Overall equipment effectiveness (OEE) evaluation for an automated ice cream production line

A case study

Panagiotis H. Tsarouhas
Department of Supply Chain Management and Logistics, Technological Educational Institute of Central Macedonia, Katerini, Greece

Received 17 March 2019
Revised 18 June 2019
10 August 2019
Accepted 10 September 2019

Abstract

Purpose – As overall equipment effectiveness (OEE) is a metric to estimate equipment effectiveness of production systems, the purpose of this paper is to identify strategic management tools and techniques based on OEE assessment of the ice cream production line.

Design/methodology/approach – This paper presents the collection and the analysis of data for ice cream production under real working conditions. The data cover a period of eight months. A framework process to improve the OEE of an automated production system was proposed. Six major stoppage losses, i.e. equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in the process, and reduced yield, were examined with the help of Pareto analysis. In addition, the actual availability (*A*), performance efficiency (*PE*) and quality rate (*QR*) measures, together with the complete OEE for each working day, week and month of the production line were shown.

Findings – The main goal of the study is to identify major stoppage losses, in order to examine and improve the overall equipment efficiency (OEE) of the ice cream production line through the application of an adequate management, i.e. TPM approach. Based on the obtained results, maintenance management strategy and production planning have been suggested to improve their maintenance procedures and the productivity as well.

Originality/value – The proposed method can be applied to each automated production system. The main benefits of this method are the improvement of productivity, quality enhancement of products, the reduction of sudden breakdowns and the cost of maintenance. Moreover, the analysis provides a useful perspective and helps managers/engineers make better decisions on the operations management of the line, and suggestions for improvement were proposed and will be implemented accordingly.

Keywords Continuous improvement, Manufacturing performance, Overall equipment effectiveness, Ice cream production, Productive maintenance

Paper type Case study

1. Introduction

The management philosophy of lean production has been derived from a wide range of factors such as the constant changes in the global market, the growing competition, the recent financial and economical crisis, the different needs of the consumers, the need for flexibility in production connected to qualified workforce and the possibilities to support further research and innovative products. For every manufacturing company, the objective is to produce goods at a profit, and this can only be achieved using an effective maintenance system that helps maximize the availability of equipment by minimizing machine downtime due to unwanted stoppage (Fore and Zuze, 2010; Muthiah *et al.*, 2008). The overall equipment effectiveness (OEE) is a strong indicator that illustrates the total effective equipment performance compared to the maximum potential yield, which identifies bottlenecks in the production process and sets new targets for improvement. Improving the efficiency of automated flow line manufacturing systems is the core objective of all companies as measured by the OEE index (Zennaro *et al.*, 2018). TPM is an effective tool for the minimization of downtime of machines, production losses

The author wishes to acknowledge financial support provided by the Research Committee of the Technological Education Institute of Central Macedonia Greece, under Grant No. SMF/LG/101018-220/09.

International Journal of Productivity and Performance Management
Vol. 69 No. 5, 2020
pp. 1009-1032

1741-0401
DOI 10.1108/IJPPM-03-2019-0126

and material scraps and to improve the working efficiency and productivity of employees and equipment (Jain *et al.*, 2014). OEE is the traditional evaluation index of total productive maintenance (TPM) and its optimization is the core objective of all industries. It compares the operational performance to the ideal or potential performance of the plant (Lanza *et al.*, 2013). Thus, the OEE is the key measure of both TPM and lean maintenance (Anvari *et al.*, 2010).

The food industry is nowadays characterized by automated flow line manufacturing systems. This means that there are several machines working in sequence, connected through various transport systems. Automation, in general, has the core aims of reducing human participation in production systems, introducing machines for doing repetitive and/or complex actions and transforming production to make it as continuous as possible (Zennaro *et al.*, 2018). Ice cream is a frozen food made from dairy products, sugars, flavorings and minor amounts of optional ingredients used to improve texture, enhance shipping and aging characteristics and make manufacturing more efficient. Any failure on the production line may lead to high costs in material and human terms and losses to performance and quality as well. In the context of TPM and total quality management (TQM) the OEE implementation, its constant monitoring and measuring evaluation contribute to helping the company build a future strategy in a sustainable and competitive way, aiming at quality and potential areas of improvement.

This paper presents the collection and the analysis of data for an automated ice cream production line under real working conditions that is representative in this section. OEE of the line that will provide a useful guide to aspects of the production process was computed. Moreover, six major stoppage losses, i.e. equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in the process, and reduced yield, were evaluated with Pareto analysis. The identification of the critical points of the line that requires further improvement through effective maintenance strategy (i.e. TPM) was provided. The proposed method can be applied to each automated production system in order to improve the reliability, the quality as well as the efficiency of the system. The analysis provides a useful perspective and helps managers/engineers make better decisions on the operations management of the line, and suggestions for improvement were proposed and will be implemented accordingly.

OEE studies are prevalent in various production sectors (i.e. aerospace, automotive, paper, etc.) but applying it to an ice cream plant is unique. In addition, a framework method is displayed to enhance the OEE that is related to the reliability and maintainability of the plant. This will help to use the research on each manufacturing plant such as oil and gas, shipyard, etc., to determine the appropriate operations management of the line, and to plan and organize the adequate maintenance strategy.

The rest of the paper is organized as follows: Section 2 deals with the literature review of the OEE. Section 3 gives the methodology undertaken in this research. Section 4 displays the case study with the description of the ice cream production line. In Section 5, the field failure data & the operations management for the production line is presented. In Section 6, the current maintenance management of the line is described. Section 7 computes the OEE for the ice cream production line, and finally Section 8 concludes the paper with discussion of the findings.

2. Literature review

OEE is used to determine how efficiently a machine or a system is running. It can be considered to combine the operation, maintenance and management of manufacturing equipment and resources (Rajput and Jayaswal, 2012). It is one of the most effective measures for driving plant improvement, which focuses on the concept of zero stoppage losses and zero wastage within the plant (Ljungberg, 1998). OEE is a powerful tool for identifying and eliminating losses, thereby developing an efficient production system for achieving world-class manufacturing (Hemanand *et al.*, 2012; Gupta *et al.*, 2015). The stoppage losses can be divided into six major categories, which affect the overall performance of the equipment. These losses include breakdown losses; setup and adjustment losses; idling and minor stoppage losses; speed losses; rework and quality defect losses; and yield losses (Parikh and Mahamuni, 2015). OEE is measured based on the six large losses, considering machine availability, performance and quality rates (Ahire and Relkar, 2012). Reduction of whole life cost of equipment and six major losses and increase of OEE are the objectives of TPM. Achieving a reliable manufacturing system is the key objective of TPM. It can be executed by maximizing the OEE (Konecny and Thun, 2011). Therefore, key performance indicators (KPIs) such as OEE, are essential for the management, control and measurement of performance in different areas such as manufacturing, maintenance, planning and scheduling, product quality and inventory among others (Teoh *et al.*, 2017).

OEE is an effective way of analyzing the efficiency of a single machine and also an integrated machinery system (Ljungberg, 1998). It is one of the most important performance measures in modern industries. OEE is a valuable tool that can help management to unleash hidden capacity and therefore reduce overtime expenditure and allow the deferral of major capital investment (Muchiri and Pintelon, 2008). In order to eliminate the negative effects of breakdown/waste on a production system, the optimization of OEE on the existing facility is usually more cost-effective over other techniques, i.e. purchasing new equipment, increasing overtime, adding a new shift, outsourcing production, investing in a new facility, etc. The improvement of OEE has the effect on increasing the production capacity, improving the quality of products, reducing downtimes, and increasing the efficiency of the system. That is, utilizing the existing equipment by improving it with the adequate operations management. In addition, OEE is the core metric for measuring the success of TPM implementation programmes (Jeong and Phillips, 2001). Thus, the continuous improvement in OEE is the main purpose of TPM.

The OEE was improved with low machine breakdown, less idling and minor stop time, less quality defects, reduced accidents in plants, an increased productivity rate, optimized process parameters, worker involvement, improved profits through cost saving methods, increased customer satisfaction and increased sales as well as improved employee morale and confidence (Kumar *et al.*, 2014; Nallusamy, 2016a). Availability, performance and quality rate (*QR*) are the three major parameters which play a critical role in calculating OEE (Sivakumar and Saravanan, 2011). It does not identify a specific reason why the machine is not as efficient as it should be, but it assists in categorizing areas in order to identify those that are in need of equipment improvement most (Eswaramurthi and Mohanram, 2013). Recently, Saleem *et al.* (2017) formulated a benchmark to increase the tyre curing press production rate while minimizing tyre curing press downtime and maintenance cost with the help of a maintenance management technique based on OEE. Fam *et al.* (2018) studied the relationship between lean manufacturing methods and Overall equipment efficiency (OEE) in paper manufacturing and paper product industry using the one-year data. Singh, Clements and Sonwaney (2018) presented measurement of OEE which serves a basis for analyzing operational efficiency in a manufacturing unit, and explains what metrics make up this OEE and the losses that are classified under each of the metrics. Baghbani *et al.* (2019) identified the relationship between risk priority number (RPN) parameters in the fuzzy process failure mode and effect analysis (PFMEA) and OEE in the production process. In another study, Tsarouhas (2013a) investigated the relationship between the factory management and the operation of the mozzarella production line through the OEE. Other publications argue that OEE figures are usually 15–25 percent below the targeted level, thus constituting one of the largest problems in industry today (Parida *et al.*, 2014). OEE and process capability are commonly used and well-accepted measures of industry performance (Garza-Reyes *et al.*, 2010). Sharma (2019) highlighted the OEE measurement in flexible manufacturing systems of a selected automobile manufacturing plant through enhancing the equipment and plant reliability by eliminating all the losses incurred. In this study, an approach is developed to identify and address the losses and failures which are responsible for lowering the OEE. Puvanasvaran *et al.* (2013) improved the OEE metric of the autoclave process through the implementation of time studies in an Aerospace industry. They concluded that there is a 4.64 percent of increment for the availability ratio.

