changes and after the Second World War maintenance came to be considered as an important support function for production and manufacturing (Baluch et al., 2012). During 1950-1980, with the advent of techniques like preventive maintenance and condition monitoring, the maintenance cost perception changed to: “it can be planned and controlled” ».

2.1.2 Maintenance in organizations

According to Parida and Kumar (2006) «Maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item or restore it to a state in which it can perform a required function (International Electrotechnical Commission, 2006) ». Maintenance provides critical support for heavy and capital-intensive industry by keeping machinery and equipment in a safe operating condition. Today it is accepted that maintenance is a key function in sustaining long-term profitability for an organization (Al Sultan and Duffuaa, 1995). Maintenance works as an important support function in business with significant investment in physical assets and plays an important role in achieving organizational goals (Tsang, 2002). Cross (1988) reported that in the UK manufacturing industry maintenance spending ranges from 12-23 percent of the total factory operating costs. In refineries, the maintenance and operations departments are very large and each department often consists of up to 30 percent of the total staffing (Dekker, 1996).

Also, continuous improvement is achieve by evaluating performance, taking corrective actions and measuring progress. For many asset-intensive industries, the maintenance costs are a significant portion of the operational cost. For example, the amount spent on maintenance budget for Europe is around 1500 billion Euros per year (Altmannshopfer, 2006) and for Sweden 20 billion Euros per year (Ahlmann, 2002). In addition, breakdowns and downtime have an impact on the plant capacity, product quality, and cost of production, as well as on health, safety and the environment. Finally, maintenance should prepare for future changes by anticipating needs and organizing flexibility.

2.1.3 Maintenance and quality in the food industry

According to Ben-D et all (1995). « The role of maintenance in the long-term profitability of an organization has long been recognized and this has led researchers and practitioners alike to develop maintenance strategies that contribute to long-term profitability. However, profitability and survival cannot be achieved without sustained product quality. For this quality is becoming a business strategy leading to success, growth, and enhanced competitive position. Organizations with successful quality improvement programs can enjoy significant competitive advantages (Ben-Daya and Duffuaa, 1995). Ollila and Malmipuro (1999) have researched and shown at 40 industries in Finland that maintenance has a great impact in quality of products. The results are not necessarily relevant regarding each industrial branch, but they give the first idea about what kind of quantitative impacts maintenance can have in different industries. The results are presented in Fig. 2.1.

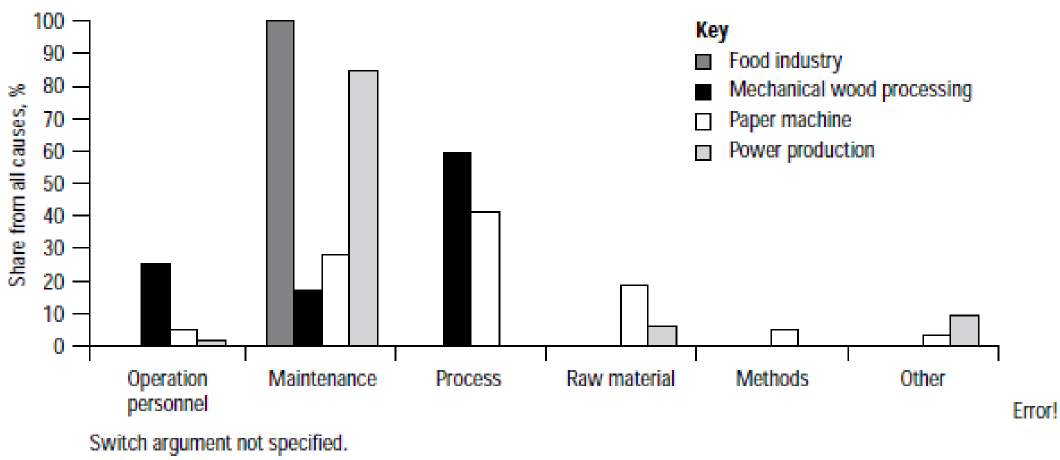

Figure 2.1. Maintenance impact in various industry sectors

Especially in the food industry there is only one quality deficiency and it is caused by maintenance. Since food processing is highly automated, lack of maintenance has a direct impact on quality. From the above it can be concluded that maintenance (specifically in the food industry) has a much bigger role with regard to quality than production and quality managers may expect ».

2.1.4 Maintenance objectives

Maintenance objectives are clustered into the following categories based on (Kelly 1998) and (Visser and Pretorius, 2003):

- Ensuring the plant functions (availability, reliability, product quality, etc.).
- Ensuring the achievement of the plant's design life.
- Ensuring plant and environmental safety.
- Ensuring cost effectiveness in maintenance and effective use of resources (energy and raw materials).

For production equipment, ensuring the system function is the prime maintenance objective. Maintenance has to provide the required reliability, availability, efficiency and capability of production system in accordance to the need of these characteristics. Ensuring system life refers to keeping the equipment in good condition to achieve or prolong their design life. Cost has to be optimized to meet the desired plant condition (Dekker 1996). Plant safety is very important in case failures have catastrophic consequences. The cost of maintenance has to be minimized while keeping the risks within strict limits and by meeting the statutory requirements. Finally, maintenance has a role of ensuring that the other plant factors, such as the effective utilization of energy, materials and maintenance resources, are met.

The maintenance performance measures/indicators (Muchiri et al., 2010) used at a given plant are directly influenced by the maintenance objectives pursued in accordance with the needs of its manufacturing environment. It is the interest of this research to investigate the influence of operating environment on the choice of maintenance performance indicators. The measurement of maintenance performance has also become an essential requirement for the industry of today. The efficiency and effectiveness of the maintenance system play a pivotal role in the organization's success and survivability. Therefore, the system's performance needs to be measured using a performance measurement technique (MPM).

2.1.5 Maintenance performance

According to Parida, A. Kumar,U (2009) « Maintenance performance aims at minimizing the maintenance cost dealing with the measurement of overall maintenance results/performance and maximizing the overall maintenance performance. Some of the measures of maintenance performances are availability, mean time between failures (MTTF), failure/breakdown frequency, mean time to repair (MTTR) and production rate index. Maintenance performance indicators measure the usage of resources, like labor, materials, contractors, tools and equipment. These components also form various cost indicators, such as manpower utilization and efficiency, material usage and work order. Control of maintenance productivity (MP) ensures that the budgeted levels of maintenance efforts are being sustained and that required plant output is achieved (Kelly, 1997). Maintenance performance deals with both maintenance effectiveness and efficiency.

For the process industry, machine downtime at the shop floor is one of the main issues for maintenance performance. Unlike operational activities, maintenance activities are mostly non-repetitive in nature. Therefore, all maintenance personnel and managers face new problems with each breakdown or downtime of the plant or system, which needs multi-skill levels to solve the conflicting multi-objectives issues. For process or manufacturing industry, the input raw material issues are important as variation in quality of the raw material prevents the information of the quantity and quality of the products. This leads to reorder or recycle of the process to overcome the shortage of the required products, which also necessitates a safety stock level (Parida, 2007).

The product availability is dependent on the production rate, available time for production and quality rate. The production rate is related to the plant or production capacity. If the maintenance effectiveness and efficiency is good, then the production rate will invariably be good. The availability time for production is also dependent on the repair or waiting time, i.e., on the maintenance effectiveness. Quality of the product is also related to the number of stops, where quality loss is there during stop and start of the plant/system, besides the skill level of operators and the quality of the raw material etc. Quality improvement programs, modern information systems, continuous improvement programs, and the evolution of performance measurement systems, tended to promote the proliferation of maintenance performance measures and measurement (Cua et al., 2001; Bamber et al., 2004; Seth and Tripathi, 2006). Due to the increase in the number and type of measures, new approaches for maintenance performance measures and measurement are needed (Kumar, 2006).

Thus, it can be seen that all the four parameters in product availability are dependent on maintenance directly or indirectly. The objective of the management of any process industry is to minimize the stock level, and increase the availability time, production and quality rate. The multiplication of the last three terms – availability, production and quality rate – provides the overall equipment effectiveness (OEE) which is one of the most important and effective key performance indicators (KPIs) in the performance measurement.

The machine breakdown or degradation of performance over time and accidents are some of the reason for the plant production interruption affecting the effectiveness of the plant. Normally, the production quantity is worked out by the management as per the market demand and situation. For achieving a greater market share, the management must be in a position to predict its plant capacity as well as improve it in a specified time. The maintenance policy and safety performance of the plant plays a significant role in achieving the operational effectiveness of the plant. The management has to depend on the predicted plant capacity in order to meet the delivery schedules, cost, quality and quantity. An appropriate maintenance and safety strategy are required to be adapted for achieving the optimal production quantities.

