REVIEWS AND CASE STUDIES

Implementation of total productive maintenance in food industry: a case study

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Abstract

Purpose – The purpose of this paper is to adopt the total productive maintenance (TPM) in the food industry and especially in bakery products. The paper aims to develop a methodology for increasing production rate, improving the quality of the products and providing a healthier and safer work environment.

Design/methodology/approach – The methodology is based on analysing the reliability data of an automatic production line. It is divided into four steps, whose aims are to bring forth improved maintenance policies of the mechanical equipment. Also, the continuous and thorough inspection of the production process is achieved through measurements of the overall equipment effectiveness (OEE).

Findings – The goal of development methodology is to bring competitive advantages, such as: increasing the productivity; improving the quality of the products; and reducing the cost production of the line.

Practical implications – The development methodology in the food industry increases the production rate, improving the quality of the products and providing a healthier and safer work environment. It can be useful to guide food product machinery manufacturers and bread and bakery products manufacturers to improve the design and operation of the production lines that they manufacture and operate.

Originality/value – This paper presents the implementation of TPM in a pizza production line and, using certain assumptions, the generalization of the results in bakery production lines.

Keywords Productive maintenance, Quality, Production management, Food industry, Bakery products

Paper type Case study

Practical implications

In the food industry, the production process requires non-stop operation of automatic production line equipment. A stoppage in a production line, due to a failure of the equipment, causes a drop in the production rate as well as quality problems on the products. The aim of this paper is the implementation of total productive maintenance (TPM) in a pizza production line and using certain assumptions the generalization of the results in bakery production lines. To achieve this, we develop a methodology for increasing the production rate, improving the quality of the products and providing a healthier and safer work environment. It can be useful to guide food product machinery manufacturers and bread and bakery products manufacturers to improve the design and operation of the production lines that they manufacture and operate.

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Introduction

Many manufacturing systems operate at a lower capacity with a consequence of a higher cost of the producing products. Low productivity is the result of the worst function of the production lines. This is can be a result of imperfect maintenance of the machines or workstations. Maintenance is undertaken to preserve the proper function of the system so that it will continue to do what it was designed to do. According to the study reported by Mobley (1990), between 15 percent to 40 percent (average 28 percent) of the total production cost is attributed to maintenance activity in the factory. These costs are associated with maintenance staff, maintenance policy (preventive, corrective maintenance), labour, spare parts acc. The importance of maintenance activity is keeping and improving the availability, product quality, safety requirement, and plant cost- effectiveness level, as maintenance costs constitute an important part of the operating budget of manufacturing firms (Al-Najjar and Alsyouf, 2003).

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).

Measurement is an important requirement of continuous improvement process. It is necessary to establish appropriate metrics for measurement purposes. From generic perspective, TPM can be defined in terms of Overall Equipment Effectiveness (OEE) which in turn can be considered a combination of the operation maintenance, equipment management and available resources (Chan *et al.*, 2005). The gaol of TPM is to maximise equipment effectiveness, and the OEE is used as a measure (Waeyenbergh and Pintelon, 2002). Nakaiima (1988) believes that OEE measurement is an effective way of analysing the efficiency of a single machine or an integrated manufacturing system, and it is a function of availability, performance rate and quality rate. Availability losses result from breakdowns i.e. failure that stop the line which is not running when it should be. Performance losses arise from stoppages of the line due to failure, idling or empty position. Quality losses consist of product reject due to quality deterioration of the products. These losses lead to low values of the OEE, which provide an indication of how successful the production process is. TPM helps raise the value of the OEE by supplying a structure to facilitate the assessment of losses, and subsequently giving priority to dealing with the more serious offenders (Eti *et al.*, 2004).

