Spring 2018

Implementing a Total Productive Maintenance Approach into an Improvement At S Company

Xiaomeng Sun
Western Kentucky University, sunxiaomeng2002@outlook.com

IMPLEMENTING A TOTAL PRODUCTIVE MAINTENANCE APPROACH INTO AN IMPROVEMENT IN COMPANY S

A Thesis
Presented to
The Faculty of the School of Engineering and Applied Sciences
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Xiaomeng Sun

May 2018

IMPLEMENTING A TOTAL PRODUCTIVE MAINTENANCE APPROACH INTO AN IMPROVEMENT AT S COMPANY

Date Recommended 2/26/2018

Mark Doggett

Mark Doggett, Director of Thesis

Daniel Jackson

Shahnaz Aly

Dean, Graduate School   Date 3/5/18

I dedicate this thesis to my parents, Junmin Sun and Caili Zhu, who are a great inspiration to me. I love you all.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to Dr. Doggett, Dr. Jackson, and Dr. Aly for their great suggestions and excellent guidance. Without their direction, the completion of this thesis would not have been possible.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

IMPLEMENTING A TOTAL PRODUCTIVE MAINTENANCE APPROACH INTO AN IMPROVEMENT AT S COMPANY

Xiaomeng Sun May 2018 104 Pages

Directed by: Mark Doggett, Daniel Jackson, and Shahnaz Aly

School of Engineering and Applied Sciences Western Kentucky University

The study improved the overall equipment effectiveness (OEE) of machines and processes through the implementation of a total productive maintenance (TPM) approach at Company S over a three-month period. By comparing the OEE of equipment before and after the implementation of autonomous maintenance, this study concluded that autonomous maintenance improves OEE. The target of this study was one general product line at a polytetrafluoroethylene (PTFE) plant. Due to time limitations, the study only applied autonomous maintenance to operational activities. This research involved machine and processes selection, condition assessment, baseline OEE assessment, operator training, execution of autonomous maintenance, and OEE measurement. The approach was based on the steps of autonomous maintenance but was simplified for the conditions of the plant.

Introduction

In China, equipment management was largely overlooked. Under the production mechanism of most Chinese companies, equipment management was the responsibility of the maintenance department. However, this situation could not cover all the elements of equipment management. According to Roland Berger Strategy Consultant's report (2016), the average level of production equipment maintenance in China was only half of the world-class level from 2010 to 2015. In China, prevention and predictability were lacking in maintenance activities. Maintenance technicians diagnosed and repaired equipment after machines break down, and breakdown maintenance was frequently performed. This result not only in low effectiveness of repair but also in high repair cost. At the same time, the lack of maintenance standards affects equipment maintenance. A systematic maintenance approach for some Chinese companies was urgently needed. Total productive maintenance was suitable for this current situation. It was a systematic approach to help companies achieve zero breakdown, zero defects, and zero environments impacted and created a good working environment by involving all employee from front-line operators to top management, in the maintenance activities (Tokutaro, 1992).

The author of this thesis worked as a technician in the PTFE department of a sealing system company in Shanghai, China from 2011 to 2012. The company has been identified as Company S. This department has three different product lines, namely the general product line, the customized product line, and the PU ball product line. Company S itself supplied the general product line's raw tube materials, while other suppliers supplied the other two. In the study, the researcher focused on the general product line because it accounts for 70% of the PTFE department's production. Figure 1 shows the raw tube materials used on the general product line, which has several

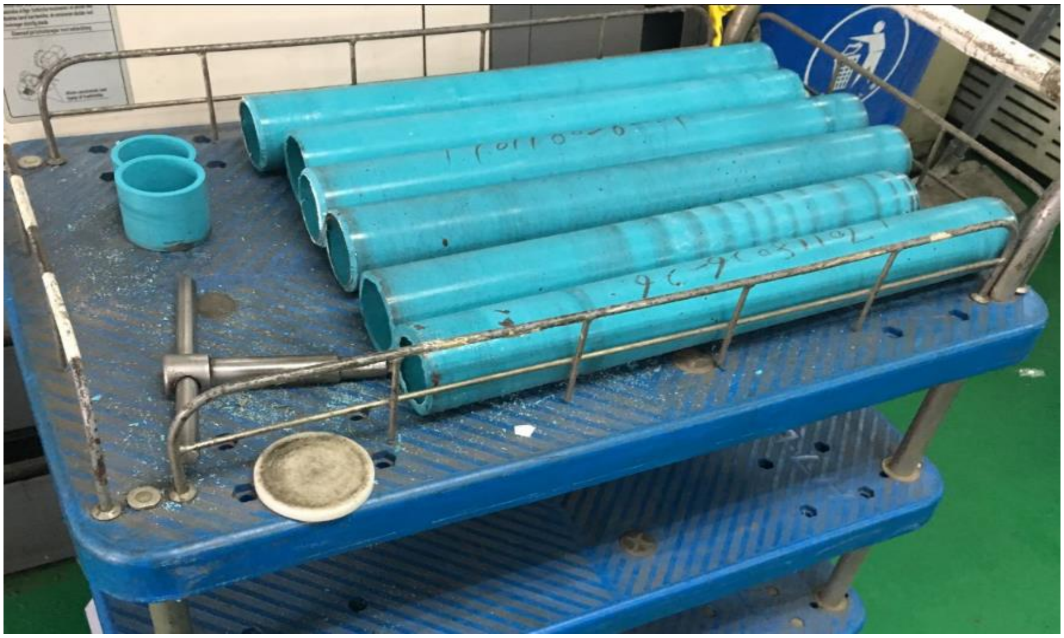

Figure 1. Example of raw tube materials used at general product line.

different sizes, based on diameter and length.

Polytetrafluoroethylene (PTFE) is a plastic material that possesses corrosion resistance and thermal resistance. PTFE has been applied in many high-technology industries including the chemicals, oil, aerospace, automotive, electronics, and medical industries. Due to PTFE's advantages, it has become one of the most common materials to produce seals (Mnif, Ben, Kacem & Elleuch, 2013).