Commitment and understanding from the company should exist for the OEE practice in order to be transmitted in all employees and make them a fundamental part of their work. As OEE is a continuous process that requires constant improvement in all the related procedures and controls established by management, i.e. six big losses. Then, by taking the necessary action to reduce these losses, the OEE will be improved immediately. Furthermore, it is essential to monitor and measure the performance of the system. Therefore, the company must have the appropriate equipment to support it. A survey conducted by Bamber *et al.* (2003) reports that OEE is often used as a means of improving the output of a company since it focuses on quality, productivity and use of the equipment at the same time. As a performance measurement tool OEE helps to manage long-term effectiveness of equipment by restoring it to as good as new conditions, thereby increasing its performability and reducing production losses (Sohal *et al.*, 2010). It captures day-to-day fluctuations with an aim to reduce equipment downtime and improve plant maintenance tasks (Zammori, 2014). Tang (2019) discussed the throughput losses from the three factors of OEE, explored the hidden information in OEE and proposed a new method based on OEE to identify the bottlenecks of complex manufacturing systems. OEE of a machine plays a significant role in the present scenario, where correct quality and correct delivery at the right time are the major factors influencing a customer (Nallusamy, 2016b). OEE is a powerful tool for identifying hidden manufacturing losses and inefficiencies (Kumar *et al.*, 2012). Soltanali *et al.* (2018) studied the performance measurement through OEE theory from two different assembly lines such as Peugeot and Sports Utility Vehicle (SUV) in an Iranian automotive industry. Esmaeel *et al.* (2018) aimed to assess the relationship between fit manufacturing (lean manufacturing, agile manufacturing and sustainability) and business performance through the mediation of OEE. In another study, Phogat and Gupta (2017) identified the main problems in maintenance operations and compared these problems with those in manufacturing operations as found in the literature for effective maintenance. They concluded that lack of top management support, lack of measurement of OEE, lack of strategic planning and implementation and many more problems are the biggest problems in maintenance operations, as well as manufacturing operations. In another study, Oliveira *et al.* (2019) presented a metric, global process effectiveness (GPE), based on OEE, which assesses effectiveness based on OEE factors and the schedule-adherence of a process to a pre-defined production plan, regarding product variety and quantity.

The OEE is used as a method to measure or/and to handle uncertainty when the production is interrupted due to failures, temporary malfunction, set-ups, minor stoppages, idling, speed losses, quality defects, etc. Dal *et al.* (2000) report that the use of OEE, not only as an operational measure but also as an indicator of process improvement activities, remark that OEE provides an excellent perspective on production improvement but should be balanced by other, more traditional operational measures, thereby retaining an overall perspective of the manufacturing environment. It should be noted that OEE is best suited for environments of high-volume process-based manufacturing where capacity utilization is of a high priority and stoppages or disruptions are expensive in terms of lost capacity (De Ron and Rooda, 2005). My Abdelbar *et al.* (2019) propose a new indicator of the OEE relying on the process approach in maintenance. This new indicator can be used to support maintenance managers to have a three-dimensional analysis based on time, financial and quality criteria, also to improve time, cost and quality of each activity of the maintenance operational processes. OEE is an approach that qualifies the effectiveness and efficiency of operation performance during its work time (Zuashkiani *et al.*, 2011).

On the other hand, the TPM can be defined as strategy-based care teams designed to maximize equipment effectiveness by developing production systems' comprehensive maintenance that covers the entire life of the equipment, which includes all equipment related fields (planning, use and maintenance) and involves everyone in the organization

(Sharma *et al.*, 2006). The objective of TPM is to improve the OEE of plant machines, which is considered the broadest set of performance measures to analyze the efficiency of a single manufacturing machine or an integrated system (Ferko and Znidarsic, 2007). Singh and Ahuja (2017) studied the TPM implementation in a food processing industry. This study reveals the exploits of Indian entrepreneurs with TPM practices and highlights the contributions of TPM in realising the overall goals and objectives of the organization. Wakjira and Singh (2012) have concluded that TPM implementation in any organization enhances the OEE by increasing equipment availability, decreasing rework, rejections and also enhancing the overall productivity of an industry. OEE has increased by 4 percent even after a small implementation of TPM in a company. It should also be noted that the changes in the maintenance policy of the company improved their performance and quality (Boban and Jenson, 2013). Heng *et al.* (2019) studied the critical factors and potential pitfalls when trying to automatically estimate the OEE of a manufacturing system, considering uncertainty. Two methods based on fuzzy arithmetic and interval arithmetic, respectively, are proposed to manage the uncertainty in estimating the production speed, the stoppage duration, and the quality losses. Gupta and Vardhan (2016) investigated how increase in sales volume has evolved by improving the OEE of machines, plant productivity and production cost through TPM initiatives in a reputed tractors manufacturing industry in India. Tsarouhas (2015) computed the OEE as a metric for evaluating the progress of TPM of a yogurt production line in a medium-sized Italian company. Singh, Singh and Sharma (2018) implemented a new concept of mobile maintenance in manufacturing industry of Northern India. This study tries to introduce the new concept of TPM program in the case company. The approach is to study the role of mobile maintenance in the context of Indian industry through significant improvement in OEE.

The main objective of the OEE is to reduce complex manufacturing problems in an easy way, aiding to improve the procedure with systematic measurements that are simple to obtain. Throughout this process, the human factor plays an essential and important role as it is present at every phase of the production procedure. The operator/worker contributes knowledge, attitudes, technical skills, human and conceptual skills, physical effort and management in the production process (Null *et al.*, 2012). OEE embraces empowerment to production operators establishing a sense of ownership in their daily operating equipment (Tsang and Chan, 2000). TPM focuses on maximizing the OEE with involvement of everyone in the company (Seng *et al.*, 2005). Ihueze and U-Dominic (2017) deployed TPM strategies to improve the production performance of a manufacturing facility. The OEE quantitative metric has been followed here to solve the underlying problem of reducing the frequency of machine failures and improving its operational efficiency. Moreover, TPM accomplished the maximization of equipment effectiveness through total employee participation and incorporated the use of autonomous maintenance in the small group activities to improve on the equipment reliability, maintainability and productivity (Chen, 1997). Training and educational issues had become one of the critical factors to establish successful TPM implementation, where proper education begins as early as during the TPM introduction and initial preparation stages (Blanchard, 1997). Calais *et al.* (2017) demonstrated the contribution of the maintenance activity for the improvement of the performance of companies especially for the water treatment companies, a case study of a Portuguese company belonging to the water treatment sector is performed. The ultimate goal of education and training for maintenance personnel and operators should be the development of capable human resources that can maintain equipment and control it with strict attention to detail, and can cope with changing work conditions, with new products and/ or new machines (Yamashina, 1995).

TPM is a stepwise strategy that combines the best features of productive and preventive maintenance with total employee engagement to maximize OEE (Tsarouhas, 2013b). Ramlan *et al.* (2015) mentioned that OEE measurement is inspired by the TPM and used as a key machine performance tool which measures availability, performance and quality rate. As an aggressive maintenance strategy, the TPM approach is used to improve equipment performance by avoiding equipment failure (Swanson, 2001). Ribeiro *et al.* (2019) focused on the use of the TPM methodology combined with a few lean thinking tools in order to optimize the availability of a critical production line in a company which produces mechanical components and gearboxes for the automotive industry. To measure the success of the implemented actions and to compare the final results with the initial situation, a few indicators were used: OEE, mean time between failures (MTBF) and mean time to repair (MTTR). In another study, Krachangchan and Thawesaengskulthai (2018) reduced loss time in the tobacco industry and improved performance rate as well as enhancing the OEE through the implementation of TPM and RCM (reliability centered maintenance) by using failure modes and effects analysis (FMEA). Ahmad *et al.* (2018) identified the major stoppage losses through the application of TPM approach, in order to examine and improve the OEE of the ring frame of a textile spinning factory in Bangladesh. Due to the increased competition and demand for quality products at lower prices, buying the latest equipment is not a solution unless it is fully utilized. For these reasons, TPM has become one of the most popular maintenance strategies for ensuring high machine reliability and it is regarded as an integral part of lean manufacturing (Rahman *et al.*, 2014). Training programs also enhance the skills and technical capabilities of the production and maintenance staff (Lazim *et al.*, 2013). TPM improves equipment operating conditions, enables the achievement of time at the highest possible machine effectiveness, and sustains equipment at an optimal level of performance and reliability (Agustiady and Cudney, 2018).

3. Methodology

3.1 Theoretical background of overall equipment effectiveness model

According to Nakajima (1988), OEE measurement is an effective way of analyzing the efficiency of a single machine or an integrated manufacturing system. The OEE is accepted as a measurement of internal efficiency (Jonsson and Lesshammar, 1999) and it is the true measure of the value-added production by equipment (Chowdhury and Mandal, 1995). It is used to identify the related losses of the equipment, with the purpose of improving total asset performance and reliability (Muchiri and Pintelon, 2008). The losses that reduce the effectiveness of the equipment could be classified into six major categories as below:

(1) equipment failure losses, contained failures modes that stop the normal operation of the equipment and reduce its production rate;

(2) setup and adjustment losses, that is, time losses which occur when production of one item ends and the equipment is adjusted to meet the requirements of another item;

(3) losses of minor stoppage and idle, these occur when the production is interrupted by a temporary malfunction or when a machine is idling;

(4) losses of reducing speed, because of the drop in speed from the nominal speed of the equipment;

(5) losses of defect (or rework) in process; and

(6) reduced performance, losses of materials because of differences in the weight of input and output.

The OEE is a function of a number of mutually exclusive characteristics, such as availability (*A*), performance efficiency (*PE*) and *QR*. It is a three-part analysis tool for equipment performance based on its availability, performance and quality rate.