Several books on TPM have presented TPM improvement activities in plants and have suggested steps for TPM implementation based on case studies (Shimbum, 1995; Hartmann, 1992; Tajiri and Gotoh, 1992; Suzuki, 1992). Ireland and Dale (2001) examined how TPM was implemented in three companies, with particular focus on the: TPM journey; TPM processes used; role of TPM co-ordinators; and the company's TPM goals. Kumar Sharma *et al.* (2006), attempted to provide an in-depth, case-based approach to implement TPM in a semi-automated cell of a company, that help maintenance managers/practitioners to understand the reality of failures, their nature and to reduce their effect by adopting suitable repair/replacement strategies. Thilander (1992) studied the benefits of different organizational aspects of TPM in two Swedish firms, and also showed the positive influence on productivity of having well-defined areas of responsibility, of appointing one individual who holds the overall responsibility for the maintenance of the machine line, and of establishing direct contact between the operators and maintenance technicians. Cooke (2000) reported the finding of the study of the production and maintenance function of four processing/manufacturing companies, and highlighted the difficulties that these companies have faced in their attempt to implement TPM initiatives between the production and maintenance departments in order to improve organisational efficiency. Tsang and Chan (2000) presented a case study of TPM implementation in such an environment – a high precision machining factory in mainland China. Bohoris *et al.* (1995), described TPM implementation in Land-Rover-Transmissions (LRT), emphasizing the practical aspects beyond the basic theory and showed the benefits of the computerized maintenance management system developed to assist the successful introduction of TPM in LRT.

There are a few articles as evidence of the success of TPM. Carter (1999) started the implementation of TPM in the US shipbuilding industry and achieved higher levels of quality and timeless and eliminated costly delays in its shipbuilding operations. In 1996, MRC Bearing implemented a TPM program, and ten months later their breakdowns losses fell to less then 30 hours, a decrease of over 540 per cent (Aerospace, 1999). The popularity of trucks like F-series meant that the Ford Windsor Engine Plant needed to produce more engines. An increase of 100,000 engines, announced in April, brought the output for 2,000 to 950,000 units (Vasilash, 1999). One of the central tenets of TPM is autonomous maintenance, hence there is an implied loss of job demarcation. McAdam and McGeough (2000) implemented TPM in a heavily demarcated and unionised organisation and reap the benefits. Ferrari *et al.* (2002) proposed a methodology for a soft introduction of TPM and a real application in ceramic production plant, showed its operative features and its good working. No report of the implementation of TPM has been done in food industry and especially in the bakery industry.

In the food industry, the production process requires the non-stop operation 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. In a recent study of an automated pizza transfer line, Liberopoulos and Tsarouhas (2005) found that the effective input rate of the line was equal to 95.45 percent of its nominal production rate, due to the unavailability of the system during failures. Yet, due to the scrapping of material during long failures, the effective output rate of the line dropped to only 90.43 percent of its nominal production rate. In other words, approximately half of the 10 percent drop in efficiency of the line was due to the gap in production caused by failures, while the other half was due to the gap caused by scrapping of material during long failures. In another study of a croissant transfer line by Liberopoulos and Tsarouhas (2002), the analysis showed that the effect of scrapping was less severe, because the dough used in croissants can remain blocked without having to be scrapped for twice as long as the dough used in pizzas, due to the different types of yeast utilized in the two products.

The aim of this paper is the implementation of TPM in a pizza production line and under certain assumption the generalization of the results in bakery production lines.

To achieve this, we develop a methodology for increasing the production rate, improving product quality and providing a healthier and safer work environment. The methodology is based on analysing the reliability data of an automatic production line. It is divided into four steps, whose aims are to bring forth improved maintenance policies of the mechanical equipment. Moreover, we achieve the continuous and thorough inspection of the production process through measurements of the overall equipment effectiveness (*OEE*).

TPM activity

The activity of TPM is the deduction and elimination of defectives and is characterised by six types of losses, namely (Nakaiima, 1988; Babicz, 2000; Chan *et al.*, 2005; Van der Wal and Lynn, 2002):

(1) *Breakdown losses:* There are two types: firstly, time losses due to equipment failure, when productivity is reduced and secondly, quantity losses, caused by defective products. Eliminating these losses is extremely difficult.

(2) *Set up and adjustment losses:* This refers to time losses from the end of the production of the previous item, cleaning, through product-change adjustment to the point where the production of the new item is completely satisfactory.