Problem Statement

For Company S, the issues in the processes were related to the production efficiencies and quality. The problems included poor product quality, excessive tool change time, and machine breakdowns. For example, cracks on the surface of the raw material PTFE tubes would stop the processes. At other times, a modeling machine would continue to produce defective products due to unknown causes. Though these issues were solved temporarily, they increased the cost of operation and reduced the effectiveness of each process. To address these issues, the researcher considered the feasibility of implementing a lean approach. Total productive maintenance (TPM) is an approach intended to improve the effectiveness of Company S's machines in the PTFE department's general product line.

Purpose

The purpose of the study was to improve the production processes of PTFE general product line in Company S by applying TPM. The researcher selected three CNC machines in CNC Workshop, one group in Modeling Workshop, and one group in Mixing Workshop. The researcher used the TPM approach, autonomous maintenance (AM), to improve the effectiveness of the general product line of the PTFE plant.

Significance

The project was intended to improve the effectiveness of the manufacturing processes. Implementing TPM may promote and positively change the maintenance system for the whole company. TPM encourages operators to be engaged in the daily maintenance of machines and processes. If successful, TPM could be introduced to the whole company. This project was the first step toward implementing TPM.

Hypothesis

Implementing autonomous maintenance in the case of a general product line of the PTFE plant will result in improved operational equipment effectiveness (OEE) on three CNC machines in the CNC Workshop, one group on the Modeling Workshop, and one group on the Mixing Workshop.

Assumption

1. Experienced operators would effectively execute autonomous maintenance into the processes.
2. Operators could be fully trained and could maintain equipment and processes.
3. Process data collected by operators was accurate.

Limitations

1. The researcher participated only in the early work of implementing TPM.
2. The study was applicable only to the PTFE plant at Company S in Shanghai.
3. The operators had more than two-year of working experience at the PTFE plant.
4. The machines and processes chosen were based on their performance, which was better than the worst machines at the plant.

Delimitations

1. The project was an initial implementation of TPM measures.
2. The initial test data of production was one to two years old.

Definitions of Terms

Autonomous maintenance (AM): An approach that involves operators in the daily maintenance of the working processes or machines.

Corrosion resistance: How well a substance can withstand damage caused by oxidization or other chemical reactions.

Cutting tool: A kind of machining tool that is used to remove material from the workpiece using shear deformation.

Focused improvement: A pillar of TPM that is focused on solving problems.

Lean principle: A theory of increasing productivity by eliminating waste and errors.

Modeling: A kind of production technology that makes products by pressing the raw material.

Overall equipment effectiveness (OEE): A metric that identifies the percentage of planned production time that is truly productive (Ade, 2014).

Planned maintenance: The periodic maintenance that can prevent the processes or machines from making errors.

PTFE: Polytetrafluoroethylene, a kind of plastic material.

Seal: A component that can prevent the product from leaking liquid.

Sealing system company: The company that produces the sealing.

Thermal resistance: The opposite of thermal conductivity. Thermal resistance is the ability of material to resist the flow of heat.

TPM: Total productive maintenance, which involves all employees in the company's maintenance processes.

Review of Literature

This section first introduces the TPM approach and its eight pillars. Second, it focuses on investigating the effects of autonomous maintenance (AM) on OEE. The general approaches of AM as applied in the industry are introduced. In addition, cases related to the application of AM or TPM are presented.

What is Total Productive Maintenance?

Total productive maintenance (TPM) is a companywide approach that involves everyone from senior management to front-line workers in equipment maintenance activities (Terry, 2004). TPM can prevent random breakdowns and reduce other failures in production procedures through proactive and preventive measures (Chris,2015). Originally, TPM was used in the manufacturing shop-floor, but it is now widely used in all departments (Terry, 2004).

History of TPM. After the Second World War, a revival of world industry began. Manufacturing management programs were created to support the development of industry development at that period, such as Just in Time (JIT) and Total Quality Control (TQC). However, companies applying these programs at their factories reported that a consistent quality product could only be asured with machines or equipment in good condition. Thus, equipment management began to be emphasized (Terry, 2004).

At first, companies applied breakdown maintenance (BM), meaning that workers fixed equipment after it broke down (Kunio & Seiichi, 1992). This basic maintenance was unsuccessful in preventing some serious failures. The concept of preventive maintenance (PM) was introduced in the 1950s and recommended to users by equipment manufacturers (Terry, 2004). PM was used to prevent breakdown and defects by performing daily activities such as equipment checks, oil changes, lubrication, precision measurements, and repair. Records of equipment deterioration also became important in reminding operators of the need to replace and repair damaged components (Kunio & Seiichi, 1992).

In light of new demands in industry, the concepts of maintainability and methods improvement (MI), and maintenance prevention (MP) were introduced. MI reduces the repetition of the same issue, such as breakdowns or defects; while MP refers to the design of equipment for convenient maintenance. MI and MP were added to preventive maintenance and integrated into a new concept called “productive maintenance”. Using these approaches, companies could maximize the productivity of their equipment processes (Kunio & Seiichi, 1992).

In the 1970s, the concept of *total* began to be incorporated into productive maintenance activities. Total refers to total employee participation, which implies “involving all the people in maintenance procedures” (Terry, 2004, p.6). Therefore, TPM evolved from productive maintenance into total productive maintenance. Figure 2 shows the evolution of TPM.