Thus, the OEE can be calculated:

$$\text{OEE} = \text{Availability} \times \text{Performance efficiency} \times \text{Quality rate} = A \times PE \times QR. \quad (1)$$

The first two losses are defined as time losses that are used for calculating the availability, *A*, of an equipment. The third and fourth losses are speed losses that measure the *PE*, of equipment. The last two losses are regarded as quality losses; these losses directly affect the quality rate, *QR*.

Availability, *A*, can be expressed as the ratio of actual operating time to loading time. Thus:

$$A = \text{Operating time}/\text{Loading time} = \text{Loading time}-\text{Downtime}/\text{Loading time}, \quad (2)$$

where loading time is the planned time available per time period (day, week or month) for production operations, and operating time is calculated from loading time minus the downtime. Downtime is the total time that the system is not operating because of equipment failures, setup/adjustment requirements, exchange of dyes and other fixtures, etc. Availability can be expressed as the ratio of actual operating time to loading time.

The performance efficiency, *PE*, can be estimated from:

$$\begin{aligned} PE &= \text{Net operating time}/\text{Operating time} \\ &= \text{Cycle time} \times \text{Processed amount}/\text{Operating time}, \end{aligned} \quad (3)$$

where net operating time is the time during which equipment produces at the standard production rate. To calculate net operating time, subtract performance time losses from the operating time. Performance time losses consist of normal production losses (production rate reduction due to start-up, shutdown, and changeover) and abnormal production losses (production rate reductions due to abnormalities). Net operating time is the processed amount multiplied by the actual cycle time.

The quality rate, *QR*, is defined as:

$$QR = \text{Processed amount–Defect amount}/\text{Processed amount}, \quad (4)$$

where processed amount refers to the number of items processed per time period (day, week or month). The defect amount represents the number of items rejected due to quality defects that require rework or become scrapped. The firms, under ideal conditions, should have availability $A > 0.90$, $PE > 0.95$, and rate of quality $Q > 0.99$. These would result an overall OEE > 0.85 benchmark, which is considered as world-class performance (Zuashkiani *et al.*, 2011; Jonsson and Lesshammar, 1999).

3.2 OEE framework

The aim of this case study is to compute OEE in an ice cream production line in order to evaluate the current operations management. The data collection was undertaken over eight months and concerns the documentation of system report in every shift. A framework process to improve the OEE of an automated production system was proposed (see Figure 1).

It is the first time that a framework process to improve the OEE of an automated production system is shown. The contribution of this consisted of the calculation of maintenance time ratio, α, which is related to reliability and maintainability of the line. The meanTBF and meanTTR are the KPIs in maintenance management of the production system. Thus, by tracking these indicators one can maximize uptime and minimize downtime of the system. As they are affected by the maintenance management one can evaluate the current policy and, if necessary, take the adequate action in order to improve it. Therefore, both the availability (*A*) and *PE* measures of the system can be optimized. In addition to direct results, we also have the indirect, i.e. the improvement of the *QR*, as well as the OEE metric. The implementation of the OEE approach ensures that the improvement is on a continuous scale

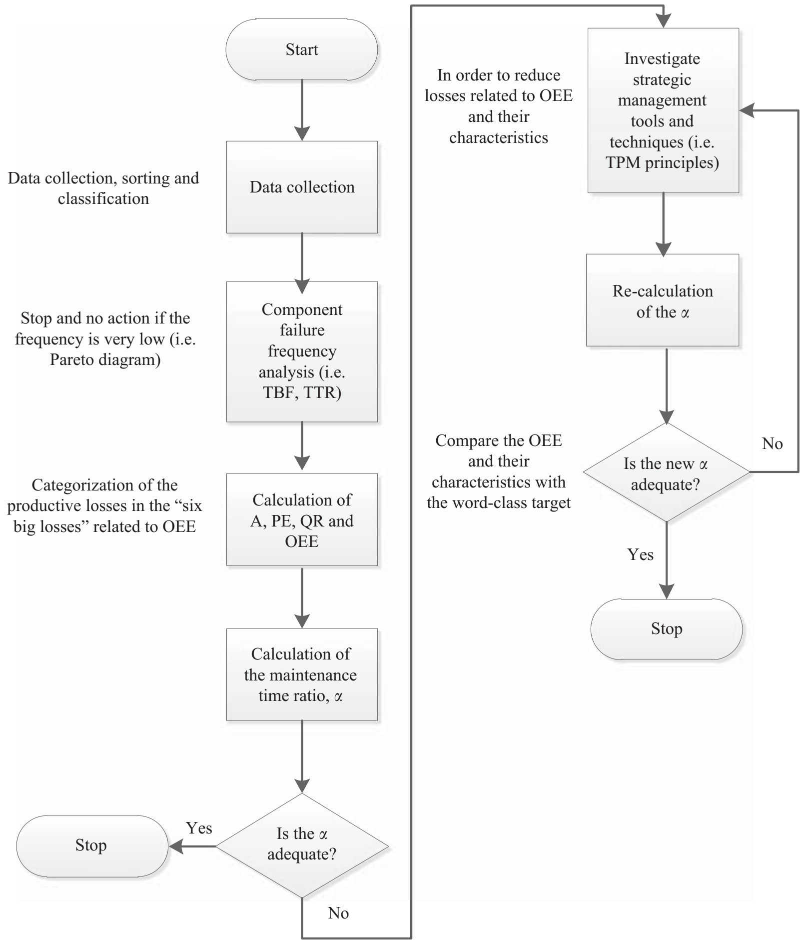


Figure 1.
The framework process to improve the OEE of an automated production system

based on plan, do, check and act (P–D–C–A) cycle. The main benefits of this method are the melioration of productivity, quality enhancement of products and the reduction of sudden breakdowns by avoiding the cost of the downtimes.

The main steps of the methodology are as follows (Tsarouhas, 2019).

The first step is the collection of data that provide information about the design and use of the respective performance measurement systems during the production process, i.e. downtime losses, planned downtime (planned maintenance, cleaning, R&D trial, etc.), changeover, number of defects, etc. The next step after collection, sorting and classification of the data is the calculation of OEE characteristics, i.e. *A*, *PE*, *QR,* as well as the OEE. Through this data it should be possible to identify the major loss by inspecting each of six category losses related to OEE separately. Then, the calculation of maintenance time ratio, *α*, which is related to reliability and maintainability of the line, is needed. It is also necessary to investigate strategic management tools and techniques to reduce losses that relate to OEE characteristics as well as the performance of the production line. After the application of widespread operation management, re-calculation of the *a*, OEE with their characteristics of the line is essential to measure its efficiency and productivity.

The novelty of this paper is a methodology to improve the OEE of an automated production system, based on the calculation of maintenance time ratio (α) that is related to reliability and maintainability of the line. It evaluates the system's current operations management and investigates strategic management tools and techniques to reduce losses that relate to OEE characteristics (*A*, *PE* and *QR*) as well as the performance of the production line. Moreover, the analysis helps to comprehend the importance of underlying the six big losses that are related to these characteristics. The benefit of the methodology is the uninterrupted observation of the production procedure through indicators and its utilizations which bring about a continuous improvement cycle within the principles of TQM. The proposed methodology was applied in an automated ice cream production line under real working conditions. The proposed method can also be applied to each automated production system, in order to improve productivity, quality enhancement of products, the reduction of sudden breakdowns and the cost of maintenance.

The objectives of this case study are:

(1) Calculate and investigate the degree of performance and quality of the ice cream production line by measuring the OEE of the line with the application of the OEE tool.

(2) Examine the factors that make up the OEE and who is/are responsible for the low performance on the production line.

(3) Identify the machines that have low maintenance time ratio, α.

(4) To draw useful conclusions that will direct the company to look for the causes of losses, to decide on priorities, corrective actions and to set new improvement targets.

4. Production process

The company is one of largest manufacturers of dairy products in Europe, making ice cream on 11 specialized processing lines. All lines are similar, but for the sake of preciseness in our presentation, we focus on a particular line, which is representative of those used in the sector. The ice cream production line in study consists of several machines in series integrated into one system by a common transfer mechanism and a common control system. The movement of material between stations is performed automatically by mechanical means. There are six machines in making ice cream: pasteurization and homogenization, aging, freezing, freezer tunnel, and packaging. Each machine is located on a separate section of the processing line (Figure 2). The process flow of the line is as follows (Mohan *et al.*, 2014).

The milk arrives at the ice cream plant in refrigerated tanker trucks from local dairy farms. The milk is then pumped into storage silos that are kept at 2°C. Pipes bring the milk in pre-measured amounts to stainless steel blenders. Premeasured amounts of eggs, sugar and additives are blended with the milk for 6 to 8 min. The ice cream mix is homogenized (2,500 to 3,000 psi) to decrease the milk fat globule size to form a better emulsion and to contribute to a smoother, creamier ice cream. Homogenization also ensures that the emulsifiers and stabilizers are well blended and evenly distributed in the ice cream mix before it is frozen (M1). Then, the ice cream mix is pasteurized at 79.4°C for 25 sec. The conditions used to pasteurize the ice cream mix are greater than those used for fluid milk because of increased viscosity of the higher fat, solids, and sweetener content, and the addition of egg yolks in custard products.