Some of the important measures of maintenance performance are:

- Total cost of maintenance/total production cost
- A (availability) = (planned time - downtime)/planned time
- P (production rate) = (standard time/unit)x(unit produced)/operating time. Where operating time = planned time – downtime
- Q (quality rate) = (total production – defective quantity or number)/total production
- Mean time to repair (MTTR) = sum of total repair time/number of breakdowns
- Mean time between failure (MTBF) = number of operating hour/number of breakdowns
- Maintenance breakdown severity = cost of breakdown repair/number of breakdown;

- Maintenance improvement = total maintenance man hours on preventive maintenance jobs ÷ total man hours available
- Maintenance cost per hour = total maintenance cost/total maintenance man hours
- Man power utilization = wrench time/total time;
- Manpower efficiency = time taken/planned time ».

2.2 Measuring the maintenance & KPIs

2.2.1 Measuring the performance maintenance

Today maintenance is considered as an integral part of the business process and it is perceived as: "It creates additional value" (Liyanage and Kumar, 2003). Has also become an essential requirement for the industry of today The importance of maintenance performance measurements have been discussed extensively by many authors (Arts et al. 1998, Tsang 1999; Visser and Pretorious 2003; Weber and Thomas 2006; Parida and Chattopadhyay, 2007). The efficiency and effectiveness of the maintenance system play a pivotal role in the organization's success and survivability. Therefore, the system's performance needs to be measured using a performance measurement technique (MPM) which is a powerful tool for aligning the strategic intent within the hierarchical levels of the entire organization. To measure performance certain key performance indicators (KPIs) are used as shown in Fig. 3. Each KPI compares actual conditions with a specific set of reference conditions (requirements) by measuring the distances between the current environmental situation and the desired situation (target), so-called 'distance to target' assessment (EEA, 1999).

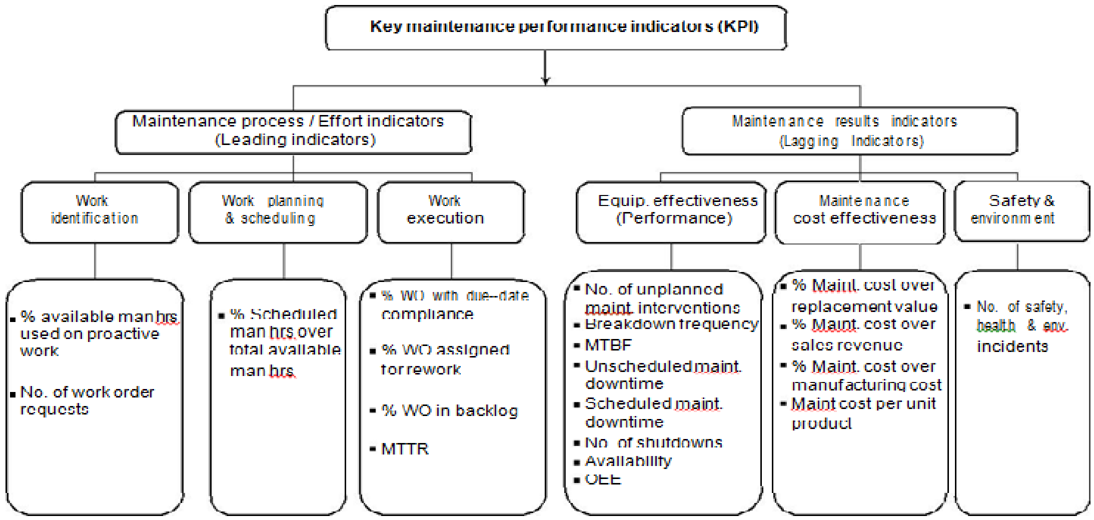

Figure 2.2. Key performance indicators

Maintenance and plant managers need performance information to monitor and control maintenance processes and results and provide indication towards improvement. Performance measures support the building of actions necessary to attain equipments performance as required by the strategic goals. It is in the interest of managers to measure the efficiency and effectiveness of maintenance process, establish the relationship between maintenance inputs and outputs, and therefore justify investments in maintenance (Parida and Chattopadhyay 2007). The maintenance performance literature shows that different authors have different ways of classifying maintenance indicators. Furthermore, measurement differences can be attributed to the choice of indicators. However, some indicators, such as OEE, MTBF, MTTR, MTBM, have been widely recognised as vital for the management of maintenance operations,.

2.2.2 Total productive maintenance (TPM)

Different categories of maintenance performance measures/indicators can be identified in literature. The total productive maintenance (TPM) concept (Nakajima 1988), launched in the 1980s, provided a quantitative metric called overall equipment effectiveness (OEE) for measuring productivity of manufacturing equipments and available resources (Chan et al., 2005). In 1971 the Japanese introduced and developed the concept of Total Productive Maintenance (TPM), in response to the maintenance and support problems encountered in manufacturing environment. TPM describes a relationship between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity, assurance and safety (Nakaiima, 1988). Another goal of TPM is an aggressive strategy focuses on actually improving the function and design of the production equipment (Swanson, 2001). TPM maximizes equipment effectiveness though two types of activity to insure that the equipment performs to design specifications which is the true focus of TPM (Venkatesh, 2005). According to Nakajima (1989), the Japanese companies, in contrast with the Americans, strived that all employees would be a part of the productive maintenance implementation, avoiding the division of labor to maintenance crews responsible to all factory maintenance, which was typical in the USA. Total Productive Maintenance is implemented by all employees, when the basic maintenance is performed by operators on their own equipment.

2.2.3 Overall equipment effectiveness (OEE)

Overall equipment effectiveness (OEE) is one of the most important and effective key performance indicators (KPIs) for the performance measurement. Moreover, OEE is a tool used in the framework of total productive maintenance (TPM). It identifies and measures losses of important aspects of manufacturing namely availability, performance / speed and quality rate. Thus, the equipment effectiveness and hence its productivity and maintainability are improved. The OEE approach has become increasingly popular and has been widely used as a quantitative tool essential for measurement equipment performance in industries (Huang and Dimukes 2003; Muchiri and Pintelon, 2008).

After all factors are taken into account, the OEE result is converted into a percentage. Therefore, the results (in %) can be regarded as a preview of the existing production efficiency of a particular line, cell or machine. The OEE values of different production lines can be used for comparison and thus highlight poor line performance. OEE values calculated for individual machine processes can identify low performance, and direct management where to focus TPM activities (Bamber et al., 2003). It is already known that manufactured goods are outcomes of a complex production process where lack of the proper measuring tools and formula may lead operations to run blindly even in the light of day.

Having the right metrics OEE provides a window to analyze out of the ordinary issues and provides an established framework for improving the whole manufacturing process. There are dozens of formulas, systems and metrics being used to improve the whole manufacturing process, but only OEE correctly reduces complex production problems into simple, easy to follow steps in handling data and information (Lemma, 2008). The OEE tool improves the process using basic measurements. The good thing about using OEE is that this particular measuring tool cannot be manipulated. OEE is a very simple metric that immediately indicates the current status of a manufacturing process. Somehow it also becomes a multifaceted tool allowing you to understand the effect of the various issues in the food process and how they affect the entire process. The biggest advantage of OEE is that it allows companies to have separate business functions by applying/using a single, easy to understand formula. OEE is by far the most effective benchmarking tool in making sound management and maintenance decisions. The overall equipment effectiveness (OEE) is given as (Vorne Industries, 2012):

$$\boldsymbol{OEE = Availability * Performance\ efficiency * Quality\ rate}$$

Where:

$$Availability = \frac{\text{Operating } time}{\text{Planned production } time}$$

$$Performance\ efficiency = \frac{(\text{Total } pieces/operating\ time)}{\text{Ideal } run\ rate}$$

$$Quality\ rate = \frac{\text{Good } pieces}{\text{Total pieces}}$$

Also:

<u>Operating time</u> = Planned production time – Down time

<u>Planned production time</u> = Number of shift lengths – Breaks

Down time = Malfunctions + Break downs

Breaks = Meal breaks + Short breaks

Good pieces = Total pieces – reject pieces

2.2.4 Mean time between failure (MTBF)

Mean Time Between Failure is a reliability term used loosely throughout many industries and has become widely abused in some (Torell and Avelar, 1998). Over the years the original meaning of this term has been altered which has led to confusion and cynicism. MTBF is largely based on assumptions and definition of failure and attention to these details are paramount to proper interpretation (IEEE,1990). Mean Time Between Failure (MTBF) has been used for over 60 years as a basis for various decisions. Over the years more than 20 methods and procedures for lifecycle predictions have been developed. Thus, "MTBF has been the daunting subject of an endless debate" (Torell and Avelar, 1998). When minutes of downtime can negatively impact the market value of a business, as in the case of IT and telecommunications equipment, it is crucial that the physical infrastructure supporting this networking environment be reliable (Torell and Avelar, 1998). The business reliability target may not be achieved without a solid understanding of MTBF. It is said that engineers are never wrong; they just make bad assumptions. The same principle applies to the MTBF estimation. Assumptions are required to simplify the process of estimating MTBF. It would be nearly impossible to collect the data required to calculate an exact number. However, all assumptions must be realistic. The MTBF is typically part of a model that assumes the failed system is immediately repaired (mean time to repair, or MTTR), as a part of a renewal process (Vicor Reliability Engineering). This is in contrast to the mean time to failure (MTTF), which measures average time to failures with the modeling assumption that the failed system is not repaired (infinite repair time). MTBF is given as (Wikipedia):

$$MTBF = \frac{\sum(start\ of\ downtime\ - start\ of\ uptime)}{\text{Number of failures}}$$