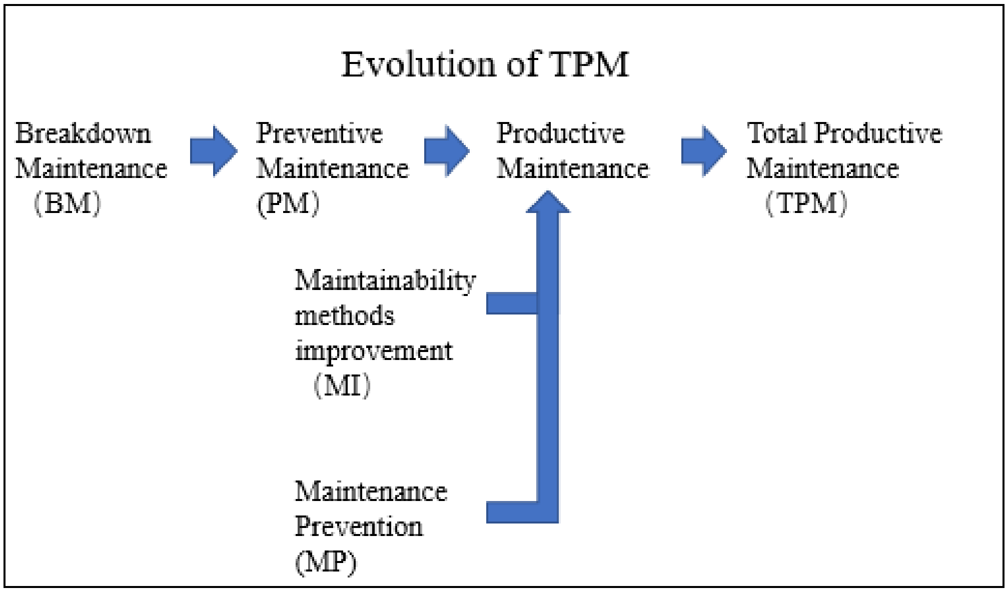

Figure 2. Evolution of TPM (Adapted from Total Productive Maintenance (p.5), by Terry Wireman, 2004, New York, NY: Industrial Press).

Definition of TPM. TPM was defined formally by the Japan Institute of Plant Maintenance (JIPM) in 1971 and 1989 respectively. It gradually evolved into a systematic approach adopted by different departments beyond production, including sales, administrative, and research and development (Tokutaro, 1994).

The implementation of TPM includes five primary points:

1. Maximize overall equipment effectiveness.
2. Build a comprehensive PM system for the life of the equipment.
3. Involve all departments that plan, use, and maintain equipment in implementing TPM.
4. Involve all employees from top management to shop-floor workers.
5. Promote PM through motivation management, i.e. autonomous small-group activities. (McCarthy & Rich, 2015, p. 35)

Eight Pillars of TPM

According to Kunio and Seiichi (1992), five common pillars support TPM's goals of improvement: focused improvement, autonomous maintenance, planned maintenance, training, and early equipment management. The new pillars of quality maintenance, safety programming, and administrative work were added for TPM in non-manufacturing circumstances (Tokutaro, 1994). This comprehensive system was developed from early TPM experiences.

A detailed description of each of the eight pillars follows:

Focused improvement. The goal is to eliminate the losses that happen during production processes (Tokutaro, 1994). This activity requires a cross-functional project team including operators, maintenance technicians, and engineers. The team checks all components of equipment and classifies the type of losses and analyzes all factors related to equipment conditions, materials, work procedures, and so on (Kunio & Seiichi, 1992).

Autonomous maintenance. Normally used for small-group maintenance, which can effectively reduce the cost of maintenance. Autonomous maintenance is especially important in the TPM system. There are three goals in an autonomous maintenance system. First, production and maintenance personnel are integrated to make equipment conditions stable. Operators learn that they not only run machines and equipment but also maintain them daily through cleaning, inspection, lubrication, and other light maintenance tasks. Second, operators learn more about the functions of their equipment, which aims to give operators a clear understanding of the problems that occur on equipment. This understanding helps operators prevent issues by detecting and eliminating abnormalities. Third, operators are encouraged to improve the performance and reliability of the equipment. This change makes the response to problems more rapid (Kunio & Seiichi, 1992).

Planned maintenance. Planned maintenance is more preventive and predictive than AM. The goal of planned maintenance is to eliminate breakdown and decrease unexpected failures (Tokutaro, 1994). In a planned maintenance program, companies monitor and analyze the mean times of tasks between failures using annual, monthly, and weekly maintenance calendars so that companies can estimate the time required for equipment shutdown maintenance before it malfunctions (Makoto & Hisao, 1994). The basic activities of planned maintenance include periodic checks, inspection, and servicing.

Training. Education and training are becoming more important in modern industry. Similarly, education and training to support TPM and related activities are effective. Two basic approaches for training are applied: on-the-job training (OJT) and self-development (Hisamitsu, 1994). OJT helps operators understand more about the equipment. Self-development educates operators, so they can make more accurate determinations of when abnormalities occur.

Early equipment management. For those equipment manufacturers that pursue a return on investment, the best way to correct equipment problems is during the equipment design stage (Hisamitsu,1994). The concept of early equipment management was introduced to address these cases. For the activities of early equipment management, two things must be considered: life-cycle costs and maintenance prevention design (Kunio &Seiichi,1994). The life-cycle cost was defined by the U.S. Office of Management and the Budget (1979, #A109) as “the sum of the direct, indirect, recurring, non-recurring, and other related costs of a large-scale system during its period of effectiveness. It is the total of all cost generated or forecast during the design, development, production, operation, maintenance, and support processes.” New equipment defects result in costly delays because they affect other related departments with rework.

In addition, maintenance prevention (MP) design activity minimizes future maintenance costs and failure losses of new equipment based on data regarding current equipment and new technology (Hisamitsu, 1994). At the same time, MP design integrates equipment design, production, and maintenance to make new equipment easy to maintain.

Quality maintenance. Quality maintenance (QM) in TPM aims to create equipment and process conditions that support companies’ other TPM measures (Ikuo, 1994). Controlling equipment and process conditions is a key to achieving zero defects and producing a perfect product. Specifically, the equipment and process conditions are related to four production inputs: raw materials, basic equipment, processing method, and people’s skills (Tokutaro, 1994). Companies must check and measure conditions related to these four production inputs periodically. Meanwhile, companies also must predict potential quality defects based on data trends. Consequently, by improving these inputs’ conditions, companies can eliminate defects effectively.