In the next step, the ice cream mix is aged at 2–4°C for at least 4 h or overnight. Aging the mix cools it down before freezing, allowing the milk fat to partially crystallize and giving the protein stabilizers time to hydrate. This improves the whipping properties of the mix (M2). Aging improves the quality of the final product. Liquid flavors and colors may be added to the mix before freezing. Only ingredients that are liquid can be added before freezing, to make sure the mix flows properly through the freezing equipment. Once the product has been pasteurized and cooled, it is placed into a chilled tank for fast cooling (M3). At this stage, the

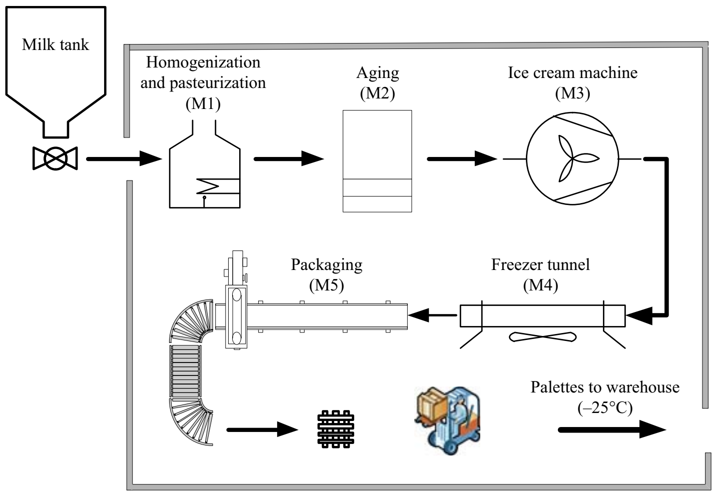


Figure 2.
Schematic presentation of the ice cream production line

semi-finished product is deposited into the ice cream machine where the mixture is at –5°C under intense stirring. The process involves freezing the mixture and incorporating air, in order to achieve the lightness or deneseness and increase the volume from 80 to 120 percent of ice cream. At this point, fruit and any bulky type of flavorings (nuts, cookie pieces, candy pieces, etc.) are added.

In the output of the freezing machine, the semi-finished product is fed into a special extruder to get its final shape (stick figure), whereby the gripper is automatically inserted onto the dosing device with a special mechanism. The extruder system is part of the cooling tunnel and is located at the entrance of the tunnel. After the ice cream has been shaped and taken in its final form, it is placed on a convector belt and travels through the cooling tunnel for the final curing phase (M4). The ice cream temperature at the entrance of this machine is –5°C and at the outlet is –12°C, while the tunnel space temperature is –40°C. Then, the products are fed into the horizontal packaging machines (M5). The final products are put into the cartons. The cartons move along the conveyer belt where they pass under the X-Ray foreign body detector and an ink jet that spray-paints an expiration date and production code onto each carton. The products are generally moved into long-term storage. The temperature in storage is basically held near −25°C,with the ability to keep the product for up to nine months.

The final sixth machine (M6) is theoretical and concerns the supply of electrical power, water and natural gas. The production line is supported by a number of auxiliary systems producing auxiliary means such as steam, cooling water, hot water, compressed air for moving parts, etc. These auxiliary systems are: the boiler room (for steam generation in the heat exchangers in the heating stages), the chiller plant (water cooling unit as a refrigerant in the cooling chillers – refrigeration complex of ammonia as a refrigerant in the refrigeration exchangers incorporated in the ice cream machines), airstrip (compressed air production to drive mechanical parts of engines, i.e. air pistons to activate automatic air valves), and the hydrostation (assembly of tanks, pumps and networks for the management of drinking water and auxiliary water use of the plant, i.e. for washing the equipment, etc.).

5. Field failure data and operation management

Data collection and recording is a project that we developed in collaboration with the company. During this project we had the continuous support of the technical department, production managers and the operators. The ice cream stick production line runs in one or two consecutive daily shifts depending on the production plan. The production period begins in January and ends in line with demand for the product at the end of August. During the rest period from September to December, the line is under preventive maintenance. Once the production line has started, it does not stop producing at all. If the line starts, it must continue to produce without pause until the scheduled production date. This is because considerable time and product waste are required after each stop to properly calibrate the cooling and swelling of the cream on the ice cream machine (M3). Scheduled interruptions by the management for scheduled maintenance, engine lubrication and cleaning, breaks, training, meetings, inspections, R&D testing, etc., are not included in the total shift time, because they take place outside the scheduled time of production. Meal breaks are done by staff turnover and continuous line operations. The data were collected from the records of the company's maintenance department and the production supervisors during each shift for the line. The data covered an entire period of eight months where the line operated for 199 working days. During this time, 468 failures were observed and the duration of the failures were recorded in a database. In addition, they were recorded per shift: the total time of the shifts, total vacation time for adjustments/setups, equipment's failure times, the line's net operating time, the quantity of acceptable products and the quantity of defective products. The total time-between-failure (TBF) and the total time-to-repair (TTR) for all machines of the ice cream production line are illustrated in Table I. TBF of equipment is defined as the time that elapses from the moment the equipment is turned on and starts operating after a failure until the moment it goes down again and stops operation due to a new failure. TTR of failed equipment is defined as the time that elapses from the moment the equipment goes down and stops until the moment it goes up and starts operating again. Both the TBF and TTR are recorded in minutes.

In Table II, the experimental data for the ice cream production line were summarized. The total time for changeovers of products (i.e. setup and adjustment of the equipment) is considered as scheduled interruption. On the other hand, unscheduled interruptions (i.e. downtime losses caused by unexpected breakdowns) are the time to repair the failures, meaning the total time to repair or 11,757 min. The following conclusions can be reached: the line produces for 89.48 percent of the time (150,753/168,480), while the remaining 10.52 percent of the time (17,727/168,480) was engaged for scheduled and unscheduled interruption. The scheduled interruption in the production line account for 3.54 percent (5,970/168,480) of the total experimental time, and the unscheduled interruption of the line, that are repair times, equals to 6.97 percent (11,757/168,480) of total experimental time.

The total TTR at machine level was evaluated by means of a Pareto diagram (see Figure 3). It is noted that: the most total TTR is observed at the pasteurization and homogenization

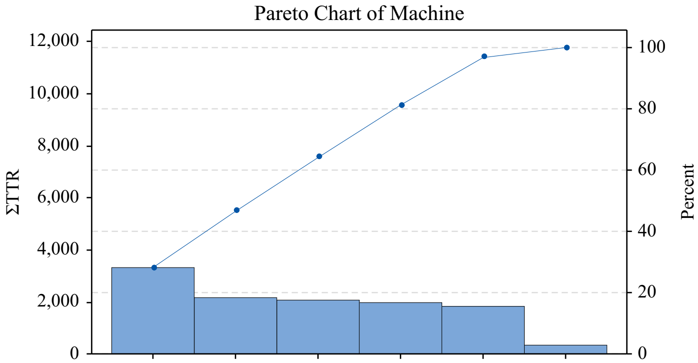
Table I. The total TBF and the total TTR at machine level for the ice cream production line

	M1	M2	M3	M4	M5	M6	Line
ΣTBF	165,159	166,506	166,292	166,416	166,627	168,123	156,723
ΣTTR	3,321	1,974	2,188	2,064	1,853	357	11,757

Table II. The experimental data for the ice cream production line

Total time	Minutes
Experiment	168,480
ΣTBF	156,723
ΣTTR	11,757
Setup and adjustment	5,970

Notes: ΣTBF: sum time-between-failure; ΣTTR: sum time-to-repair



Machine	M1	M3	M4	M2	M5	M6
ΣTTR	3,321	2,188	2,064	1,974	1,853	357
Percent	28.2	18.6	17.6	16.8	15.8	3.0
Cum %	28.2	46.9	64.4	81.2	97.0	100.0

Figure 3.
Pareto diagram for total time-to-repair at machine level for ice cream production line

machine (M1), amounting to 28.2 percent of all the TTR. The second total TTR is on the ice cream machine (M3) standing for 18.6 percent of all the TTR. The third total TTR is on the freezer tunnel machine (M4) standing for 17.6 percent and about 65 percent of total TTR of the ice cream production line is observed at those machines (M1, M3 and M4).

6. Maintenance management strategy

Equipment maintenance must be done very carefully and in a timely manner to avoid machine failure (Jain *et al.*, 2014). The maintenance strategy that is applied on the ice cream production line, is:

(1) Breakdown maintenance: this refers to the maintenance when the equipment fails or the equipment performance declines. In this type of maintenance, machines are serviced only when maintenance is drastically required. This concept has the disadvantage of unplanned stoppages, excessive damage, spare parts problems, high repair costs, excessive waiting and maintenance time and high troubleshooting problems (Telang, 1998). The main stages are: stopping the machine, diagnosing the failure, finding spare parts, repairing the failure, controlling and re-opening. In this case, maintenance takes place after a failure occurs, which means high cost, a large number of man-hours and long stoppage times for the line. The main drawback of this type of maintenance is that because we cannot know the time that the failure will occur, but also the type of failure, there is a need for a large stock of spare parts and difficulty in managing them. But repair time may be too long and greatly reduce the availability of the line.

(2) Preventive maintenance: in this type of maintenance, a physical checkup of equipment is performed to prevent equipment breakdown and increase equipment service life. In this phase, the maintenance function is established and time-based maintenance activities are generally accepted (Pai, 1997). The preventive maintenance work includes equipment lubrication, cleaning, parts replacement, tightening and adjustment of nuts and bolts. The production equipment may also be inspected for signs of deterioration during preventive maintenance work (Telang, 1998). The main stages are: machine shutdown, maintenance, control and re-opening. In order to design the preventive maintenance program, which is daily, weekly, monthly or yearly, the manufacturer's recommendations and the experience of the technical staff are taken into account. In addition the maintenance points and the periodicity are determined. The phases of

maintaining and implementing a preventive maintenance program are: work order, implementation by the technician, confirmation by the supervisor and database update.