Where:

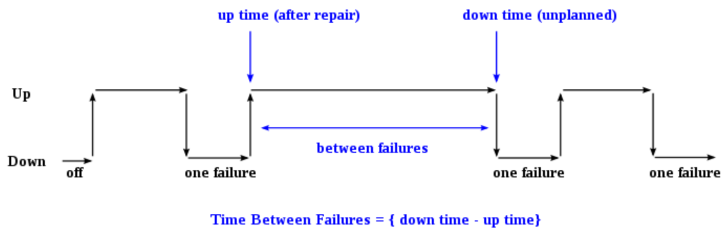

Figure 2.3. Time between failures

2.2.5 Mean time between repair (MTTR)

According to site: http://www.criticalpowerandcooling.com « MTTR, or Mean Time to Repair (or Recover), is the expected time to recover a system from a failure. This may include the time it takes to diagnose the problem, the time it takes to get a repair technician onsite, and the time it takes to physically repair the system ». Expressed mathematically, it is the total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time (institute for telecommunication sciences). Similar to MTBF, MTTR is represented in units of hours. MTTR shows impacts availability and not reliability (Xie et al., 2003). The longer the MTTR, the worst off a system is. Simply put, if it takes longer to recover a system from a failure, the system is going to have a lower availability. As the MTBF goes up, availability goes up. As the MTTR goes up, availability goes down. It generally does not include lead time for parts not readily available or other Administrative or Logistic Downtime. In fault-tolerant design, MTTR is usually considered to also include the time the fault is latent (the time from when the failure occurs until it is detected). If a latent fault goes undetected until an independent failure occurs, the system may not be able to recover. MTTR is often part of a maintenance contract, where a system whose MTTR is 24 hours is generally more valuable than for one of 7 days if mean time between failures is equal, because its Operational Availability is higher (www.encode.com). The MTBM is calculated using the following expression:

$$MTTR = \frac{\text{Total corrective maintenance time}}{Number\ of\ maintenance}$$

(www.maintenanceassistant.com)

2.2.6 Mean time between maintenance (MTBM)

MTBM is a measure of the reliability that takes into account the maintenance policy. More specifically, MTBM is the total number of life units expended by a given time divided by the total number of maintenance events (scheduled and unscheduled) performed on that item (Lee, 2006). During the operating cycle of the system we need to know an average time when a maintenance action will be required to fix the failed component/LRU (Lowest Replaceable Unit). It must be kept in mind that even though the system may not be down due to a failed component/LRU, corrective maintenance will be required to repair/replace the failed item. It is often true that whenever there is a failure of an LRU, it will bring the system down and initiate a maintenance action. Once the LRU has been replaced, the system begins to function normally until the next failure. The MTBM is calculated by dividing the system uptime by the total number of maintenance events (www.weibull.com):

$$MTBM = \frac{\text{Uptime}}{\text{Number of maintenance}}$$

2.2.7 Maintenance score card and total performance maintenance

Tsang (1998) and Tsang et al. (1999) presented a strategic approach for managing maintenance performance that is based on the four perspectives of the BSC concept as suggested by Kaplan and Norton (1993). Liyanage and Kumar (2003) presented an attempt to develop architecture for effective management of operations and maintenance performance, linking results to performance drivers and further extended them to apply the BSC concept. The Balanced Scorecard had been implemented in a number of major corporations in the engineering, construction, microelectronics and computer industries Kaplan and Norton (1993). Experience in these pioneering organizations indicates that the Scorecard will get its greatest impact on maintenance performance only if it is used to drive a change process. The development of a Balanced Scorecard also engenders the emergence of a strategic management system that links long-term strategic objectives to short- term actions as shown Figure -4- (Kaplan and Norton, 1996a; 1996b)

Figure 2.4. Scorecard

To develop a performance measurement system for maintenance the overall performance must be defined. Biasotto et al. (2010) give an example of determining an overall maintenance performance as part of the balance Scorecard for Maintenance Excellence. The overall performance is useful as an early indicator of problems and is therefore recommended for any maintenance system. Overall performance can be defined as a linear combination of the product of a number of performance indicators and weight factors. The following equation describes how Total Maintenance Performance *(TMP)* is calculated.

$$TMP = \sum^{n} W_i \cdot B_i$$

In the above equation the variable B_i represents the benefit value of individual performance parameters, e.g. worker utilization, availability, reliability, etc. The variable W_i represents weight factors to indicate the relative importance of the performance parameters. It is recommended that **8 – 12** performance indicators or parameters be used to define and calculate the total maintenance performance, *TMP*.

Whereas the Tompkins model uses tables to determine the score or benefit for each indicator, it is easier to define a benefit function or equation for each selected parameter. The benefit function transforms the value of a parameter to a normalized value between 0 and 1 (or 0 and 100%). The benefit, *B*, can also be expressed as a mathematical formula that will facilitate the calculation by means of a spreadsheet, e.g.

$$B = m \cdot x + c$$

Where *x* is the performance parameter, for example maintenance cost, MTBF etc. and *m* and *c* are the parameters of the straight line. In some cases the relationship is not a simple straight line since there could be an optimum value between a minimum and maximum. A performance measurement system should address the right evaluation parameters to give consistent results. The maintenance manager must feel confident that the performance system will indicate whether the management of the maintenance system (division or department) is improved or not. An example of the calculation of the total maintenance performance, using nine performance parameters, is given in the following table (Table 1.) (Visser and Pretorius, 2003)

Table 2.1. Maintenance performance parameters and values

Maintenance Indicator	W_i	***Minimum***	***Maximum***	***Value***	B_i	$B_i \cdot W_i$
Availability (%)	15	85	95	91	0.60	0.090
MTBF (hours)	15	100	200	165	0.65	0.098
PM Ratio	15	20	40	32	0.60	0.090
Maintenance Cost Ratio	15	10	30	24	0.30	0.045
Maintenance Errors (%)	10	0	10	2	0.80	0.080
Store Turns Ratio	5	0.8	1.2	1.1	0.75	0.038
Stores Service Level (%)	10	80	100	97	0.85	0.085
Personnel Cost Ratio (%)	5	30	40	32	0.80	0.040
System Image (%)	10	50	100	85	0.70	0.070
Total Maintenance Performance, *TMP*						0.635

Although it is a common belief in industry that strategic planning is important for ensuring an organization's future success, very often the performance measures and the actual company improvement programs are inconsistent with the declared strategy. Such a discrepancy between strategic intent and operational objectives and measures is reported in a survey conducted in the Belgian manufacturing industry (Gelders et al., 1994). This unsatisfactory situation can indeed be avoided by introducing the Balanced Scorecard.

2.2.8 Advantages and disadvantages using KPIs to measure maintenance performance

Various KPIs have been described in the document above. Among the advantages (Pacaiova, 2012) when implementing a systemic approach into maintenance management the following items are mainly included:

- compliance with elements / requirements of other management systems
- clearly specified participation in achieving goals
- pointing out the importance of planning stage in maintenance - selecting and verifying suitable strategies
- possibility of measurement and control
- effective costs control
- higher competitiveness

Among the disadvantages (Pacaiova, 2012) belong these aspects:

- lack of understanding (ignorance) of analysis methods (planning stage) - selection only some of them without understanding their contribution
- understanding concepts as a tool for reducing the number of maintenance workers or maintenance costs reduction
- expecting return quickly without sufficient support
- inappropriate way of management
- inaccurate specification of KPI structure and the need for measurements in maintenance processes
- difficulty in educating maintenance staff, as well as operators (e.g. TPM)
- insufficient communication and management support
- unsuitable corporate culture

2.3 Maintenance performance measurement in practice: Evidence from various industries

2.3.1 Belgian industries

Peter et al. (2009) explore the use of indicators in managing maintenance performance in the Belgian industries. Investigate how these indicators are sourced or chosen and the influence of manufacturing environment/maintenance objectives on KPI choice, and finally investigate the effective use of these indicators in managing the maintenance function based on measurement frequencies, maintenance actions triggered and manager's satisfaction in the use of indicators. According to Peter et al (2009) « The research was chosen as it allows collections of a large amount of data from a sizeable population through the administered questionnaire (Saunders et al., 2007).

(Peter et al., 2009) found that the top 10 maintenance KPIs are dominated by equipment performance. OEE metric and its variants came out as the most popular equipment performance indicator capable of measuring different production losses ».