Safety and environment. Currently, building a safe environment is essential in many workplaces. Similarly, safety and environment have been a part of TPM activities;

they refer to eliminating accidents and reducing pollution (Ikuo, 1994). The aim of safety and environment activities in TPM is to achieve zero accidents and zero pollution. There are many different TPM methods to improve safety. For example, autonomous maintenance and focused improvement eliminate potentially unsafe parts; TPM training helps operators understand more about the functions of the machines they run, which encourages them to detect abnormalities. Safety and environment activities are related to other TPM activities, much like QM.

TPM in administration. Administrative activities can be thought of as the “head” of a company that supports other departments, such as production, sales, design, and maintenance, by processing information collected from external and internal resources and sharing it with other departments (Makoto, 1994). At the same time, the administrative function can respond quickly to changes. TPM activities can also be effectively employed in administrative functions. The key to implementing TPM in administrative departments is to think of it as a plant that collects, analyzes, and allocates information (Tokutaro, 1994). Focused improvement, autonomous maintenance, training, and education are implemented, and staff’s allocation and performance must be considered during TPM implementation (Makoto, 1994).

Benefits of implementing TPM

TPM can increase the competitiveness of manufacturing companies. By achieving zero failures, zero breakdown, zero defects, and zero accidents and pollution, companies can easily reach the world-class standard. Seiichi’s report (1991, p.295) showed the results of the companies implementing TPM:

Productivity: Breakdowns were reduced by 98% (from 1000 to 20 times/month).

Quality: The defect rate was reduced by 65% (from 0.23% to 0.08%).

Cost: Labor cost was reduced by 30%; Maintenance cost was reduced by 15%-30%; Energy consumption was reduced by 30%.

Delivery: Inventory turnover increased by 200% (from 3to 6 times per month).

Morale: improvement ideas increased by 127% (from 36.8 to 83.6 ideas/person per year).

Safety: No accidents.

Environment: No Pollution.

OEE Components and the Six Losses

Implementing TPM improves overall equipment effectiveness (OEE). The way to improve OEE in the TPM system is to eliminate the six major losses in production. These are breakdown losses, setup and adjustment losses, idling and minor stoppage losses, speed losses, quality defects and rework, and start-up losses (Kunio & Seiichi, 1992). Measuring these losses is one of the basic approaches for analyzing the impact of TPM.

Overall equipment effectiveness is a percentage that directly indicates the waste situation of a plant or company (Nicholas, 1998). A high percentage means there are fewer waste issues during production and operations. OEE has three components: availability rate, performance rate, and quality rate. These three parameters are measured separately to indicate the status of equipment or a process's operation. The formula for OEE is shown in (1) as follows (Edward & Hartmann, 1992).

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{1}$$

Availability rate. The availability rate refers to the percentage of available equipment running time (Kunio & Seiichi, 1992). In other words, is the equipment available when needed? The following equation (2) is its formula:

$$\text{Availability} = \frac{\text{Planned Production Time} - \text{Stop Time}}{\text{Planned Production Time}} \tag{2}$$

Planned production time refers to the available time of the equipment daily (weekly or monthly) minus all other scheduled stoppages, such general maintenance and daily meetings. Stop time refers to unscheduled stoppages, which are related to two of the six big losses, breakdown, and setups and adjustments. For example, a workplace has a daily morning meeting that lasts about five minutes, the general maintenance is 20 minutes before operators end work and the total working time is eight hours (480 minutes). At the same time, if production has a breakdown of 20 minutes, with another 20 minutes for adjusting operation parameters, the planned production time would be 455 minutes (480-25=455) and stop time would be 40 minutes (Kunio & Seiichi, 1992). The availability rate would be calculated as:

$$\text{Availability} = \frac{455 - 40}{455} = 91.21\%$$

This parameter indicates the daily rate of equipment use.

Performance rate. The performance rate is based on the operating speed rate and the net operating time (Kunio & Seiichi, 1992). This parameter shows the hidden losses inside the equipment. The performance rate formula is as follows (3):

$$\text{Performance} = \frac{\text{Ideal Cycle Time} \times \text{Total count}}{\text{Planned Production Time} - \text{Stop Time}}$$

(3)

This formula is combined with the operating speed rate and the net operating time (Kunio & Seiichi, 1992), which are related to speed losses, and idling and minor stoppage losses separately.

The operating speed rate is a percentage derived by comparing the ideal cycle time per product with the actual time per product (Kunio & Seiichi, 1992). This data indicates the condition of speed losses during operation. The formula (4) is given below:

$$\text{Operating speed rate } = \frac{\text{Ideal Cycle Time}}{\text{Actual Cycle Time}}$$

(4)

For example, if a machine's ideal cycle time per product is two minutes and the actual cycle time per product is three minutes, the calculations would be:

$$\text{Operating speed rate} = \frac{2\text{mins}}{3\text{mins}}$$

=66.6%

The net operating time rate is a rate between actual production time and planned production time (Kunio & Seiichi, 1992), which indicates losses caused by idling and minor stoppages. The formula is as follows (5):

$$\text{Net operating time} = \frac{\text{Total count} \times \text{actual cycle time}}{\text{Planned production time} - \text{stop time}}$$

(5)

For example, if a machine's total count produced per day is 130, the actual cycle time is three minutes, and the actual operation time is 415 minutes, the calculations would be:

$$\text{Net operating time} = \frac{130 \times 3\text{mins}}{415\text{mins}} = 93.98\%$$

These figures can then be used to calculate:

$$\text{Performance} = 66.66\% \times 93.98\% \text{ or } \frac{2\text{mins} \times 130}{455\text{mins} - 40\text{mins}} = 62.65\%$$

This performance rate shows the equipment performance condition.