(3) *Idling and minor stoppage losses:* Idling and minor stoppage losses occur when production is interrupted by a temporary malfunction or machine is Idling. These problems are often overlooked as removing the offending item rectifies the problem. Zero minor stoppages is the goal.

(4) *Reduced speed losses:* These losses are the difference between design speed and actual operating speed. The reason for the difference in speed could be quality or mechanical problems.

(5) *Quality defects and rework losses:* Quality defects and rework are losses in quality caused by malfunctioning production equipment. Elimination of these defects required repairing defective products to turn them into excellent products.

(6) *Start-up losses:* Start-up losses are losses that occur during the early stages of production. Start-up after periodic repair and start-up after (long-time stoppage) are defined as time losses which are used for calculating the availability of equipment. Start-up after holiday and start-up after lunch breaks are defined as speed losses which measure the performance efficiency of equipment.

The first two are time losses, the next two are speed losses. The last two losses are regarded as quality losses. These losses directly affect the quality rate of the equipment. Maggard and Rhyne (1992) concur with the view expressed by both Nakaiima (1988) and Shirose (1992) but add a factor to be included under the general heading of TPM that is the aspect of safety. They insist that assuring safety and preventing any adverse environmental impacts are important priorities in any TPM effort.

After the losses measurement for determined interval that will cover all the products in the production line, we will be calculate the following indicators, which can be expressed as follows (Nakajima (1989)):

- Availability: *A*.
- Performance efficiency: *PE*.
- Quality rate: *QR*.
- Overall Equipment Effectiveness: *OEE*.

The calculation of *OEE* contributes three major sectors in the production line: production, maintenance and product quality. The attendance of each has been quantified and it has been expressed in the indicators that were reported above.

The indicator *A* is influenced by time losses that decrease the available time of production and is defined as:

$$\text{Availability} = (\text{Loading time} - \text{Downtime})/\text{Loading time} \quad (1)$$

The indicator *PE* is influenced by the number of produced items in a given period of time, and is defined as:

$$\text{Performance efficiency} = (\text{Processed amount} \times \text{Actual cycle time})/\text{Operating time} \quad (2)$$

The indicator *QR* takes into consideration the number of reject products at the production process (scrap) due to quality defects, and is defined as:

$$\text{Quality rate} = (\text{Processed amount} - \text{Defect amount})/\text{Processed amount} \quad (3)$$

The three above indicators contribute to the determination of indicator *OEE* that globally expresses the production line effectiveness, and is defined as:

$$OEE = \text{Availability} \times \text{Productivity efficiency} \times \text{Quality rate} = A \times PE \times QR \quad (4)$$

The quotations of indicators reveal the weaknesses of the system and they will indicate the points that where improvements and changes should occur.

Methodology

In the food industry and more specifically in the production of bakery products, the process of production requires the unhindered operation of mechanical equipment. An attitude in one of the line workstations can be a reason of failure, and beyond the reduction of production, can also involve qualitative problems in the produced products. For this reason we develop a methodology for direct confrontation of the problem, ensuring simultaneous and better safety and health conditions in the workplace.

For reasons of better analysis all the methodology will be separated into four steps, which are as follows:

Step 1: Collection of data, timing and recording

In the production line we must make a detailed recording of the company's maintenance files (if they are recorded), time to failure and time to repair so that a database is created. Together with the mathematic models of Ebeling (1997) and Bain and Engelhardt (1991), we will have the reliability for each machine and each workstation of the production line. In case the data is not available, the process of recording it should begin immediately so that an elementary database is created and the same policy that we described above is applied.

Then all the components that compose the production and maintenance of the system will be recorded from the first to the last machine of the production line.

The above process will be useful to locate the critical points of the line. As “critical” points we consider these points that constitute sources of problems and prevent smooth operation of the line.

Also it will be timing and recording the time losses that are observed in the production process. The following are included in the tasks that must be done:

- determination of operations when the model time will be measured;
- planning of implementation method (choice between instantaneous observations or direct timing);
- implementation of timing; and
- publication of model times per machine or workstation in the production line.