2.3.2 Food industry

The work in Tsarouhas (2011) is relevant to our case study in this thesis since it applies to food industries. In particular, in the work by Tsarouhas (2011), investigates the relationship between the factory management and the operation of the limoncello production line. According to Tsarouhas (2011) «The limoncello production line consists of eight independent machines in series with a common transfer mechanism and control system. Each machine consists of components that have different failure modes. The technical department is responsible for collecting the failure and repair data of the line. At the end of the shift the maintenance staff reports the failure date and time, the failed machine, failure mode, and the repair time the data covered a time period of 245 days, i.e. 8 months. During this period, the line operated for 8 hours a day, with one 8-hour shift during each day, for a total of 174 working days. From this study company and, particularly, the operation and technical department can extract useful information about production capabilities to increase the productivity in the future ».

2.3.3 Cellular industry

Chand and Shirvani (2000) investigate how the TPM is implemented in cellular industries. A feasibility study was conducted on a semi-automated assembly cell, in order to determine the OEE of the cell as well as establishing the associated big losses. According to Chand and Shirvani (2000) «The new modern built plant has recently set-up and also there are employs around 150 people. The manufacturing layout comprises of three distinct cells which are gradually becoming more customer-focused. The production operation includes: forming shop, tool-room and a fully equipped product test-room. There are three assembly cells: semi-automated, manually-operated and flexible cell. An integrated computer system is used to control and monitor production planning and scheduling which provides accurate and `real-time' processing of information to control production progress which is linked to an electronic data interchange (EDI) system for scheduling and customer order processing. The production output of the cell over the observed period was 26515, which represented 97% good components, 0.33% scrap and 2.67% rework. The number of stoppages recorded was 156, where the 10 most common causes were identified. The OEE was 62% and the six big losses represent 38% loss of the productive time. Chand and Shirvani (2000) state that: “it is recommended that the company can go ahead with plans to implement TPM using OEE methodology”».

2.3.4 Textile industry

Lemma (2008) research mainly deals with the principles and concepts of Total Productive Maintenance based on a literature review and the assessment of the existing maintenance activities of the KK textile industry in Ethiopia. According to Lemma (2008) « The main objective of this research was to improve the existing maintenance system of the company in order to have better capacity utilization and to enhance the effectiveness of its equipment. The research found that there was a high rate of unplanned failures. This can be attributed to the condition of equipment, the negligence of the operator and the shortage of spare parts. The underprivileged preventive maintenance system of the industry contributed to this effect, as well. The line of investigation winds up that the effect of not involving the operator in minor inspection and restoration of equipment escalates unexpected number of failures which challenges the sustainability of the proactive maintenance program ».

2.3.5 Esthetic dental industry

Ben Or (2010) investigated the process of Nobel Biocare. This company offers a large number of products including standard titanium implants and abutments in different shapes and sizes and individualized prosthetics.

Ben Or (2010) used OEE equation, as well, and found that major losses are closely related to frequency of changeovers in machining processes with 68% average effectiveness rate. In surface treatment and packaging equipment inspected the values were found to be between 46% and 59% as the major common cause was the absence of work due to unstable flow of orders. Assessing process orientation and maturity levels, the findings indicate high levels in general. However, areas of weakness were identified in the different processes in which the potential for improvement is embedded. In those areas, lower OEE values were registered, low levels of maturity and process orientation were found, as low development of losses improvement were assessed.

Based on the bibliographic review, it is clear that even though the performance indicators discussed in the previous sections have been utilized in a variety of domains in the food industry (Tsarouhas, 2013), their application has not been investigated in the fresh-cut vegetables sub-sector. Therefore, this thesis aims to expand the applicability of the aforementioned performance indicators to food industries specialized in fresh produce and perform an analysis with respect to their corresponding validity and usefulness. To support our analysis and research on this topic, we will make use of data from the food plant Greenfood located in the industrial area of Thessaloniki, Greece.

Chapter 3 – Methodology

Case study as a research strategy often emerges as an obvious option for students and other new researchers who are seeking to undertake a modest scale research project based on their workplace or the comparison of a limited number of organizations (Rowley, 2002). Case study research can be based on a mix of quantitative and qualitative approaches. Typically, it uses multiple data sources including two or more of: direct detailed observations, interviews, and documents (Yin, 2003).

3.2 Strengths and weaknesses of the case study methodology

3.2.1 Weaknesses

According to Melbourne University and faculty of business and economics « Case studies involve analysis of small data sets, such as one or two companies, that may lead the researcher to gain some insights about trends in relevant industries.. The data is "real life" in the sense that a company or companies have been chosen as the source of the data. Case studies are a "qualitative" research method in some black and white sense. Instead, many case studies collect large masses of quantitative data – performance data, profitability data, employment data, marketing data, etc. for a specific organization (Harvard University, 2005). However, the studies involve "small-n" data and therefore conventional empirical techniques cannot be used, or where they are used, they may have limited application as there may not be enough data to meet requirements for statistical significance.

3.2.2 Strengths

The case study method involves detailed, holistic investigation (for example, all aspects of a company) and can utilize a range of different measurement techniques (the case study researcher is not limited to any one methodological tool). Data can be collected over a period of time, and it is contextual (relative to a certain industry). The histories and stories that can be told about the company are also something that can be assessed and documented—not just empirical data, for example, stories and anecdotes about how the company interacts with the marketplace can be used » (University of Melbourne, 2011).

Chapter 4 – Case company

4.1 Company history

The case company is an industrial unit located in the industrial zone of Thessaloniki and specializes in the processing of leafy vegetables for the production and packing of washed chopped salad ready to eat. Greenfood s.a. was founded in June 2005 and produces for Barba Stathis S.A. a series of innovative and pioneering products made for the Greek retail under the name “Uncle Stathis”.

4.2 Products

The company belongs to the group VIVARTIA, which holds 77.64% of the issued shares. The company also produces a wide range of goods for the HO.RE.CA. market on behalf of major clients, and has developed a significant export activity in the Balkans. Greenfood s.a. offers customers vegetables of high and consistent quality and safety through the implementation of strict quality and food safety systems in both the primary sector and the manufacturing sector. The company has certified its production process in accordance with the requirements of the ELOT EN ISO 22000: 2005 and IFS FOOD version 6 standards. For the procurement of raw materials the company applies the agriculture under contracts and chooses to work with producers selected against strict criteria. The aim of Greenfood s.a. is to deliver innovative, freshly cleaned, washed, cut vegetables with high nutritional value and safety that will allow customers to save time, cost and trouble (www.greenfood.gr).

4.3 Raw materials

The cooperating growers monitored by agronomists of the company regarding the selection of varieties, the cultivation and selection and use of plant protection products. At the same time, many vendors have introduced certification of crops by independent system operator in integrated farm management GLOBAL GAP. In this way, cover the entire supply chain from farm to table and ensure traceability. The company has invested significantly in the development of Greek agriculture. He experimented with different crops and varieties to ensure the required quantity and quality of raw materials throughout the year. Now, the company manages to meet its needs in fresh vegetables from local producers from all corners of Greece, the Peloponnese, Crete and Northern Greece. Greenfood salads thanks to the choice of high quality raw materials, following the strict protocols of hygiene and food safety in the treatment process and the use of high expertise for the selection of packaging parameters, are kept fresh, vibrant and of high nutritional value throughout their lifespan.

4.4 The Sindos plant

The number of employees is around 90 of which 75 are workers in production plan. The othe employees work at Quality control, accounting and agronomy department. The total space of the plant is 16000 m^2 of which 6000 m^2 are dedicated to process. Plant capacity in term of major production equipment is including 4 process lines. In addition there are 5 vegetables cutting machines, 1 autonomous washer, 2 autonomous dryers, 2 spray rejecters and 5 packaging complex which conclude from multi weight scales, input and output conveyors, metal detectors and vertical packaging machines. Also there is an autonomous formative cartons machine.

The production process after order load can be divided to five sub-processes of machining, first preparation, cutting, washing and drying, sorting contaminants and packaging. During the preparation process (process lines), there is a long table with ten workers who cut and check the leaves. The vegetables continue to weight hoppers (two) as in this point created the mix of salad. After this the mix continue to cutting machine and then to first washing station (pre-washer). The pre-washing station works to clear the sludge off the vegetables. Then the vegetables mix continues to second and third washers for better cleaning and removal of the microbial load. At the end of the third stage, there is a dryer which dries the vegetables mix to remove water from the previous procedure. The critical point is the next station, where the spray rejecters remove foreign matter and any leaves colored differently from the product specifications. At the end of the procedure the vegetables mix is controlled by metal detectors so that any traces of metal, stainless steel and plastic are removed prior to the refrigeration storage. It is important to mention that all the process plant operates under 10^o Celsius maintained by a big refrigeration unit which uses ammonia to freeze all production areas. Furthermore, all process lines are monitored by automatic systems like operation panels and programming control logic (PLCs) units.