Quality rate. The quality rate is a percentage of output produced by equipment that has no defects (Nicholas, 1998). Rework and scrap are usually the main effects in quality issues along with the start-up and yield losses (Kunio & Seiichi, 1992). Sometimes quality is highly dependent upon worker training and test operations, among other factors (Kunio & Seiichi, 1992). The formula for quality rate is as follows (6):

$$\text{Quality} = \frac{\text{Good Count}}{\text{Total Count}} \tag{6}$$

For example, if a machine produces 130 units per day, and the average of defects per day is about ten units, the calculation is as follows:

$$\text{Quality} = \frac{120}{130} = 92.30\%$$

In summation, for example, using all the data above, the OEE of this machine is calculated:

$$\text{OEE} = 92.21\% \times 62.65\% \times 92.30\% = 53.32\%$$

This number shows that there is potential for this machine to improve. By analyzing data, management can determine what should be improved or what they should do to improve future production.

Autonomous Maintenance

Autonomous maintenance plays a key role in the TPM system. Before implementing an autonomous maintenance program, management should know the goals of AM. The first goal of AM aims to prevent equipment deterioration by daily maintenance. The second is to restore the condition of equipment or process to its ideal status. At the same time, the basic condition should be established. It requires that workers have a high-level ability to know and operate their equipment or process to achieve the basic condition. Another important goal is to teach people a new way of thinking and working that involves operators in the maintenance activities. (Koichi, 1994)

Seven Steps of Autonomous Maintenance

Autonomous maintenance has several goals as mentioned above. However, achieving these goals requires a step-by-step approach. There are seven steps in the implementation of autonomous maintenance. Kunio (1992) and Tokutaro's (1994) presented seven common steps. Figure 3 shows the steps of autonomous maintenance.

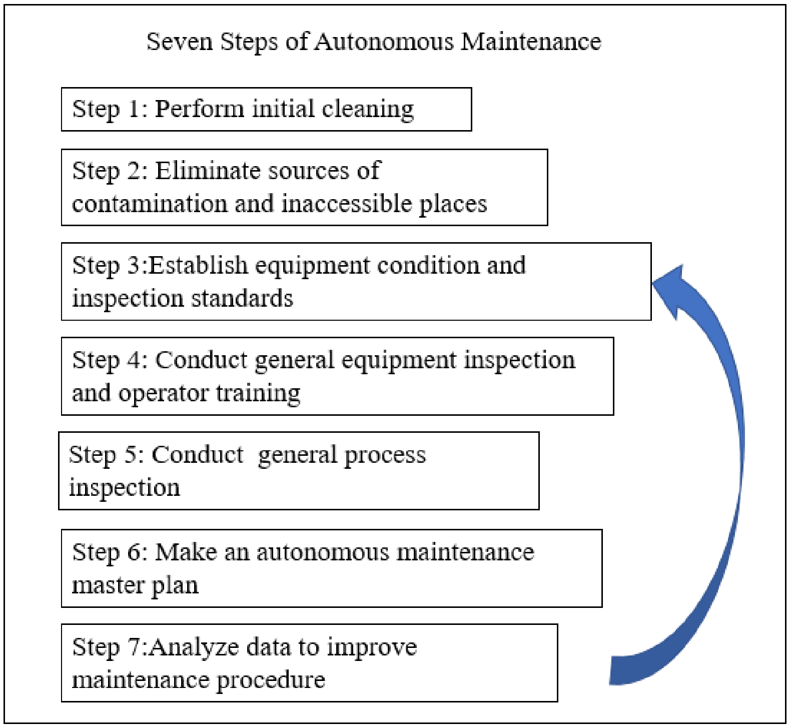

Figure 3. Seven steps of autonomous maintenance. Reprinted from *TPM in Process* Industries (p.102), by Koichi, 1994, New York: Productivity Press.

Step 1. Perform initial cleaning. In this step, several activities should be performed. First, operators must eliminate dust and dirt from the equipment they run to prevent accelerated deterioration. At the same time, management teaches operators why cleaning important for production. By thoroughly cleaning the equipment, operators discover abnormalities that they have never seen. However, because this is the first time that operators have seen the abnormalities, they do not know how to distinguish between normal or abnormal. Therefore, they require a maintenance technician to teach them. Some basic tools can be applied at this step, e.g., use of a card to tag the location of the abnormalities.

Step 2. Eliminate sources of contamination and inaccessible places. The goal of this step is to reduce the time for cleaning, checking, and lubricating by eliminating the sources of contamination. Two tasks are performed in this step. The first is the removal of the sources of contamination. The second entails improving the procedures of cleaning, checking, and lubricating. For example, if operators remove some sources of contamination thoroughly, the cleaning time would be reduced. Similarly, repositioning the lubricant inlets can make lubrication easier.

Step 3. Establish cleaning and inspection standards. In this step, operators cooperate with maintenance technicians to standardize cleaning and lubricating procedures based on the results of the first two steps. The team (composed of operators and maintenance technicians) decides the specifics of cleaning, checking, and lubricating by answering the "five Ws and one H" (what, where, why, when, who, and how). Through this method, operators know what parts of the equipment they need to clean and lubricate, when to inspect and lubricate them, why to clean and lubricate them, and how to check them.

Step 4. Conduct general equipment inspection and training. Step four is a path whereby an operator gains autonomous maintenance skill. The step consists of preparation, training, transference, and skills evaluation. In the first stage, maintenance technicians prepare training materials based on the categories of selection. The training consists of the required components of the equipment with their name and functions, yield data, inspection procedures, and the actions to be performed in the case of abnormalities. Next, general inspection skills are transferred from the maintenance technicians to the team leader, and from the maintenance technicians to operators via training. Usually, this training is on-the-job. The third stage is a general inspection of every component of equipment that was selected in the first three steps. Finally, the consolidation stage requires an evaluation of operators' individual skills regarding the general inspection and other skills needed.

Step 5. Conduct general process inspection. This step makes sure that an autonomous inspection is performed correctly and reliably on every piece of equipment across the process. Every item and method for cleaning, inspection, and lubrication must be reviewed by a team involving production and maintenance. Other factors are also considered during this step, including as time limitations and the operators' inspection skills.