At this point, the following times will be calculated for each machine and each product that is produced in the machine:

- start-up time (beginning of production until stabilisation);
- set-up time (change of product in the production line and adjustments up to the smooth flow of operation); and
- time process of the product.

Also to be recorded:

- the downtime due to failure;
- the speed operation of the machine (real) which will be compared to that given by the manufacturer (nominal);
- the number of products which require rework and the useless products (scrap); and
- lost time from the small stoppages of machines (i.e. blocking pans) that are easily and immediately corrected.

The above are recorded in collaboration with the operators equipment after previously:

- having been drawn the suitable forms in order to have recorded the times and the documents that are required; and
- they have been informed and trained for the terminology that is used and the importance of precision of measurements.

Step 2: Growth of a training program and measurement of overall equipment effectiveness

Personnel’s training is one of the main causes of success in the installation, application and development of the work. The training would be insufficient and substantially inadequate if it does not include work tools and leadership in the new requirements that we will place. These requirements should become comprehensible and consolidate themselves completely, after they constitute daily duty of personnel who are involved. With the combination of equations (1)-(3), we obtain the overall equipment effectiveness *OEE* for the production line. The indicator *OEE* gives us the measurement of equipment performance; taking into account all factors that reduce the capacity utilisation.

Step 3: Methods for minimising time loss

In the production line the manager will be focused on the improvements that are possible to be achieved. In this step the following questions will be answered:

- Is the reduction of time for implementation work, adjustment and cleaning of equipment possible?
- Which ways of maintenance planning for technological equipment are best so that the production and the quality of the products are ensured?
- Which profit is expected by the better exploitation of machines?
- How much easier will quality control be henceforth?

More concretely they will become:

Application of methods for a determinate action plan of balancing times, and reducing of losses reason to the failure of the equipment.

Concession of competences for adjustment and maintenance to the operators that will simultaneously become controllers in the line.

Application of maintenance policies, preventive maintenance, replacement and periodical control in order to increase the reliability of the machines.

Continuous training of operators based on the results of the above actions.

Step 4: Estimation of the personnel's opinion of the results of study – Second estimation of time losses

Then, the quotations of indicators with the opinion of the persons that are involved with the methodology should be compared. That is with the operators of the machines, the foremen, the maintenance technicians, the heads of production of qualitative control and maintenance. In this way we will also have an internal indicator, a self-valuation of work that has been done.

With the experience that we will have acquired after the use of "new" maintenance policy new quotations - objectives will be fixed for the indicators. Then the process of calculating times and recalculating of indicators will be applied again. The interesting thing is that the personnel will be called to reach objectives that they will have placed.

Finally the whole effort will be globally evaluated and we will be gaining important experience on how we will become better and more efficient in the future.

Case study

The methodology is applied in a pizza production line, which is a representative transfer line. Initially the analysis of data of reliability from the files of maintenance occurs for about five years, with the use of statistical program SPSS and the following was realised (Liberopoulos and Tsarouhas (2005)):

- the failures of the machines and workstations of the line follow the Weibull distribution; and
- there is no relation between time to failure (TTF) and time to repair (TTR).

The maintenance policy, which is adopted and applied up to today, so that we increase the Reliability and the Availability of line, is preventive maintenance every two weeks, in combination with predictive maintenance. In the latter certain serious problems that have been observed in the duration of the production process are evaluated and are repaired in the first gap of production or otherwise, if they do not create an immediate problem in the production, they are programmed for the next preventive maintenance. Also corrective maintenance is applied each time when a failure in the production process happens. The combination of maintenance policies mentioned above, lead us to the following conclusions:

- The shape parameter (b) of Weibull distribution has a decreasing failure rate ($b < 1$), so that the system presents very good reliability.
- The longer the time between two failures, the more problems accumulate, and therefore the longer the time it takes to fix the latter failure.
- The more time the technicians spend fixing a failure, the more careful a job they do, and therefore the longer the time until the next failure.