4.5 Maintenance department

In addition to the maintenance manager, the maintenance staff at Greenfood S.A. consists of 3 engineers and sometimes an apprentice. These are engineers with knowledge of mechanics, electronics and machine programming. The work structure is based on 2 shifts (early 08:00-16:00 and late 12:00-20:00) per day. This means that one electrical engineer works on each shift and one mechanical engineer either on the early or on the late shift. Sometimes there are two engineers on the same shift supported by one technician for the whole work-day, since the week production schedule starts from Monday and ends on Saturday. This creates certain schedule gaps, because the technicians work five days per week.

4.6 Research focus

The company under study is the national leader in the production of fresh cut produce. Greenfood offers a large number of vegetables products in the retail market. The Sindos plant is responsible for the production of washed, cut, ready to eat, packaged vegetables. The major process lines include production equipment which consists of cutting machines, washers, dryers, and rejecters of many lettuce varieties. The production system operating at the factory today includes five stages that are: receiving area, storage, process lines, packaging and shipping area. The whole plant works under refrigerated conditions, since the specifications of these industries require a cooling ambient. Taking into account that the products are fresh with shelf life of just seven days there is a need to lower inventory levels and at the same time provide a large assortment of products on time to customers. Hence, flexibility in production is required or, otherwise, the need is raised for production in a larger number of smaller production batches for daily shipments. Production in smaller batches increases the number of different procedures such as order initiations, kitting, setups of machines, adjustments, inspections, packaging adjustments and others which challenges the efficiency of operations and production line flow. As a result, there is an imperative requirement for improvement of processes by understanding how the current situation looks like and by identifying possibilities and potential for improvement of processes and maintenance. These changes (setup) for product to product often create malfunctions and process breakdowns, as well. At this point, the maintenance department has a critical role to avoid these malfunctions.

Next we will discuss the initial steps of our case study analysis which consists of the following steps: The first step provides a fundamental description of the production process and operation management in Greenfood. The second step describes the data collection process which includes the measurement of quality parameters and the measurement of the breakdown time.

Chapter 5 – Case study analysis

5.1. Description of the production process and the operation management – line A

In the study, the core process of production was primarily examined focusing on line A (see Fig. 5.1.), which is the oldest at Greenfood's plant.

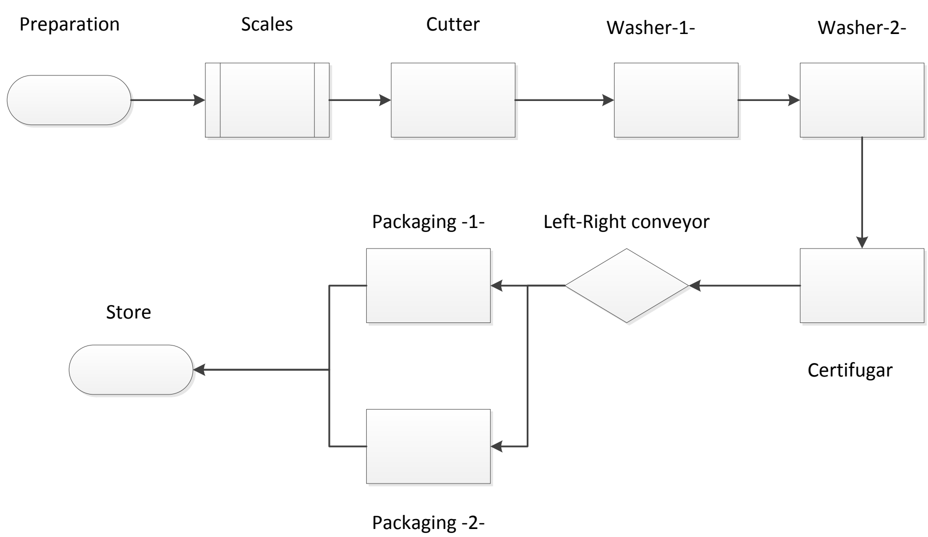

Figure 5.1. Production line A

As mentioned above, the line has a preparation table with ten work positions as shown in Fig. 5.2..

Figure 5.2. Preparation table

Next there are: Weight-mix scales, cutters, washers and many conveyors. The collected data are from preparation until left – right conveyor (two directions) which is the end of process line (Fig. 7) and not until after the packaging machines.

Figure 5.3. Conveyor

This is because many times either packaging machine -1- or packaging machine -2- package products for other two lines, specified from line –E- and line –G-. With this production schedule it is difficult to collect (at this point in the investigation) data from the whole line shown in Fig. 5.

5.2 Data collection

The study was carried out on site under a period of about eight weeks, starting October until the end of November. Data from process line was collected and studied while measurements, observations were employed on daily basis, allowing thorough study of the organization and its operations. Additional information was collected from receiving and production offices giving all information about raw materials. This is very important in order to calculate the quality index of OEE equation.

For the recording of data automation equipment was used from Siemens and Ifm company which connected with main operation campinet of line –A- and upload daily, all parameters so that to calculate the OEE, MTBM, MTBF and MTBR key performance indicators. Specifically established a photocell sensor (Fig. 8) which measures or detects the products (fresh mixed salad) on the conveyor belt. With this sensor it is ensured that production time is continuously recorded.

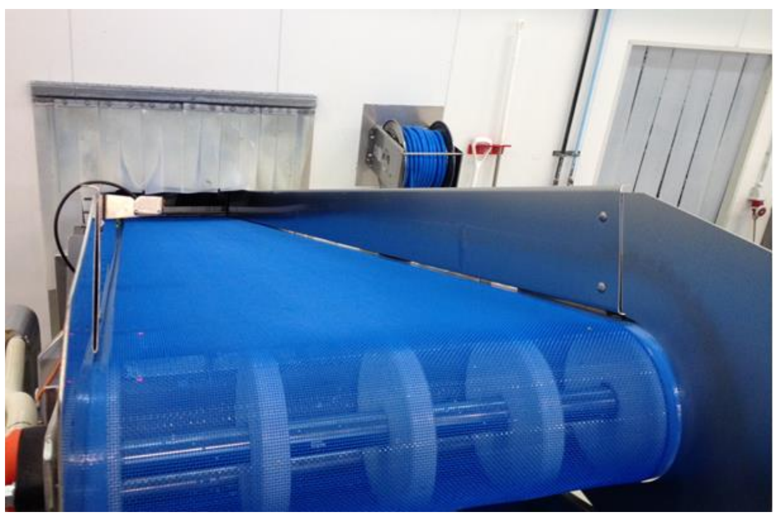

Figure 5.4. Photocell sensor

The 100% of necessary values for the measurement MTBF, MTBM MTBR and OEE are recorded in Excel program and are calculated daily. Only for the parameter Quality, all the data are given from the two responsible foremen who operate the process lines and record both all the incoming raw materials (vegetables) and all the finished products. Additionally to measure MTBF, MTBR and MTBM both for packaging machines -1-, -2- and process line –A- used manually recorded method. When there were malfunctions or programmed maintenance, after the work out, technicians write on a specific paper form, the collected data.

5.3. Measuring the quality parameters

As mentioned before, the measurements reach the left-right conveyor which is the end of process line –A-. Nevertheless the measurement of quality level goes one stage further at the packaging steps -1- and -2- because in that point it is very easy to find the number of good products. It would be best to measure the good products after the left – right conveyor, as the other parameters, but it is very difficult because it is required continuous weight conveyor belt that could weight in real time the good products and continioulsy calculate the total production.

5.4 Measuring the breakdown time

At this point it is important to say that malfunctions from packaging machines -1- and -2- included in process line –A- only for OEE measurement as break down time. Both collected manually without the automation equipment as the other parameters. This is occurs because when there is a stop at packaging -1- or -2-, line –A- continues to run and the product (manually from workers) is collected in plastic beans. After the end of this product code, process of line –A- stops until the products in beans (at the end of line) packs from packaging machines -1- and -2- after the solution of malfunction. Then the process starts again and the product continuously packs at real time.

Chapter 6 – Data analysis

6.1 Overall equipment effectiveness

As written above the OEE measured only for the line –A-. An example of the data framework designed by Excel software program is given below (Fig. 6.1). These data are always collected and recorded from the specific equipment at the end of plant production time. To ensure this procedure all technicians from maintenance department are trained accordingly.