Step 6. Systematize autonomous maintenance. This step establishes procedures for autonomous maintenance by arranging the last five steps in an autonomous maintenance master plan.

Step 7. Continue improvement by autonomous maintenance. Up to this point, the operator team has become more involved in autonomous maintenance system. However, the team also needs to analyze equipment data such as the results of equipment inspections, defects, and conditions of tool wear. This can improve equipment and increase process reliability, safety, maintainability, quality, and operability. Additionally, this makes operators partners in equipment maintenance and involved in the TPM program, which improves the ease of further TPM implementation. (Koichi, 1992; Kunio & Seiichi, 1992, Cloves & Jandercy, 2016; Melesse & Ananth, 2014)

Benefits of Implementing AM

Reduced breakdown time. Reducing breakdown time is one of benefit of implementing autonomous maintenance to production. Through daily cleaning, inspection, and lubricating activities, AM effectively prevents components of equipment from accelerated deterioration resulting breakdown and abnormalities (Koichi, 1992).

Reduced cost. In most cases, maintenance activities are costly for small companies. By involving operators in the daily maintenance, companies can reduce the cost of maintenance labor. As breakdown time decreases, the requirement for a maintenance technician goes down (Ade, 2014).

Good working environment. Usually, in a non-TPM company, production department and maintenance department are often opposed because of their different responsibilities. By training, operators improve their understanding of their equipment and the importance of equipment maintenance. The relationship between operators and maintenance technicians is thereby transformed into a partnership. (Ade, 2014)

Application Related to AM and TPM

Assela Malt Factory case. In Melesse and Ananth's research (2014), the Assela Malt Factory gained a significant achievement by applying autonomous maintenance to the company's boiler plant. This factory was a supplier of malt to local breweries in Ethiopia. The research reported the following data between January 2011 and June 2012: The breakdown time decreased by 46.38% (from 186.39 hours to 99.94 hours monthly) after the application of AM. The average capacity increased by 8.75% (from 2185.12 to 2394.57 tons monthly) Machine idle time only increased by 8.01% (from 54 hours per month to 58.7 hours per month). Maintenance cost was reduced by 64.42% (from $520 to $185 every month). Plant OEE increased by 13.79% (from 66.44% to 80.23%). Through the application of AM, this plant achieved improvement in one and half years (Melesse & Ananth, 2016).

A glazing-line case. In another study, Amir (2015) indicated that a glazing line of one company reduced defect rates by 8.49% from 14.61% to 6.12% and reduced the breakdown time from 2502 to 1161 minutes. The OEE improved from 22.12% to 28.61% monthly from April to September 2014. Although the OEE was still very low, the AM activities played a positive role in this company's improvement (Amir, 2015).

A case of a semiconductor material manufacturer. This study integrated the Root Cause Analysis (RCA) and Failure Mode Effects Analysis (FMEA) to reduce the company's manufacturing costs and promote employee and equipment productivity, through on autonomous maintenance and planned maintenance. The breakdown frequency of the company decreased by 23 occurrences monthly (from 96 times to 68 times). The OEE increased from 48.24% to 61.40%, and the availability rate rose substantially from 69% to 82%. In this case, AM contributed to the improvement of reduction of the breakdown time with preventive maintenance (Chen, 2013).

Summary of Literature Review

As the literature review shows, the steps of autonomous maintenance are associated with the pillars of TPM, which are an integral part of the system. When carrying out an autonomous maintenance program, management must consider operator training, future planned maintenance, and focused improvement. An autonomous maintenance program is a first step in the TPM process. Basic equipment conditions and operator training are the two priorities of this study.

Methodology

Participants

The study was conducted at a PTFE sealing production plant, located at Company S. The PTFE plant had approximately 80 employees, which included operators, managers, supervisors, and engineers. Three processes were studied: CNC, Mixing, and Modeling. One supervisor and one engineer were in charge of each process.

The researcher gave a brief introduction of the study to the management of this PTFE plant upon initial contact. The researcher and management then built a cross-functional team of five experienced operators from the processes consisting of one experienced maintenance technician, one quality engineer, and two lead technicians. This team participated in the implementation of TPM. In this team, teammates were familiar with the maintenance and operation of the machines or processes chosen. Finally, the operators assisted the researcher in collecting the data for each process.

Variables

The primary goal of the research was to improve Overall Equipment Effective (OEE) of each production process by improving the conditions of equipment elements. OEE was identified as “the percentage of planned production time that is truly productive” (Ade, 2014, p.7). OEE comprises three components, namely availability, performance, and quality. The OEE of each machine was the dependent variable in this project. The dependent variable describes the effectiveness of each process, which are affected by the six major losses (i.e., unplanned stops, setups and adjustments, small stops, slow running, production defects, and reduced yield).

Autonomous Maintenance (AM) was employed to improve the conditions of the equipment. The implementation of AM was designated as the independent variable in this project. The status of AM implementation used was “not daily” and “done daily”. Before and after implementing the AM approach in the processes, the OEE of each machine in the product line was measured.

Experimental Procedures

The researcher applied the autonomous maintenance scheme as the framework to conduct this research. TPM is a systematic approach to making production processes more effective by involving all people including operators, managers, and maintenance technicians in the process. The TPM approaches are preventive, proactive, and corrective. The procedure of this study emphasized autonomous maintenance, which is more preventive and proactive. The study provided the manager of this PTFE department with a direction to apply a TPM approach in production. Because of the time limitation, the researcher spent three months conducting the research and the steps were simplified. The portion AM that deal with the restoring the conditions of equipment was replaced by selecting machines in better condition. Then TPM would be continually managed in the future daily production.

The research included the following phases:

1. Machines and process selection
2. Condition assessment
3. Baseline OEE measurement
4. Operator training
5. Execution of autonomous maintenance

6. OEE measurement after implementation of AM

Machine and process selection. The researcher and management selected the best machines and processes based on whether all the components of the machine worked normally in the past operation records. There were three CNC machines from CNC Workshop, one group from Mixing Workshop, one group from Modeling Workshop. The cross-functional team was also formed during this phase.