The food industries present the peculiarity (in contrary to other industries) that, because of the nature of product, which is the preparation of bakery products, the production process must evolve smoothly and without interruptions or stoppages due to failure. It has been discovered that if the production stops for up to 30 minutes in a pizza production line, due to failure, then the product that is found in the workstations (kneading, lamination, and oven) should be scraped because of the rise of the dough. As a result, the corresponding circle time is also added to the time of repair from the first workstation of line until the workstation where the failure has happened.

Thus in the relation (1) the downtime is increased considerably, decreasing the Availability of system and at extension the efficiency of the line. The same is valid for the croissant production line where the maximum acceptable standstill time of product is 35 to 45 minutes. For the bread production line the standstill time is from 40 to 50 minutes and for biscuits production line is from 50 to 60 minutes. The production process of bakery products is almost the same for all the products, using the same machines (silo, mixer, lamination machine, oven, wrapping machines, conveyor belts), then we can also consider that the Reliability of line for each product is almost the same. Thus having made an accurate reliability analysis of the data from a pizza production line and changing the maximum acceptable standstill time each time, we receive the following Figure 1. The results presided in Figure 1 are obtained by the thorough statistical analysis of the failure-repair data of an automated pizza production line, covering a period of five years and generalizing for all the bakery products that used the same machinery equipment and have the same production process.

From Figure 1 we can observe the following:

- For an acceptable standstill time longer than 80 minutes, the efficiency of the line should reach the highest value (95.5 percent), without any immediate influence by the product.
- If the product is very sensitive (max acceptable standstill $<$ 25 minutes), we obtain efficiency $<$ 89 percent thus, decreasing the efficiency of the line up to 6.5 units. Therefore, minor (in time) failures provoke an additional production

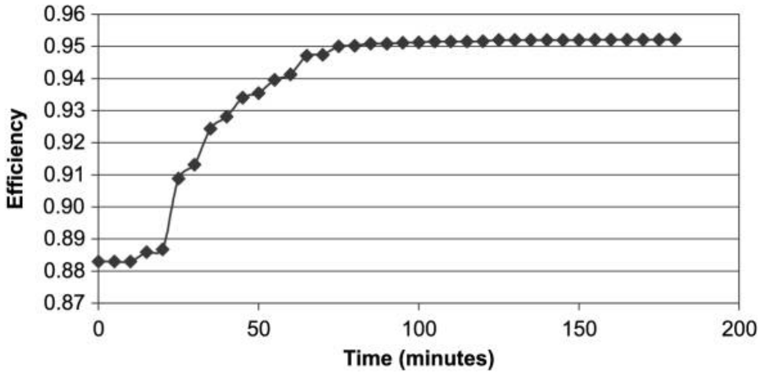

Figure 1.
Efficiency of bakery production line in relation to the maximum acceptable standstill time

gap, because some or all of the in-process material will have to be scrapped due to quality deterioration during the stoppage.

- The critical acceptable standstill time is observed between 20 minutes (88.7 percent) and 25 minutes (90.9 percent), causing the biggest change of the efficiency of line (2.2 units). This is happens because the major failures (67 percent) have 20 minutes of repairing time.

The results for the indicators of a pizza production line per year, and over a period of five years are roughly presented in Table I. The biggest improvement after the application of the methodology present the indicators *PE* and *QR* (increase at 10 units roughly), while indicator *A* can be considered almost immutable. In indicator *A* 20 minutes per shift are debited, as break time for the personnel of production line. Thus we have: 20 minutes $\times$ 3 shifts $=$ 60 minutes per day, which correspond to 4.17 percent of availability of the line. Consequently the real biggest value that the *A* can reach is 95.83 percent (100 percent-4.17 percent). Our aim is that the indicator *OEE* is found between 0.80 percent-0.90 percent, hence our next objective is the further improvement of indicators *A* and *PE*, maintaining constantly *QR* in the level 98 percent.The operations management policies of the pizza production line for the continuous improvement processes are:

- maintenance programs that contain proactive maintenance (preventive and predictive maintenance) and corrective maintenance;
- training programs for managers, technicians, and equipment operators; and
- autonomous maintenance.