CALCULATING OEE WORKSHEET

Overall Equipment Effectiveness

Line / Cell : Line -A
Process : Vegetables produce
Machine : Turatti
Date : Οκτώβριος 2014

Date :	1	2	3	4	5
	1/10/2014	2/10/2014	3/10/2014	4/10/2014	5/10/2014
Total Time (Minutes) :	652	595	757	724	Κυριακη
Break time = (Short Breaks + Meal breaks+Setup time)	60	60	60	60	
Planned production time (Minutes) :	592	535	697	664	
Down time = (Break down + Malfunction+Setup time) (minutes) :	171	134	168	217	
Operating Time (Minutes) :	421	401	529	447	
Processed Products (Kgr) :	6163	3648	7554	5235	
Good Products (Kgr) :	5351	3404	5400,7	4817,6	
Maximum capacity of line -A- (Kgr/ hour) :	1000	1000	1000	1000	
Ideal run rate (Kgr/minute) :	16,66666667	16,66666667	16,66666667	16,66666667	
Availability	71,11%	74,95%	75,90%	67,32%	
Performance	87,83%	54,58%	85,68%	70,27%	
Quality	86,82%	93,31%	71,49%	92,03%	
Daily OEE	**54,23%**	**38,18%**	**46,49%**	**43,53%**	

Figure 6.1. OEE Worksheet

The above table is analyzed below. The values of total time are given by the installed equipment on the production line every day. The break time is always the same as referred to the short and meal daily breaks. As defined in relative literature plant production time is the total time minus the scheduled breaks (short, meals) from workers. Downtime is the time from malfunction caused by mechanical or electrical dysfunctions. Times such as start-up of every morning or time between the changes from product to product are included at downtime. Operating time is the planned production time minus the downtime. Maximum capacity of each peace of equipment is specified by the respective manufacturers. In the following figure (Fig. 6.2) there are measurement curves for all parameters of the OEE function.

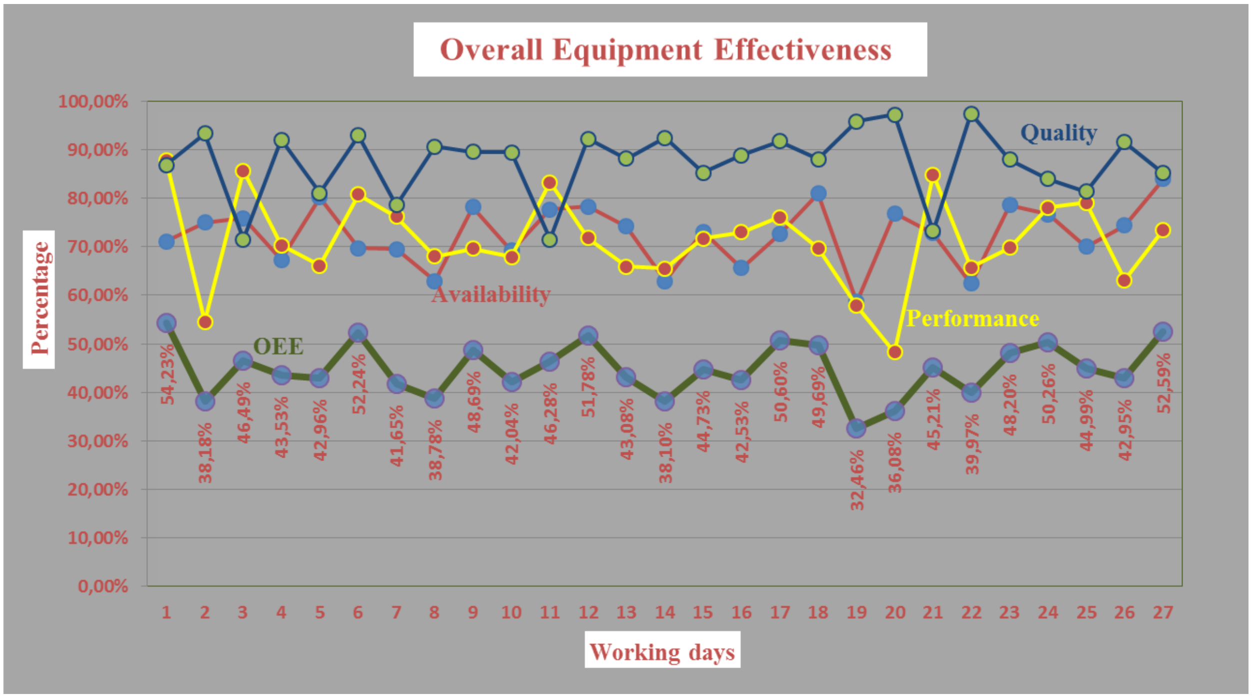

Figure 6.2. Overall Equipment Effectiveness parameters

From the above figure we observe a circularity of values at the four graphs. This shows stability in the production process without unforeseen events like injuries and dysfunctions of electromechanical equipment. Specifically, we see that every five to six days of production the OEE ratio reaches a maximum, and minimum respectively while the same periodicity. We could easily say that identifying the factors that lead to the improvement of such a production process is easy because there are no unforeseen events. So we can see each index individually and how this could be improved.

6.2 Effect of availability, quality and performance to OEE

In order to examine the effect of availability, quality and performance to the Overall Equipment Effectiveness (OEE) in the following paragraphs availability, quality and performance are measured and presented in relation with OEE separately for twenty seven working days on October.

6.2.1 OEE in relation to availability

It is clear that availability affects the OEE the most (Fig. 6.3.). When availability rises, OEE rises, as well. The same happens when availability decreases. In the case of Greenfood s.a. 90% - 95% of availability is generated from the start-up time and setup time during the By transition from one product to another.

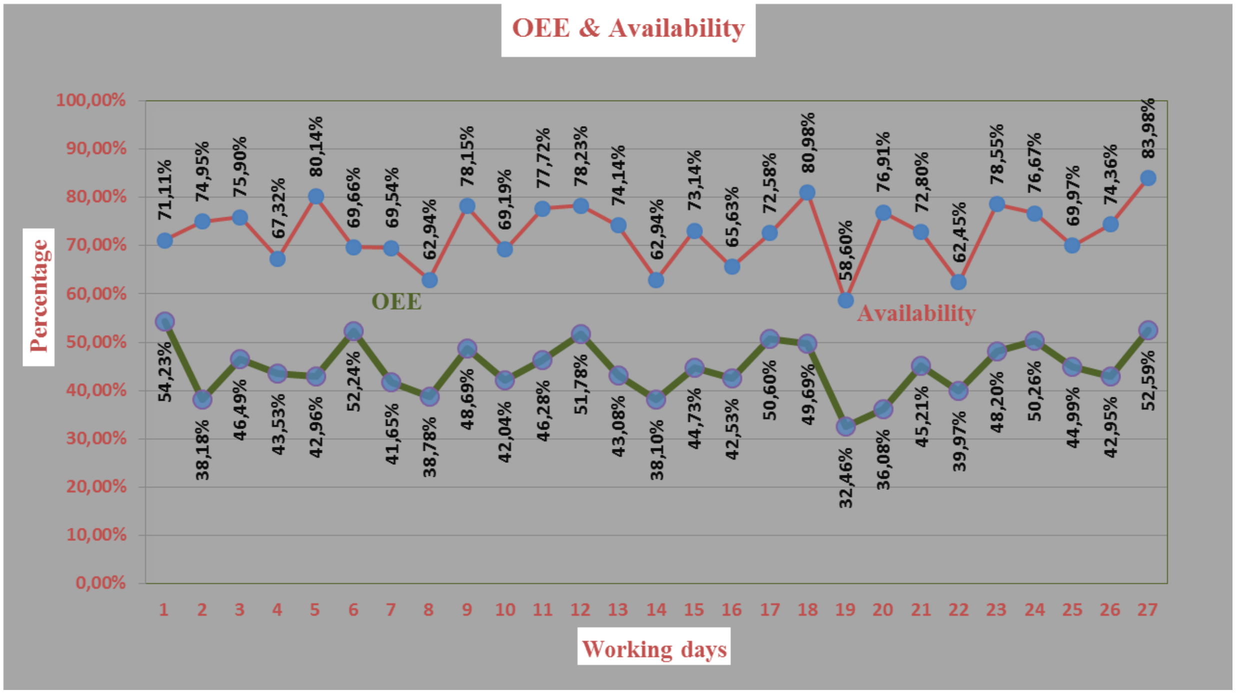

Figure 6.3. OEE and availability

More specifically, in the table below (Table 6.1.) the downtime and availability are separetely analyzed. It is shown that downtime affects availability the most.

Table 6.1. Downtime and availability of plant – October 2014

Month: October	
Average of down time	175,4074
Average of down time without start up	145,4074
Start-up as percentage to downtime	17,10%
Downtime total	4736
Downtime without start up. 30 min every morning	3926
Malfunctions total	122
Net downtime total	3804
Operation time total	12753
Net downtime as percentage to Operation time	29,83%
Malfunctions as percentage of downtime time	3,21%

We show that the mean daily down time of process line A is 175,4 min. This means that every day the line works without products approximately for three hours. This time is too high, but when we analyzed the data more, we show that 30 min every day is the start-up time. This time is default by the manufacturer of the process line and refects the 17,1 % of downtime. It is the time until the washers of process line filled with water. This delay can not be avoided unfortunately. It is calculated that 29,83% of operation time is the downtime. This means that the daily availability is approximately 70%. Next, the malfunction time is found to be 122 min for month October and corresponds to only the 3,21% of the downtime. This means that the maintainability or servicibility of this line is too low and hence the long term profitability impact from line A to Greenfood s.a is low as well, in line with prior research (Al Sultan and Duffuaa, 1995). Conclusively we could say that availability affects the OEE to the same direction. For the above it could be said that availability is effected more than for the production processes (strengths and weeknesses of process lines) rather than for the malfunctions from the electromechanical equimpent.