Condition assessment. According to the literature mentioned above, before the plant started to implement the TPM approach, the researcher and participants needed to perform the preparation work. The preparation work involved a criticality assessment and condition appraisal (Tables 1 and 2), which helped the researcher and management to create basic equipment conditions. Operators would clean and lubricate equipment based on their condition assessments from Table 1 and 2.

The researcher assessed the production equipment and agreed to the relative criticality of each element, with regard to the overall impact on the production alongside operators and maintenance technicians. Specifically, the researcher reviewed the production process for team members to help them understand the mechanisms, controls, material processing, and operating methods. Meanwhile, operators and maintenance technicians were involved in ranking the key parts of the processes. Table 1 shows an example of a typical matrix form that recorded equipment elements and criteria scores.

Table 1.

An example of criticality impact assessment matrix form of CNC #1.

Equipment Description	1-3 ranking as impact on: CNC #1								
	S	A	P	Q	R	M	E	C	Total
Spindle bearing	1	3	3	3	3	3	1	3	
Spindle belt	1	3	3	3	3	3	1	2	
Servo shaft linear guide	1	3	3	3	3	3	1	3	
Servo shaft bearing	1	3	3	3	3	3	1	3	
Coupling	1	3	3	3	3	3	1	3	
Hydraulic station	1	3	3	3	3	3	2	3	
Hydraulic valve	1	3	3	3	3	3	2	2	
Hydraulic cylinder	1	3	3	3	3	3	2	3	
Rotary cylinder	1	3	3	3	3	3	2	3	
Power module circuit	1	3	3	3	3	3	1	3	
Spindle module circuit	1	3	3	3	3	3	1	3	
Spindle servo motor	1	3	3	3	3	3	1	3	
Servo X axis module circuit	1	3	3	3	3	3	1	3	
Servo X axis motor	1	3	3	3	3	3	1	3	
Servo Z axis module circuit	1	3	3	3	3	3	1	3	
Servo Z axis motor	1	3	3	3	3	3	1	3	
Safety module circuit	3	3	2	1	1	3	1	3	
Relay board	2	3	3	2	3	3	1	3	
Control panel	1	3	3	2	3	3	1	3	
Servo turret controller	1	3	3	3	3	3	1	3	
Servo turret motor	1	3	3	3	3	3	1	3	

S=Safety R=Reliability 1=No impact
A=Availability M=Maintainability 2=Some impact
P=Performance E=Environment 3=Significant impact
Q=Quality C=Cost

The researcher then used the same criticality assessment elements to assess the present condition of the equipment. In other words, the present condition of each piece of equipment was assessed, e.g., the panel of the CNC machine and the motor of the modeling machine. The researcher filled out the form according to the actual condition. Table 2 shows an example of a present condition appraisal of CNC #1.

Table 2.

Example of present condition appraisal of CNC #1.

		Condition Appraisal				
Machine Description: CNC workshop Machine # 1						
Asset No.: 1	Year of Purchase: 2009	Appraisal By:				
Machine No.: 1	Location: PTFE department CNC workshop	Appraisal Date:				
Item No.	Appraisal Rating by Sub Asset	Not applicable	Satisfactory	Broken Down	Need Attention Now	Need Attention Later
1	Electronic					
	Power module circuit		√			
	Spindle module circuit		√			
	Spindle servo motor		√			
	Servo X-axis module circuit		√			
	Servo X-axis motor		√			
	Servo Z-axis module circuit		√			
	Servo Z-axis motor		√			
2	Safety module circuit					
	Relay board		√			
	Control panel		√			
	Servo turret controller		√			
	Servo turret motor		√			
3	Hydraulic					
	Hydraulic station					√
	Hydraulic valve				√	
	Hydraulic cylinder				√	

Item No.	Appraisal Rating by Sub Asset	Not applicable	Satisfactory	Broken Down	Need Attention Now	Need Attention Later
	Rotary cylinder		√			
4	Mechanical					
	Spindle bearing		√			
	Spindle belt		√			
	Servo shaft linear guide		√			
	Servo shaft bearing		√			
	Coupling		√			

Baseline OEE measurement. In this step, the researcher chose data from three months of the past year and calculated the initial OEE of the selected machines. These data were compared with the data after autonomous maintenance was applied.

Operators training. In this phase, the researcher needed the cooperation of supervisors to set a schedule of operator training (see Table 3). In addition, a checklist titled “Daily Cleaning and Inspection Checks” was cooperatively created with operators and maintenance technicians, which guided the daily activities in cleaning, checking, and inspection. Table 4 shows an example of the daily cleaning and inspection checks.

Table 3.

Training schedule form.

TOTAL PRODUCTIVE MAINTENANCE PROGRAM					
CNC workshop's lathe group					
Operator Training Schedule					
Member / Item	Q. Chen	W. Sun	Z. Chen		
Chuck pressure gauge (5-40Bar)	4	3	4		
Rail oil	4	4	4		
Cutting fluid	4	4	4		
Operation panel switch	4	3	4		
Safety lock	4	4	4		
Oil pipeline leaks	4	4	4		
Conveyer belt	4	4	4		
Tricolor lamp	4	4	4		
Machine interior lighting	4	4	4		
Pneumatic safety door	4	4	4		
Chuck clamping	4	4	4		
Panel has alarm	4	3	4		
1=Trained in procedures by maintenance	2= Carried out process	3=Competent in process	4=Able to train others		

(adapted from Willmott & McCarthy, 2001)

Table 4.

An example of the daily cleaning and inspection checks checklist for CNC #1.