Year	*A*	*QR*	*PE*	*OEE*
1	0.8896	0.8741	0.8021	0.6237
2	0.8946	0.8931	0.8439	0.6746
3	0.9109	0.9184	0.9703	0.7280
4	0.9162	0.9326	0.8870	0.7578
5	0.9021	0.9718	0.9077	0.7957

Table I.
The indicators of a pizza production line over a five-year time period

The pizza production line operates in three eight-hour shifts during each workday, and pauses during the weekends. The last shift of the week ends early on Saturday morning, and after that the process of setting up starts, which contains a series of operations from the removal of jigs and fixture with clearing up and cleaning. At the same time proactive maintenance operations on the line occur. The goal of proactive maintenance is to ensure good operating conditions for the line in order to prevent future failures. Proactive maintenance includes preventive and predictive maintenance. Preventive maintenance is performed periodically on weekends and involves a well-defined set of tasks, such as inspection, cleaning, lubrication, adjustment, alignment, etc., at specific points of the line. It is meant to ensure good operating conditions for the line. Predictive maintenance estimates when a piece of equipment is near failure and should therefore be repaired during the regular preventive maintenance operations of the immediately following weekend. This estimation is based on simple visual signs and acoustic emissions usually observed by the equipment operators who are responsible for the proper operation of their equipment. The equipment operators must protect and maintain the equipment used in good operating conditions. Preventive and predictive maintenance is meant to increase the reliability of the pizza production line but cannot fully prevent failures from occurring during production. When a failure occurs, the technicians who are responsible for the proper operation of the line during production perform the necessary corrective maintenance operations to repair the failure.

When the maintenance program is completed and before the first shift of the following week starts late on Sunday evening, the pizza production line for the next production is prepared. The Assembly of jigs, fixture and their components is necessary, and after that adjustment, trial processing, readjustment, measurement and production occurs.

We reduce all the losses mentioned in Section 3 with these actions, having a direct effect on the Availability, Performance Efficiency of the line and on the product quality because they improve the indicators *A, PE*, and *QR*. From Figures 2-5 we can observe how the indicators of a pizza production line affect the system's performance separately.

Firstly, let us see how the Equipment Availability and Performance efficiency affect the system's performance. As Availability and Performance increase in the first three years the *OEE* increases proportionally, whereas as Availability and Performance