(3) Condition Based maintenance: this technique is used to measure the physical condition, such as temperature, noise, vibration, lubrication and corrosion, of the equipment (Brook, 1998). When one or more of these indicators reaches a predetermined deterioration level, maintenance initiatives are undertaken to restore the equipment to desired condition. This means that equipment is taken out of service only when direct evidence exists that deterioration has taken place. Condition-based maintenance is premised on the same principle as preventive maintenance, although it employs a different criterion to determine the need for specific maintenance activities. The additional benefit comes from the need to perform maintenance only when the need is imminent, not after the passage of a specified period of time (Herbaty, 1990). The main stages are: machine stop, repair, check and re-opening. The state of the machines is monitored while they are operated by means of special instruments, such as fault finding sensors, counters, recording systems, alarm systems, etc. that inform and alert imminent damage and intervene when necessary. This type of maintenance tends to be applied to the maintenance policy of the company and is considered by the technician to be the most suitable because it is more economical than preventive maintenance, since preventive maintenance does not exhaust the life of spare parts which translates into higher costs. Still, unnecessary maintenance work is drastically reduced, the personnel is freed from this work and the production time and the availability of machines are increased. Of course, the issue of costs and investment in diagnostic instruments and devices, as well as the proper processing and evaluation of the information gathered, as well as the training for operators to make appropriate maintenance interventions at the right time.

The company addresses the internal and external failures, focuses on the excellent quality of incoming (raw materials) and outgoing (produced) products. This is accomplished by careful cooperation and selection of suppliers after evaluation, by reducing work time that reduces real production time such as configuration, customization, product code changes, etc. Moreover, in order to increase the efficiency of the production process, the use of new technologies was introduced i.e. automated control, staff training, flexibility in the transport of raw materials from the take-over stage machines, etc. In addition, standardization of procedures, teamwork, the use of standards for quality assurance and environmental standards and the implementation of appropriate maintenance methods were applied based on the continuous improvement of the plant. The important thing is to adopt a policy that is aimed at balancing the gain with the costs of loss reduction measures.

Reliability and maintainability jointly determine the inherent availability of a system. Thus, when an availability requirement is specified, there is a distinct possibility of trading-off between reliability and maintainability since, in the steady state, availability depends only on the ratio, *a*, that is referred to as maintenance time ratio (MIL-HDBK-338B, 1998):

$$\alpha = \frac{\text{meanTTR}}{\text{meanTBF}}. \tag{5}$$

Preventive maintenance is one of the most effective strategies to improve the performance of an industrial plant by maintaining the OEE at an improved level. The managers/engineers can monitor the equipment by analyzing production data, empowering them to make better decisions about "how" and "when" preventive maintenance should be performed. Preventive maintenance reduces the risk of unplanned downtime, keeps the system on uninterrupted operation by saving unplanned breakdown expense and elevating OEE. The maintenance times ratio, α, that related to meanTBF and meanTTR should be as small as possible in order for reliability, maintainability and availability growth of the plant. This can be done by the adequate preventive maintenance by increasing the meanTBF of the system, and by decreasing the meanTTR with warehouse spare parts management, training program for technicians/operators, etc. In addition, it gives us the ability to identify the weaknesses in the equipment, so that we can intervene directly and effectively.

In Table III, the maintenance time ratio and inherent availability at machine and line level for the ice cream production line were computed. The inherent availability (A_i) is calculated as the mean time between failure (meanTBF) divided by the mean time between failure plus the mean time to repair (meanTTR) or $A_i =$ meanTBF/(meanTBF+meanTTR).

The A_i related to equipment failure losses, contained failure modes that stop normal operation of the equipment and reduce its production rate. In addition, when a random failure occurs for the production line, the failed machine stops and forces most of the line downstream of the failure to operate without processing, whereas the material of the line upstream may have to be scrapped due to quality deterioration during the stoppage. Thus, these losses are classified as time losses (reduced productivity), and quality losses (occurrence of defective products) caused by equipment failure or breakdown. Therefore, the A and the QR, as well as the OEE of the line can be influenced.

From Table III the following observations can be made: the mean TBF at line level is 334.16 min or about 5.6 h, meaning that about 1.5 failures per shift at the ice cream production line is displayed, whereas the mean TTR a failure is 25.06 min. In other words, every 5.6 h on the manufacturing system there is a failure where the repair process lasts an average of 25.06 min. The minimum value of mean TBF is 1,342.75 min at the pasteurization and homogenization machine (M1), and with 1,633.59 at the packaging machine (M5). Thus, the TBFs of those machines must be increased with the adequate maintenance strategy. The maintenance staff should apply a preventive and condition based maintenance program on these machines, in order to eliminate their causes of failures. If improvements are made on these machines, the line efficiency will be directly influenced favorably. The maximum value of mean TTR is 51 min at the theoretical machine (M6). The ice cream machine (M3) and the pasteurization and homogenization machine (M1) have 31.25 and 27 min for mean TTR, respectively. Therefore, the repair rate of those machines must be decreased with the adequate maintenance management, i.e. training programs for operators and technicians, autonomous maintenance, etc. The minimum inherent availabilities are observed at the pasteurization & homogenization machine (M1) and at the ice cream machine (M3) with 98.02 and 98.7 percent, respectively. The highest maintenance times ratio are at the pasteurization and homogenization machine (M1), the ice cream machine (M3) and the freezer tunnel machine (M4) with 0.02011, 0.01316 and 0.0124, respectively. Therefore, maintenance times of these machines must also be reduced by adequate maintenance strategy (i.e. warehouse spare parts management, training program for technicians/operators etc.), in order to increase the inherent availability of the machines. The lowest maintenance time ratio are at the theoretical machine (M6), the packaging machine (M5), and the aging machine (M2) with 0.00212, 0.01112 and 0.01185, respectively. Therefore, the maintenance of these machines is satisfactory and no further maintenance action is needed. The inherent

Table III. Calculation of maintenance time ratio (α) and inherent availability (A_i) at machine and line level for the entire ice cream production line

Machine	meanTBF	meanTTR	α	A_i
M1	1,342.7561	27	0.020108	0.980288
M2	1,913.8621	22.6896552	0.011855	0.988283
M3	2,375.6	31.2571429	0.013158	0.987013
M4	1,957.8353	24.2823529	0.012403	0.987749
M5	1,633.598	18.1666667	0.011121	0.989002
M6	24,017.571	51	0.002123	0.997881
Line	334.16418	25.0682303	0.075018	0.930217

availability of the line due to failures (unscheduled interruptions) is 93.02 percent, whereas the maintenance time ratio is 0.07502. Thus, the maintenance time ratio of the line is high and should be optimized with the adequate maintenance policy based on TPM principles. The TPM strategy is based on individuals, procedures and facilities. It is a method that maintains and enhances the operational integrity and efficiency of the production system through the machinery, procedures and the human resources. Moreover, the TPM loss and waste program including OEE.

7. OEE calculation

The OEE consists of three components, where the first is the availability (*A*) that is an interpretation of design parameter for equipment and the reliability/maintainability trade-offs (Ebeling, 2008). The second component of the OEE calculation is the *PE* where the actual amount of production is measured. This component is affected by the speed of the production line and by mirror stoppages, i.e., adjustment losses. The third component of the OEE calculation is the *QR*, which is the proportion of good production to the total production volume. The *QR* is immediately related to the defective products of the line.

In order to start the OEE measurement process, operational performance data collection of the three OEE variables (availability, performance and quality) were carried out during a period of eight months. The data required for the OEE measurement was collected on a daily basis by the maintenance staff who are responsible for the continuous and correct operation of the ice cream production line. The actual availability, *PE* and *QR* measures as well as the OEE figure for each working day, week and month are shown in Figure 4. The red dashed line represents the work-class target, i.e. for: *A* is 0.9, *PE* is 0.95, *QR* is 0.99, and OEE is 0.85. In Figure 4(c) it is observed that the average values for the OEE and *PE* per each month are lower than the work class target. While, for both *A* and *QR* the average values of the third, fourth and eight months are higher than the work-class target.

Table IV presents the actual average OEE value calculated with the three components (*A*, *PE* and *QR*) for the entire period of operation. Moreover, the following observations can be made: the availability of the line is 89.48 percent which is slightly minor to the target's availability (90 percent) of the production line. That is the component *A* includes all events that stop planned production for an appreciable length of time i.e. planned and unplanned stops. The actual PE of the line is 91.44 percent, which abstains enough from the target (95 percent) of the production line. These losses are usually connected to the minor stoppages due to abnormalities on the freezer tunnel machine (M4) and during packaging (M5). For the component *PE* that is because the production operates at less than the maximum possible speed when running. The actual *QR* (98.91) approximates the target (99 percent) for the line. The number of the ice cream production line is rejected due to quality defects occurring during the setups and adjustment process. For the component *QR* that is products which do not meet quality standards, including pieces that require rework. The overall OEE performance of the line is low (80.93 percent), considering the target of an 85 percent benchmark as world-class performance. The main causes are speed losses, and excessive breakdowns of the equipment.