6.2.2 OEE in relation to quality

As shown in the following graph (Fig. 6.4) the quality has a different effect to the OEE index. We notice that when quality is high, the OEE is low. This does not happen at 100% of the 27 working days. Quality in these processes is mostly related with raw materials (Parida, 2007). At the washing stage the vegetables haven't any process lesions or damages. However, the leaves of vegetables are some times more and some times less hard and this is the reason why quality goes either up or down. The packaging stage is another critical point for changes in quality, because many times there are malfunctions with either the centering or celling of the film. When packaging malfunctions happen, the need for repackaging of products is increased. Sometimes the malfunctions of the film are created by operation mistakes in setting wrong program parameters and not by electromechanical dysfunction. Consequently, quality is affected mostly by the raw materials, less by human errors and far less by equipment failures. This means that maintenance has low impact to the quality of products.

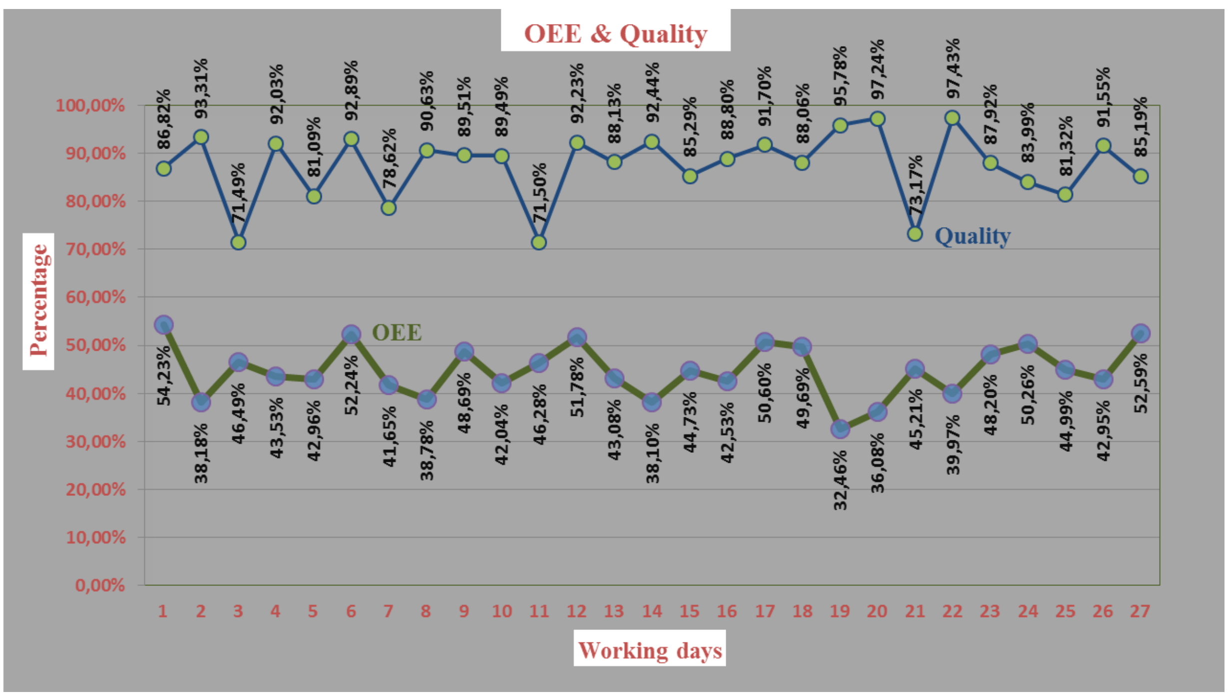

Figure 6.4. OEE and quality6.2.3 OEE in relation to performance

As observed in the following graph (Fig. 6.5.) performance has a similar effect as the availability in OEE index. There is a circularity in the values of the parameters and this is due purely to the production of goods on specific days of the week. At this point it should be emphasized something very important which influences the performance of the production line and therefore the index OEE but does not reflect the reality. In our case the maximum performance of the production line is 1000 kilos per hour. This value is widely reported by machinery manufacturers for a wide range of products. So when products are produced with low specific weight like leafy lettuce, the kilos per hour can be very low. For example, in the production of rocket productivity ranges are 300 to 450 kilos per hour while in production of iceberg productivity rate can reach 1200 kilos per hour. Therefore, many times the daily performance is very low while they really are very high. Respectively can be very high, e.g. 110% while something may not apply. Other scrap or productivity have leafy vegetables and other have a radiccio or iceberg. The above description leads us to a quick conclusion that for correct measurements and conclusions of individual quality and performance indicators for the index OEE should the measurements to be made separately for each production code. Unlike availability that has to do with the dead times from damage or uncorrectable production schedule which can be tracked and measured in total production.

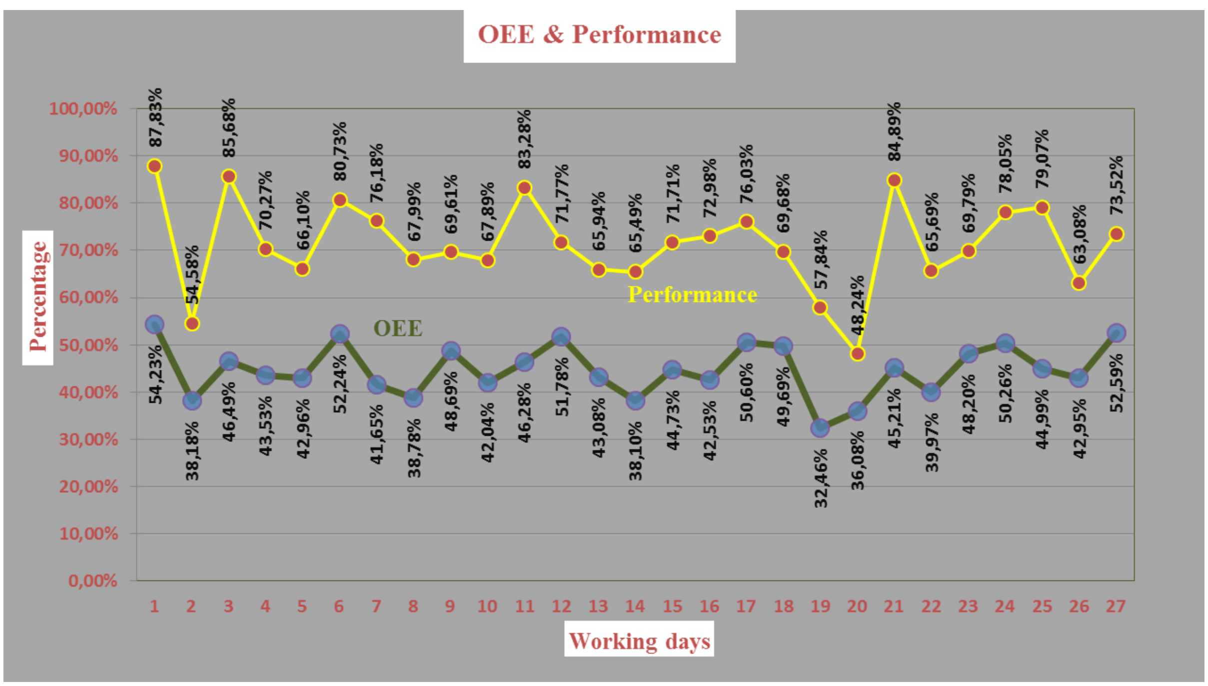

Figure 6.5. OEE and quality

6.2.4 Performance in relation to quality

Analyzing all the relevant indicators of the OEE we noticed something very important which happens in most industrial processes. In figure 10 we see that quality and performance have a counterslope. When the quality increases, the performance has a negative tendency. This is because with the increased production, processed products on the production line move more rapidly, creating scrap (corrupted-damaged). Also production speed ratio (performance) many times creates glitches at the two packaging machines due to either error handling (such that changes in program management) or mechanical and electrical problems. Therefore, we have to decide on how to improve the OEE index depending on our interests as a whole. We can, for example, improve the efficiency rate by up to 10% with the quality being reduced by 20%, causing an overall reduction of OEE by -10% (the availability index remains constant). Therefore, it is very important to know the interaction of the two individual indicators in order to assure that the corrective actions will improve the overall OEE index. Yet, all the above considerations constitute the directly measurable results. Usually a rise of performance (production speed) causes damages to the equipment in the long term. Then, wear and tear of equipment cause malfunctions, damages and processes interruption. Then interruptions in the production lines destroy products and, hence, reduce the quality score. If we take into account the cost of mechanical failures (purchases of spare parts) and the cost of labour (overtime in cases of damage) we will an upward trend with a decrease in profits to the company (Cross, 1988). Thus, we can decide what we want to improve and how, by understanding the improvement of the indicator OEE as a multifactorial process by directly and indirectly influenced results.