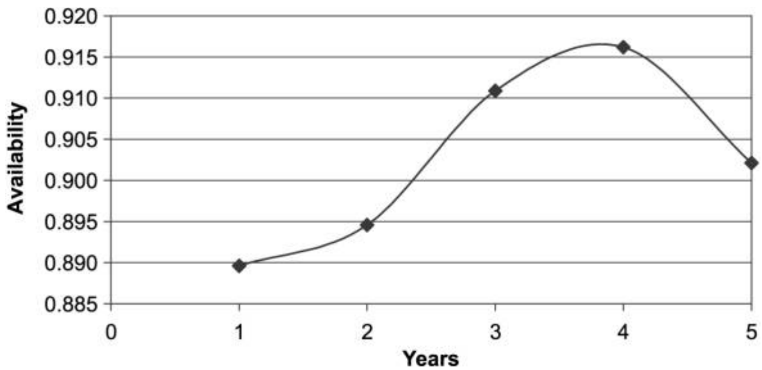

Figure 2.
Equipment availability of a pizza production line vr. years

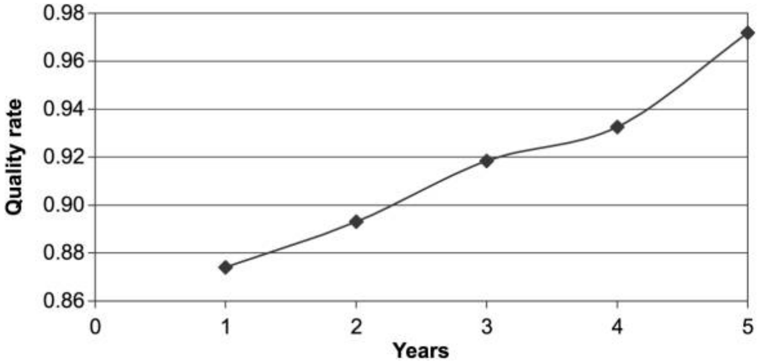

Figure 3.
Quality rate of a pizza production line vr. years

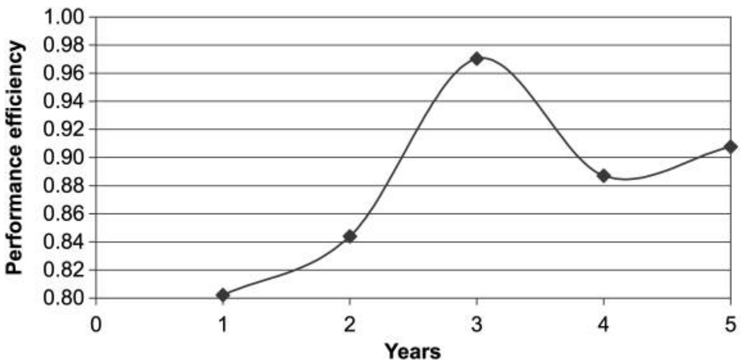

Figure 4.
Performance efficiency of a pizza production line vr. years

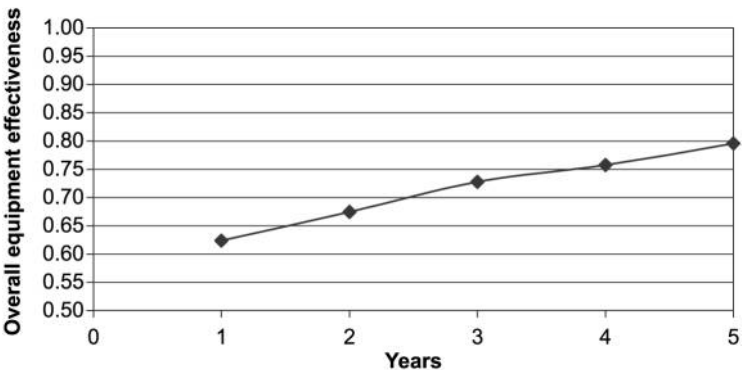

Figure 5.
Overall equipment effectiveness of a pizza production line vr. years

decrease in the last two years the *OEE* increases none proportionally (Figure 5). On the other hand, the Quality rate maintains a constant increasing rate (Figure 3).

Conclusions

In this paper we implemented a TPM program in a pizza production line for a period of five years. The developed methodology has an aim to bring, concerning the creation of competitive advantages, exploitation increase of mechanical equipment of a company. This can be analyzed in:

- Increase of productivity, via the reduction of downtime of the equipment.
- Product quality improvement, via the increase of indicator *QR*.
- Improvement for a healthier and safer work environment, via the increase of attendance of operators in adjustment and maintenance of the equipment.
- Reduction of the cost production via measurement of times and improvement of losses.
- A complete image of the performance between "machine - operator " will be given, via the recording of time losses and their qualitative expression via the indicators.
- Weak points will be revealed and priorities in the application of corrective actions will be given.
- Economy in natural resources and energy, via the reduction of downtimes, the total process time as well as the application of coordinated maintenance.
- Reduction of delayed deliveries, because of the better knowledge of production capacity.

The competitive advantages are also extended beyond immediate visibility. Something very important is that the company acquires the possibility of self-valuation via the possibility of process control in production and maintenance. The following are still achieved:

- Improvement of ability of operators, because of the concession of competences but also the undertaking of responsibilities.
- Standardisation of production processes via records and adaptation taking into consideration the existing international models in which it should be arranged.
- Alternative solutions in altered demands via the change of product mix in the lines, and the times improvement for start up or set up.

A promising direction for future research following this work would be to extend the analysis in this line for more time. Also, there would be an implementation TPM program to the other bakery production lines (e.g. croissant, biscuits, cakes, etc.) and confront the results.

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