Pareto diagram for the scheduled and unscheduled interruptions of the ice cream production process was shown in Figure 5. It is a graphical presentation of interruptions in ranking order from the most frequent, down to the least frequent. It illustrates which is the most important issue in order to act immediately and get the most significant improvement. Thus, the following suggestions can be formulated:

(1) The upmost serious problem of the ice cream production system is related to the speed losses that stand for 42.4 percent of all the losses. In practice, speed losses are anything that reduces the speed of the production line from the nominal. The main causes are: dirty or worn out equipment, tooling wear, sensor blockage, component jams, operator inexperience, poor environmental conditions, product misfeeds, etc. Therefore, the

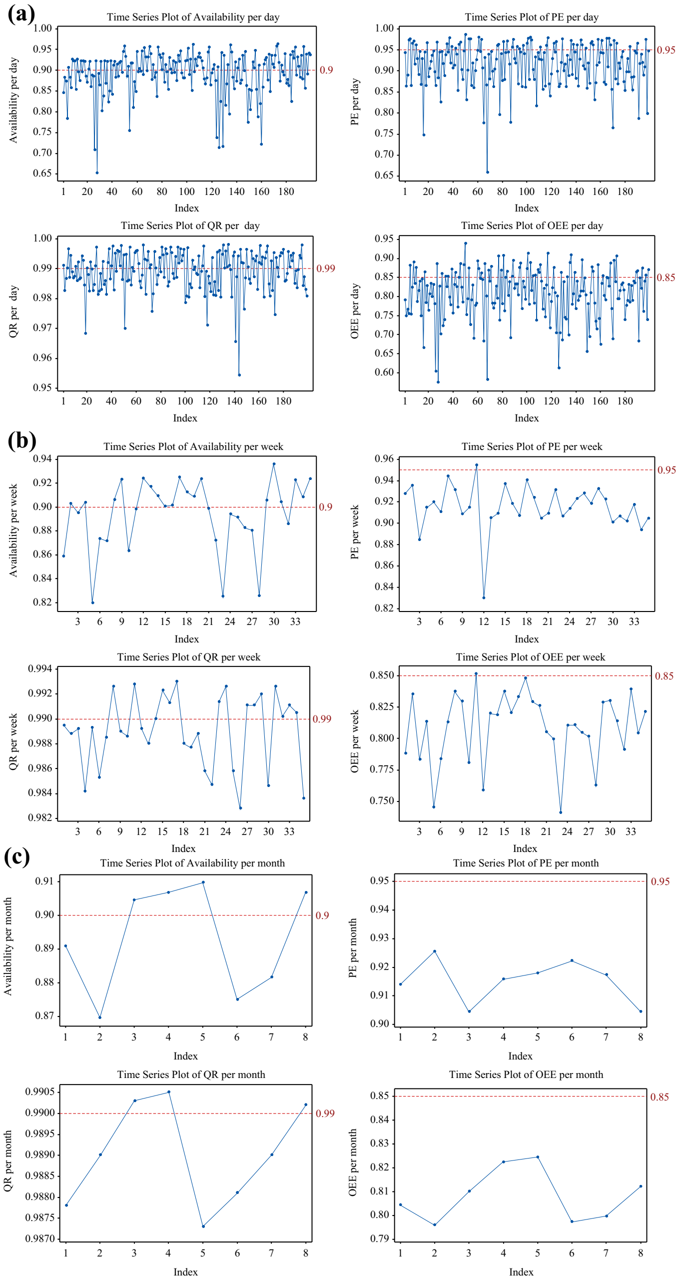


Figure 4.
The actual availability (*A*), performance efficiency (*PE*) and quality rate (*QR*) measures, together with the complete OEE figure for each (a) day, (b) week and (c) month for the entire ice cream production line

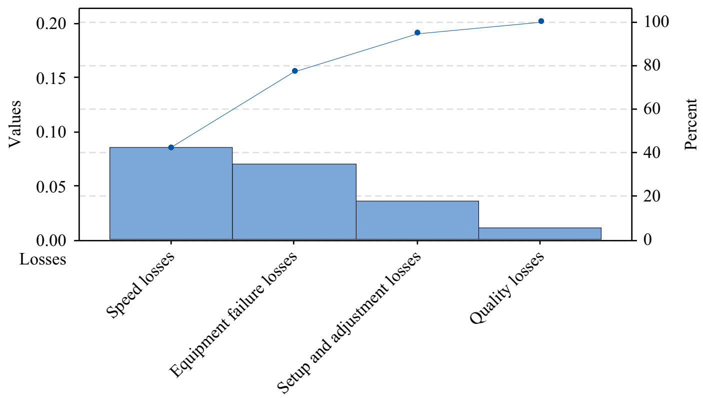
main objective on the manufacturing system is to reduce (or eliminate) these speed losses. This could be done by the adequate operation management for the line, i.e. minor stoppages of a temporary malfunction of the packaging machine (M5), i.e. due to inappropriate packaging film. The drop in speed from the nominal speed of the freezer tunnel machine (M4) in order to freeze the product better. Thus, training and education programs for operators, workers, and technicians, autonomous maintenance management, planned maintenance program, identifying the constraints in process, etc. could be some practices to deal with the reduction of speed losses.

(2) The second way is related to eliminating the unscheduled interruptions that consist of 34.6 percent of all the losses, due to failures that are downtime losses caused by unexpected breakdowns, tooling damage, equipment failure, unplanned maintenance. This could be done with the proper maintenance strategy based on the TPM implementation program, in order to optimize equipment effectiveness. For instance, preventive maintenance (lubrication, adjustment of conveyor belts tension, bolt tightening, cleaning, inspection, etc.) of each machine for the ice cream production line during the predetermined times should be done by operators (or/and maintenance staff) to prevent breakdowns and faster reactions are necessary if a certain failure has been detected. Both the speed losses and the equipment failures (downtime losses) stand for 77 percent of the ice cream production line.

(3) The third way is to eliminate or restrict the scheduled interruptions that stand for 17.6 percent of all the losses. The main reasons of these losses are: changeovers, setup, process warm up, adjustment, material shortage, operator shortage, etc. These can be addressed by the adequate operations management for the line, i.e. scheduling changeovers may be programmed early at the beginning of the working day, so that their time losses are reduced. Alternatively, the operator or/and the maintenance staff could program the changeover and setup during the break of the workers.

Table IV. The actual average OEE value calculated with the three components (*A*, *PE* and *QR*) for the entire period of operation in comparison to the world-class target

%	*A*	*PE*	*QR*	OEE
World class	90	95	99	85
Average	89.48	91.44	98.91	80.93
Difference	–0.52	–3.56	–0.09	–4.07



Values	0.0854	0.0697	0.0354	0.0109
Percent	42.4	34.6	17.6	5.4
Cum %	42.4	77.0	94.6	100.0

Figure 5. Pareto diagram for the scheduled and unscheduled interruptions of the ice cream production process

(4) The fourth way is related to the quality losses that stand for 5.4 percent of all the losses. These are mainly due to: tolerance adjustment, scrap, in process damage, rejects, rework, incorrect assembly, etc. That is defective goods produced from startup until stable production process is reached. It could be avoided by the operators that must clean and prepare the equipment before starting again (i.e. changeovers or at the beginning of each working day), so that rejection or rework may be reduced. Moreover, continuous quality control is required during the steady-state production, i.e. statistical process control (SPC).

The contribution of each of the above suggestions is to eliminate the inconvenient consequences of the scheduled and unscheduled interruptions on the production process, in order to improve the productivity, efficiency and the availability of the manufacturing system. Thus, a system can unleash concealed ability and profit from tracking simple OEE information by decreasing downtime, minimizing setup time and improving operator performance.

8. Conclusions

In this study, we calculated the OEE with their components (*A*, *PE* and *QR*) of ice cream production line, and we compared them with the world class. A framework process to improve the OEE of an automated production system is shown and is applied in ice cream industry. In order to improve line's performance and efficiency, the company must intervene in their losses that relate with the KPIs. The main research findings of the ice cream production line can be summarized as follows:

(1) The line produces for 89.48 percent of the time while the remaining 10.52 percent of the time was engaged for scheduled and unscheduled interruption. The scheduled interruption account for 3.54 percent i.e. setups and adjustments, whereas the unscheduled interruption of the line that is repair times equals to 6.97 percent of the time.

(2) The actual PE of the line is 91.44 percent, which abstains enough from the target (95 percent) of the production line. These losses are usually connected to the minor stoppages due to abnormalities on the freezer tunnel machine (M4) and during the packaging (M5). On the other hand, the actual *QR* (98.91) approximates the target (99 percent) for the line.

(3) The mean TBF at line level is 334.16 min or about 5.6 h, meaning that about 1.5 failures per shift at the ice cream production line is displayed, whereas the mean TTR a failure is 25.06 min.

(4) The maintenance time ratio at line level is 0.07502. Thus, the maintenance time ratio of the line is high and should be optimized with the adequate maintenance policy based on TPM principles.

(5) The pasteurization and homogenization machine (M1) and the ice cream machine (M3) standing for 46.8 percent of total TTR of the ice cream production line. Thus, the improvements can be made on these machines which will directly positively influence the line performance.

(6) The highest maintenance times ratio are at the pasteurization and homogenization machine (M1), the ice cream machine (M3) and the freezer tunnel machine (M4). Therefore, maintenance times of these machines must also be reduced by adequate maintenance strategy (i.e. warehouse spare parts management, training program for technicians/operators, etc.), to increase the inherent availability of the machines.

(7) The lowest maintenance time ratio at machine level are at the theoretical machine (M6), the packaging machine (M5) and the aging machine (M2). Therefore, the maintenance of these machines is satisfactory and no further maintenance action is needed.

The company should reduce their losses in order to improve the line performance. To avoid the negative consequences of the scheduled and unscheduled interruptions, the production managers and engineers have to concentrate in four ways: the first way is related to the speed losses that stand for 42.4 percent. The second way is related to eliminating the unscheduled interruptions that consist of 34.6 percent due to failures that are downtime losses caused by unexpected breakdowns. The third way is to eliminate or restrict the scheduled interruptions that stand for 17.6 percent and the fourth way is related to the quality losses that stand for 5.4 percent. This could be done with adequate operation management and with the proper maintenance strategy based on the TPM implementation program, in order to optimize equipment effectiveness. Schedule changeovers may be programmed early at the beginning of the working day, so that their time losses are reduced. Moreover, preventive maintenance (lubrication, adjustment of conveyor belts tension, bolt tightening, cleaning, inspection, etc.) of each machine for the ice cream production line during the predetermined times should be done by operators (or/and maintenance staff) to prevent breakdowns and faster reactions are necessary if a certain failure has been detected. In addition, the company's quality and safety requirements should be met.

The advance of this method is the reduction in the "six big losses" by improved quality, increased throughput and elimination of equipment breakdowns, in order to obtain a world-class target. Moreover, there are some indirect benefits, i.e. continuous maintenance and controlling of the equipment, enhanced quality of work life, reduced absenteeism and enhanced communication in the workplace. OEE is a metric that counters progress in improving the effectiveness and efficiency of a manufacturing process, i.e. TPM program. Implementing an improvement strategy (i.e. TPM) needs a shifting working culture toward an ongoing culture of enhancement that can be hard and have an effect on the staff engaged.