6.2.5 Maintenance indices: MTBM, MTTR and MTBF

The indices of MTBM, MTBF and MTTR are presented in the following table (Table 6.2.). These indexes have been recorded as the aforementioned key performance indicators in the month October 2014 in process line A.

Table 6.2. Maintenance indices in process line A – October 2014

Month	Οκτώβριος 2014
Name of Machine	Γραμμή -A-
Brand	Turatti
Downtime (minutes/month)	267
Operation availability (minutes/month)	18780
Number of failures	9
MTBF (min)	**2.057**
MTTR (min)	**30**
MTBM (min)	**2086,66667**

		Down time			Operation Time					
No.	**Date**	**Time Start**	**Time Finish**	**Down (min)**	**Time Start**	**Time Stop**	**Operation (min)**	**Replacement**	**Technician**	**Operator**
1	1-Οκτ				8:00	17:00	540			
2	2-Οκτ				8:00	17:55	595			
3	3-Οκτ	8:25	8:38	13	8:00	20:37	757	Καθαρισμός	Ταυλαρίδης	Μανωλάκης
4	4-Οκτ	8:30	8:45	15	8:00	20:00	720	Reset program	Ταυλαρίδης	Κωνσταντινίδης Γιάννης
5	5-Οκτ									
6	6-Οκτ	12:20	12:28	8	7:00	20:00	780	Grasse		
7	7-Οκτ				8:00	18:50	650			
8	8-Οκτ	18:50	20:20	90	8:00	17:57	597	Glycol batterfly	Ταυλαρίδης	Μανωλάκης
9	9-Οκτ	11:19	11:25	6	8:00	17:57	597		Ταυλαρίδης	Μανωλάκης
10	10-Οκτ				8:00	20:31	751			
11	11-Οκτ				8:00	18:33	633			
12	12-Οκτ									
13	13-Οκτ	13:50	14:40	50	7:00	20:32	812	Inox part	Ταυλαρίδης	Μανωλάκης
14	14-Οκτ				8:00	21:04	784			
15	15-Οκτ	21:45	22:40	55	8:00	19:38	698	Inox part	Ταυλαρίδης	Σιαπάτρας
16	16-Οκτ				8:00	17:57	597			
17	17-Οκτ				8:00	20:51	771			
18	18-Οκτ				8:00	20:12	732			
19	19-Οκτ									
20	20-Οκτ				7:00	21:15	855			
21	21-Οκτ				8:00	21:11	791			
22	22-Οκτ				8:00	19:16	676			
23	23-Οκτ				8:00	19:15	675			
24	24-Οκτ				8:00	19:14	674			
25	25-Οκτ				8:00	16:46	526			
26	26-Οκτ									
27	27-Οκτ	8:00	8:10	10	7:00	19:16	736	switch	Λιθοξόπουλος	Μανωλάκης
28	28-Οκτ				8:00	19:00	660			
29	29-Οκτ	17:00	17:20	20	8:00	20:56	776	Inox cover	Λιθοξόπουλος	Μανωλάκης
30	30-Οκτ				8:00	19:28	688			
31	31-Οκτ				8:00	19:49	709			
	Total time (min)			267			18.780			

From the table above it is observed that line A operated for 18780 min (with and without products) which equal 313 hours. This means that for 27 working days the mean daily operating time is 695 min which is appoximately 12 hours per day. The monthly duration of service or maintenance is 267 minutes. A more detailed analysis is given in the table below (Table 6.3.).

Table 6.3. Downtime analysis

Month: October	
Operating time	18780
Downtime total	267
Downtime_1 During the production time	122
Downtime_2: Except the production time	145
Downtime_1 as percentage to downtime total	45,69%
Downtime_2 as percentage to downtime total	54,31%
Downtime_1 as percentage to operation time	0,65%
Downtime_2 as percentage to operation time	0,77%
Downtime total as percentage the operation time	1,42%

From the above data of table 6.3. many results arise. Of the 267 minutes which is the time of repairs and maintenance of the line A, there are two separated times: downtime_1 and downtime_2. The first is the time required to repair the damages of equipment of the process line during operation. These damages cause stoppages of the process line and therefore they must be repaired immediately. The second time consists of the time for preventive maintenance and the time required for repairs on the production line at non-operating hours. This downtime corresponds to repairs that can be transferred from production hours so as not to stop production. Also in table 6.3. there are some more details about the downtime that need to be discussed further. Only 45,69% of total downtime has an impact to availabilty (Xie et al., 2003), which is the downtime related to the corrective maintenance policy or scheduled maintenance (Lee, 2006). The rest 54,31% is the percentage related to the preventive maintenance policy, which hasn't any impact to availability. The MTBM is 2086 minutes or approximately 37 hours. The MTBF is 2057 minutes or 34 hours. As it is clear from the literature the bigger the MTBF the lower the availability and the bigger the

MTBM the bigger the availability. From the above it could be said that these indicators give a direct information about technical operation in any company unlike with OEE indicator which is more complex.

Chapter 7 – Conclusions

In the present thesis we researched, firstly, some of the indicators for measuring the performance of technical department and, secondly, we examined how these indicators are applied in practice in a food plant. For this purpose, a real application was developed in one of the production lines in the company Greenfood S.A.. Through indicators, such as OEE, MTTR, MTBF MTBM, an effort has been made to assess the performance of the technical department and to decide whether this measurement procedure can be used as an evaluation criterion. To this end, appropriate equipment was placed for the collection of data in order to calculate the aforementioned indicators and data was measured and analyzed for 27 working days in the month of October 2014.

Findings show that the OEE is a very useful tool for the monitoring of production equipment as calculated from production speed, quality and availability. Furthermore, OEE could be used as an index to evaluate the technical department under certain conditions. Usually, the quality of products (see OEE indices above) is related to the maintenance of production equipment. While in our case we found that quality of products is more affected by the quality of raw materials than by equipment maintenance. In contrast to the quality index, the two other indices of OEE, i.e. the percentage of availability and performance, are strongly affected from the maintenance of production equipment. This is obvious, since from a bad maintained production line lesions can be created that result to stoppages in production, as well as, low production speed.

Unlike the OEE indicator, the indicators MTBF, MTTR and MTBM seem to approach the measurement of technical performance services better. More specifically, as regards the MTTR, which is the mean time of parts replacement, it is highlighted that it can be used to facilitate the assessment of the response time needed for the technical department to resolve some lesions. With a deeper understanding and further justification of the aforementioned indices corrective and preventive actions can be planned and controlled, in order for the causes of damage to be mitigated. Moreover, the MTBM shows clearly the average time between maintenances while the MTBF shows the average time between failures. It is also observed that from these two indicators it can easily be found whether the Technical Department of an organization works proactively or reactively. This is very important for the proper functioning of the machinery of production because the more preventive maintenance applies the lower injuries will occur. This is for example a criterion to define whether the technical department is continuously improving (positive evaluation). For example, if the value of the MTBM index is constant and the value of MTMF index decreases then the technical department works proactively. On the other hand, if the two values are equal, then there is no preventative maintenance which could be result as a positive evaluation.

All the above are findings from the application at company Greenfood s.a. In order to avoid incorrect conclusions it would be best to make some assumptions. For example, in many organizations the administration doesn't wish to have a large degree of preventive maintenance because this entails an increase of the operating costs, resulting in reduced profitability. In other industries, such as refineries or power stations, preventive maintenance has a high importance, because stoppages in production process (fault reasons) have much more economic impact in relation with the respective cost of the preventive maintenance.

Practitioners and theorist could be use these indicators for control and improve the operation of your company but should take into account certain limitations and conditions for the correct implementation of the measurements

- Should be designed and installed the appropriate measurement systems (industrial automation).
- There must be the appropriate programs (Software) for calculation and presentation of the results.
- The measurements should always involve the same production lines and in the same places.
- Measurements should be continuous, uninterrupted, to ensure the comparison with previous values (previous year, periods).
- Some times (depends of size of values) there will be an extra job position.
- Many times values and indexes causing self-purpose and not throughout the work (good maintain etc.).

To improve current state, balance scorecard could be used assigning the desired weight to each indicator so that the final score result (from the monthly review) would cover fully both the needs and operation philosophy of each company. For example a different degree of significance may be assigned for the indicator OEE and other for the indicator MTTR.

Generally future research could focus on further analysis of the list of KPIs in order to generate more specific results by food industry and specifically for the fresh cut produce.

In the present thesis it is shown that performance measurement indicators are a very useful tool especially for large corporations or groups. As the maintenance cost ranges between 20% and 30% of total operation cost, this tool could be used by senior managers in order to ensure the best possible operation towards business excellence.

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