The results of this study were discussed with the factory's management, and they considered it very important and in the right direction to adopt and implement them. Indeed, from the first weeks of the implementation of the program, a small reduction of breakdowns and improvement of the system's operation was observed. It is a continuous and time-consuming process which requires persistence, patience and funding, which the company should apply it. There are still a lot of things to do, but with the continuous support of the administration everything is yet possible.

Of course, these results clearly identify implications that have come up both in the company and in the local society itself. We have enhanced quality of work life, reduced absenteeism and enhanced communication in the workplace. Moreover, these are implications which have indirect impact in society (more and new jobs, skills knowledge and competences, attracting other companies, research institutes, etc.) that can be used for the development of the region wide.

Further research would be the consequences of the results of this case study. Then, after a significant period of time, re-calculation of the KPIs such as OEE in order to compare the new results with the previous ones. Thus, we are in the frame of continuous improvement based on the TPM principles by measuring and meliorating the efficiency, productivity and the availability of the manufacturing system.

References

Agustiady, T.K. and Cudney, E.A. (2018), "Total productive maintenance", *Total Quality Management & Business Excellence*, doi: 10.1080/14783363.2018.1438843.

Ahire, C.P. and Relkar, A.S. (2012), "Correlating failure mode effect analysis (FMEA) & overall equipment effectiveness (OEE)", *Procedia Engineering*, Vol. 38, pp. 3482-3486.

Ahmad, N., Hossen, J. and Ali, S.M. (2018), "Improvement of overall equipment efficiency of ring frame through total productive maintenance: a textile case", *The International Journal of Advanced Manufacturing Technology*, Vol. 94 Nos 1-4, pp. 239-256.

Anvari, F., Edwards, R. and Starr, A. (2010), "Evaluation of overall equipment effectiveness based on market", *Journal of Quality in Maintenance Engineering*, Vol. 16 No. 3, pp. 256-270.

Baghbani, M., Iranzadeh, S. and Bagherzadeh khajeh, M. (2019), "Investigating the relationship between RPN parameters in fuzzy PFMEA and OEE in a sugar factory", *Journal of Loss Prevention in the Process Industries*, Vol. 60, July, pp. 221-232.

Bamber, C., Castka, P., Sharp, J. and Motara, Y. (2003), "Cross-functional team working for overall equipment effectiveness", *Journal of Quality in Maintenance Engineering*, Vol. 9 No. 3, pp. 223-239.

Blanchard, B.S. (1997), "An enhanced approach for implementing total productive maintenance in the manufacturing environment", *Journal of Quality in Maintenance Engineering*, Vol. 3 No. 2, pp. 69-80.

Boban, B. and Jenson, J.E. (2013), "Enhancing overall equipment effectiveness for a manufacturing firm through total productive maintenance", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 3 No. 8, pp. 425-429.

Brook, R. (1998), "Total predictive maintenance cuts plant costs", *Plant Engineering*, Vol. 52 No. 4, pp. 93-95.

Calais, J.F.L.G., Azevedo, S.G. and Matias, J.C.D.O. (2017), "Management and operations maintenance for a water treatment and supply company", *International Journal of Industrial and Systems Engineering*, Vol. 25 No. 3, pp. 360-382.

Chen, F. (1997), "Issue in the continuous improvement process for preventive maintenance: observations from Honda, Nippondenso and Toyota", *Production and Inventory Management Journal*, Vol. 38 No. 4, pp. 13-16.

Chowdhury, C. and Mandal, T.K. (1995), "Equipment effectiveness and six big losses", *Productivity*, Vol. 36 No. 1, pp. 110-117.

Dal, B., Tugwell, P. and Greatbanks, R. (2000), "Overall equipment effectiveness as a measure of operational improvement," *International Journal Operations Production Management*, Vol. 20 No. 12, pp. 1488-1502.

De Ron, A.J. and Rooda, J.E. (2005), "Equipment effectiveness: OEE revisited", *IEEE Transaction on Semiconductor Manufacturing*, Vol. 18 No. 1, pp. 190-196.

Ebeling, C. (2008), *An Introduction to Reliability and Maintainability Engineering*, 10th ed., Tata McGraw-Hill, New Delhi.

Esmaeel, R.I., Zakuan, N., Jamal, N.M. and Taherdoost, H. (2018), "Understanding of business performance from the perspective of manufacturing strategies: fit manufacturing and overall equipment effectiveness", *Procedia Manufacturing*, Vol. 22, pp. 998-1006.

Eswaramurthi, K.G. and Mohanram, P.V. (2013), "Improvement of manufacturing performance measurement system and evaluation of overall resource effectiveness", *American Journal of Applied Sciences*, Vol. 10, pp. 131-138.

Fam, S.F., Ismail, N., Yanto, H., Prastyo, D.D. and Lau, B.P. (2018), "Lean manufacturing and overall equipment efficiency (OEE) in paper manufacturing and paper products industry", *Journal of Advanced Manufacturing Technology*, Vol. 12 No. 1, pp. 461-474.

Ferko, R. and Znidarsic, A. (2007), "Using OEE approach for improving manufacturing Performance", *Information MIDEM*, Vol. 37, pp. 105-111.

Fore, S. and Zuze, L. (2010), "Improvement of overall equipment effectiveness through total productive maintenance", *International Journal of Industrial and Manufacturing Engineering*, Vol. 4 No. 1, pp. 85-93.

Garza-Reyes, J.A., Eldridge, S., Barber Kevin, D. and Soriano-Meier, H. (2010), "Overall equipment effectiveness (OEE) and process capability (PC) measures: a relationship analysis", *International Journal of Quality & Reliability Management*, Vol. 27 No. 1, pp. 48-62.

Gupta, P. and Vardhan, S. (2016), "Optimizing OEE, productivity and production cost for improving sales volume in an automobile industry through TPM: a case study", *International Journal of Production Research*, Vol. 54 No. 10, pp. 2976-2988.

Gupta, P., Vardhan, S. and Haque, M.S.A. (2015), "Study of success factors of TPM implementation in Indian industry towards operational excellence: an overview", *Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management, Aveiro, March 3-5*, pp. 2485-2490.

Hemanand, K., Amuthuselvan, D., Raja, S.C. and Sundararaja, G. (2012), "Improving productivity of manufacturing division using lean concepts and development of material gravity Feeder-a case study", *International Journal of Lean Thinking*, Vol. 3 No. 2, pp. 117-134.

Heng, Z., Aiping, L., Liyun, X. and Moroni, G. (2019), "Automatic estimate of OEE considering uncertainty", *Procedia CIRP*, Vol. 21, pp. 630-635.

Herbaty, F. (1990), *Handbook of Maintenance Management: Cost Effective Practices*, 2nd ed., Noyes Publications, Park Ridge, NJ.

Ihueze, C.C. and U-Dominic, C.M. (2017), "Maximizing overall equipment effectiveness in a food processing industry: a case study", *Archives of Current Research International*, Vol. 11 No. 4, pp. 1-10.

Jain, A., Bhatti, R. and Singh, H. (2014), "Total productive maintenance (TPM) implementation practice: a literature review and directions", *International Journal of Lean Six Sigma*, Vol. 5 No. 3, pp. 293-323.

Jeong, K.-Y. and Phillips, D.T. (2001), "Operational efficiency and effectiveness measurement", *International Journal of Operations & Production Management*, Vol. 21 No. 11, pp. 1404-1416.

Jonsson, P. and Lesshammar, M. (1999), "Evaluation and improvement of manufacturing performance measurement systems - the role of OEE", *International Journal of Operations and Production Management*, Vol. 19 No. 1, pp. 55-78.

Konecny, P.A. and Thun, J.H. (2011), "Do it separately or simultaneously- an empirical analysis of a conjoint implementation of TQM and TPM on plant performance", *International Journal of Production Economics*, Vol. 133 No. 2, pp. 496-507.

Krachangchan, K. and Thawesaengskulthai, N. (2018), "Loss time reduction for improve overall equipment effectiveness (OEE)", *5th International Conference on Industrial Engineering and Applications*, Vol. 1, pp. 396-400.

Kumar, P., Varambally, K.V.M. and Rodrigues, L.L.R. (2012), "A methodology for implementing total productive maintenance in manufacturing industries – a case study", *International Journal of Engineering Research and Development*, Vol. 5 No. 2, pp. 32-39.

Kumar, S.V., Mani, V.G. and Devraj, N. (2014), "Production planning and process improvement in an impeller manufacturing using scheduling and OEE techniques", *Procedia Materials Science*, Vol. 5, pp. 1710-1715.

Lanza, G., Stoll, J., Stricker, N., Peters, S. and Lorenz, C. (2013), "Measuring global production effectiveness", *Procedia CIRP*, Vol. 7, pp. 31-36.

Lazim, H.M., Salleh, M.N., Subramaniam, C. and Othman, S.N. (2013), "Total productive maintenance and manufacturing performance: does technical complexity in the production process matter?", *International Journal of Monetary Economics and Finance*, Vol. 4 No. 6, pp. 380-383.

Ljungberg, Õ. (1998), "Measurement of overall equipment effectiveness as a basis for TPM activities", *International Journal of Operations & Production Management*, Vol. 18 No. 5, pp. 495-507.

Mohan, M.S., Hopkinson, J. and Harte, F. (2014), "Milk and ice cream processing", in Clark, S., Jung, S. and Lamsal, B. (Eds), *Food Processing: Principles and Applications*, 2nd ed., Wiley Blackwell, IA, pp. 383-404.

Muchiri, P. and Pintelon, L. (2008), "Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion", *International Journal of Production Research*, Vol. 46 No. 13, pp. 3517-3535.

Muthiah, K.M.N., Huang, S.H. and Mahadevan, S. (2008), "Automating factory performance diagnostics using overall throughput effectiveness (OTE) metric", *The International Journal of Advanced Manufacturing Technology*, Vol. 36 No. 7, pp. 811-824.

My Abdelbar, K., Bouami, D. and Elfezazi, S. (2019), "New approach towards formulation of the overall equipment effectiveness", *Journal of Quality in Maintenance Engineering*, Vol. 25 No. 1, pp. 90-127.

Nakajima, S. (1988), *Introduction to TPM*, Productivity Press, Cambridge, MA.

Nallusamy, S. (2016a), "Frequency analysis of lean manufacturing system by different critical issues in Indian automotive industries", *International Journal of Engineering Research in Africa*, Vol. 23, pp. 181-187.

Nallusamy, S. (2016b), "Enhancement of productivity and efficiency of CNC machines in a small scale industry using total productive maintenance", *International Journal of Engineering Research in Africa*, Vol. 25, pp. 119-126.

Null, C., Marvel, M. and Rodríguez Monroy, C. (2012), "Productividad y factores humanos. Un modelo con ecuaciones estructurales", *Interciencia: Revista de Ciencia y Tecnología de América*, Vol. 37 No. 2, pp. 121-127.

Oliveira, R., Taki, S.A., Sousa, S. and Salimi, M.A. (2019), "Global process effectiveness: when overall equipment effectiveness meets adherence to schedule", Procedia Manufacturing (in press).

Pai, K.G. (1997), "Maintenance management", *Maintenance Journal*, pp. 8-12.

Parida, A., Kumar, U., Galar, D. and Stenström, C. (2014), "Performance measurement and management for maintenance: a literature review", *Journal of Quality in Maintenance Engineering*, Vol. 21 No. 1, pp. 2-33.

Parikh, Y. and Mahamuni, P. (2015), "Total productive maintenance: need & framework", *International International Journal of Innovative Research in Advanced Engineering*, Vol. 2 No. 2, pp. 126-130.

Phogat, S. and Gupta, A.K. (2017), "Identification of problems in maintenance operations and comparison with manufacturing operations: a review", *Journal of Quality in Maintenance Engineering*, Vol. 23 No. 2, pp. 226-238.

Puvanasvaran, A.P., Mei, C.Z. and Alagendran, V.A. (2013), "Overall equipment efficiency improvementusing time study in an aerospace industry", *Procedia Engineering*, Vol. 68, pp. 271-277.

Rahman, C.M., Hoque, M.A. and Uddin, S.M. (2014), "Assessment of total productive maintenance implementation through downtime and mean downtime analysis (case study: a semi-automated manufacturing company of Bangladesh)", *IOSR Journal of Engineering*, Vol. 4 No. 9, pp. 38-47.

Rajput, H.S. and Jayaswal, P. (2012), "A total productive maintenance (TPM) approach to improve overall equipment efficiency", *International Journal of Modern Engineering Research*, Vol. 2 No. 6, pp. 4383-4386.

Ramlan, R., Ngadiman, Y., Omar, S.S. and Yassin, A.M. (2015), "Quantification of machine performance through overall equipment effectiveness", *2015 International Symposium on Technology Management and Emerging Technologies*, *August 25-27*, pp. 429-433.

Ribeiro, I.M., Godina, R. and Matias, J.C.O. (2019), "Improving the availability of a production line through tpm in an automotive gearbox industrial unit", in Reis, J., Pinelas, S. and Melão, N. (Eds), *Industrial Engineering and Operations Management II, XXIVIJCIEOM 2018. Springer Proceedings in Mathematics & Statistics*, Vol. 281, Springer, Cham, pp. 149-156.

Saleem, F., Nisar, S., Khan, M.A., Khan, S.Z. and Sheikh, M.A. (2017), "Overall equipement effectiveness of tyre curing press: a case study", *Journal of Quality in Maintenance Engineering*, Vol. 23, pp. 39-56.

Seng, O.Y., Jantan, M. and Ramayah, T. (2005), "Implementing total productive maintenance (TPM) in Malaysian manufacturing organization: an operational strategy study", *The ICFAI Journal of Operations Management*, Vol. 4 No. 2, pp. 53-62.

Sharma, R. (2019), "Overall equipment effectiveness measurement of TPM manager model machines in flexible manufacturing environment: a case study of automobile sector", *International Journal of Productivity and Quality Management*, Vol. 26 No. 2, pp. 206-222.

Sharma, R.K., Kumar, D. and Kumar, P. (2006), "Manufacturing excellence through TPM implementation: a practical analysis", *Industrial Management and Data Systems*, Vol. 106 No. 2, pp. 256-280.

Singh, J., Singh, H. and Sharma, V. (2018), "Success of TPM concept in a manufacturing unit – a case study", *International Journal of Productivity and Performance Management*, Vol. 67 No. 3, pp. 536-549.

Singh, R.K., Clements, E.J. and Sonwaney, V. (2018), "Measurement of overall equipment effectiveness to improve operational efficiency", *International Journal of Process Management and Benchmarking*, Vol. 8 No. 2, pp. 246-261.

Singh, T.P. and Ahuja, I.S. (2017), "Evaluating manufacturing performance through strategic total productive maintenance implementation in a food processing industry", *International Journal of Productivity and Quality Management*, Vol. 21 No. 4, pp. 429-442.

Sivakumar, A. and Saravanan, K. (2011), "Simulation based analysis for improvement of productivity in sick chemical dyeing factory: a research article", *International Journal of Electronic Transport*, Vol. 1 No. 1, pp. 96-110.

Sohal, A., Olhager, J., O'Neill, P. and Prajogo, D. (2010), "Implementation of OEE issues and challenges", *Proceedings of the International Conference on Advances in Production Management Systems*, *Como*, *October 11-13*, pp. 1-8.

Soltanali, H., Rohani, A., Tabasizadeh, M., Abbaspour- Fard, M.H. and Parida, A. (2018), "Improving the performance measurement using overall equipment effectiveness in an automotive industry", *International Journal of Automotive Engineering*, Vol. 8 No. 3, pp. 2781-2791.

Swanson, L. (2001), "Linking maintenance strategies to performance", *International Journal of Production Economics*, Vol. 70 No. 3, pp. 237-244.

Tang, H. (2019), "A new method of bottleneck analysis for manufacturing systems", *Manufacturing Letters*, Vol. 19, January, pp. 21-24.

Telang, A.D. (1998), "Preventive maintenance", in Vijayakumar, K. (Ed.), *Proceedings of the National Conference on Maintenance and Condition Monitoring*, Government Engineering College, Institution of Engineers, Cochin Local Centre, Thissur, February 14, pp. 160-173.

Teoh, Y.S., Ito, T. and Perumal, P. (2017), "Invisibility of impact from customer demand and relations between processes in overall equipment effectiveness (OEE)", *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, Vol. 11 No. 5, pp. 1-11.

Tsang, A.H.C. and Chan, P.K. (2000), "TPM implementation in China: a case study", *International Journal of Quality & Reliability Management*, Vol. 17 No. 2, pp. 144-157.

Tsarouhas, P. (2019), "Improving operation of the croissant production line through overall equipment effectiveness (OEE): a case study", *International Journal of Productivity and Performance Management*, Vol. 68 No. 1, pp. 88-108.

Tsarouhas, P.H. (2013a), "Equipment performance evaluation in a production plant of traditional Italian cheese", *International Journal of Production Research*, Vol. 51 No. 19, pp. 5897-5907.

Tsarouhas, P.H. (2013b), "Evaluation of overall equipment effectiveness in the beverage industry: a case study", *International Journal of Production Research*, Vol. 51 No. 2, pp. 515-523.

Tsarouhas, P.H. (2015), "Evaluation of maintenance management through the overall equipment effectiveness of a yogurt production line in a medium-sized Italian company", *International Journal of Productivity and Quality Management*, Vol. 16 No. 3, pp. 298-311.

Wakjira, M.W. and Singh, A.P. (2012), "Total productive maintenance: a case study in manufacturing industry", *Global Journal of Researches in Industrial Engineering*, Vol. 12 No. 1, pp. 25-32.

Yamashina, H. (1995), "Japanese manufacturing strategy and the role of total productive maintenance", *Journal of Quality in Maintenance Engineering*, Vol. 1 No. 1, pp. 27-38.

Zammori, F. (2014), "Fuzzy overall equipment effectiveness (FOEE): capturing performance fluctuations through LR fuzzy numbers", *Production Planning & Control*, Vol. 26 No. 6, pp. 451-466.

Zennaro, I., Battini, D., Sgarbossa, F., Persona, A. and De Marchi, R. (2018), "Micro downtime: data collection, analysis and impact on OEE in bottling lines the San Benedetto case study", *International Journal of Quality & Reliability Management*, Vol. 35 No. 4, pp. 965-995.

Zuashkiani, A., Rahmandad, H. and Jardine, A.K.S. (2011), "Mapping the dynamics of overall equipment effectiveness to enhance asset management practices", *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 1, pp. 74-92.

About the author

Dr Panagiotis H. Tsarouhas, Dipl. Eng., PhD is Associate Professor at Technological Educational Institute of Central Macedonia (Greece), Department of Supply Chain Management and Logistics and Tutor in postgraduate course on Quality Assurance in Hellenic Open University. He received his Diploma in Mechanical Engineering from Universita degli studi di Napoli Federico II (Italy), and both PhD and MSc from the Department of Mechanical and Industrial Engineering from the University of Thessaly in Volos, Greece. For about ten years he was at the Technical Department as production and maintenance operation head in food industry "Chipita International SA" in Lamia, Greece. He has about 28 years research/teaching experience, and more than 65 research papers in international journals, book chapters and conference proceedings. He has been involved in many research and practical projects in the field of reliability analysis and maintenance engineering. His areas of interest are reliability and maintenance engineering, quality engineering and supply chain management. Dr Panagiotis H. Tsarouhas can be contacted at: ptsarouhas@teicm.gr