Machine No.	Year: Month:										Department: PTFE				
Daily Cleaning and Inspection Checks															
Items/ Details	1	2	3	4	5	6	7	8	…	26	27	28	29	30	31
Chuck pressure gauge (5-40Bar)	√	√	√	√	√	√	√								
Rail oil	√	√	√	√	√	√	√								
Cutting fluid	√		√	√	√	√	√								

Daily Cleaning and Inspection Checks																
Items/ Details	1	2	3	4	5	6	7	8	…	26	27	28	29	30	31
Operation panel switch	√	√	√	√	√	√	√								
Safety lock	√	√	√	√	√	√	√								
Oil pipeline leaks	√	√	√	√	√	√	√								
Conveyer belt	√		√	√	√	√	√								
Tricolor lamp	√		√	√	√	√	√								
Machine interior lighting	√		√	√	√	√	√								
Pneumatic safety door	√	√	√	√	√	√	√								
Chuck clamping	√	√	√	√	√	√	√								
Panel has alarm	√	√	√	√	√	√	√								
Responsibility Signature	Chen	Sun	Chen	Sun	Sun	SUN	Chen								
If normal, use " √ " to indicate; for abnormal, use "×".															

During the training period, a standardized procedure of cleaning, checking, and inspection was created with experienced operators, maintenance technicians, and engineers. Operators then implemented these activities.

Execution of autonomous maintenance. In this phase, the operators began to execute the daily checking based on the basic conditions of all equipment that had been set, and the daily checking and cleaning checklist.

OEE Measurement after AM. First, the actual OEE was calculated based on current history record. Second, the operators monitored the OEE of each process every week from the start of the application of the TPM approach. Operators recorded any time losses during the work and entered them into Excel forms. The OEE formulas shown in the literature review (Equations 1-6) were used.

After applying all the steps, the team reviewed the daily checklist based on the feedback. The period of recording the OEE data was divided into two periods, called "before implementing the AM approach" and "after implementing the AM approach".

Instrumentation

In this study, the instruments previously described aided the participants in applying the TPM measures to the processes of the PTFE plant.

1. *Criticality assessment matrix form.*
2. *Condition appraisal.*
3. *Daily checking and inspection form.*
4. *Autonomous maintenance training schedule (for operators).*

Equipment and Processes

Figure 4 shows the flow of the general product line from raw material to final products across the three selected processes

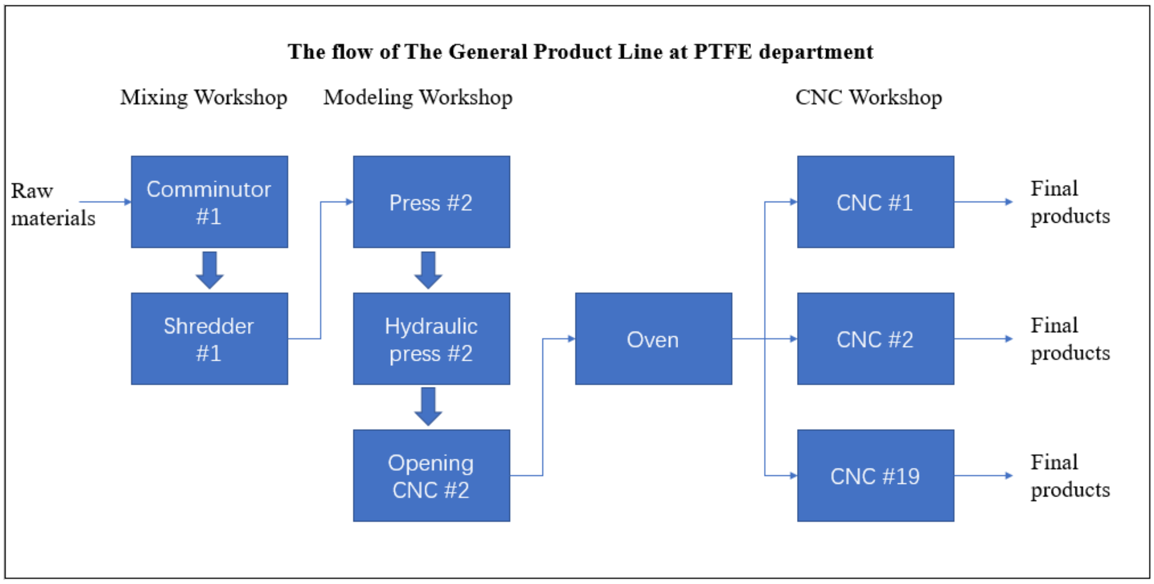

Figure 4. The flow of the general product line at PTFE department

The machines measured for OEE were:

1. CNC workshop: CNC #1, CNC #2, CNC #19 *(see Figures 5, 6, and 7)*

2. Modeling workshop: Group #2 (Hydraulic press #2, Press #2, Opening CNC #2)

3. Mixing workshop: Group #1 (Comminutor #1, Shredder #1)

(The Modeling Workshop and Mixing Workshop have proprietary information, so they cannot be shown.)

Figure 5. PTFE plant’s CNC workshop Machine #1.

Figure 6. PTFE plant’s CNC workshop Machine #2.

Figure 7. PTFE plant's CNC workshop Machine #19.

Threats to Validity

The procedure of implementing TPM requires a long-term period to achieve the optimization. However, there was not adequate time to observe the improved procedure and participate in the work to continually improve the processes. In addition, the researcher and managers did not have previous experience in TPM measures. Furthermore, at the beginning of implementing TPM, there could have been negative effects on availability, affecting the OEE of the production processes.

Data Analysis

The purpose of data analysis was to check whether the TPM approach was effective and suited to improving the OEE of this PTFE plant's processes. After data collection, the data was analyzed using descriptive analysis. According to the record of the processes' OEE value, the values of means, standard deviations, and ranges of OEE and its components were calculated using numerical analysis. Charts were drawn for three CNC machines from CNC Workshop, one group from Modeling Workshop, and one group from Mixing Workshop, which supported the analysis of the OEE trend of its components “before implementing AM” to “after implementing AM”.

Results

This chapter presents the production data of the machines or processes selected in the previous. The data was analyzed by comparing the change of the OEE mean and standard deviation, and other related data for each selected machine and process during a three-month period in 2016 and after implementing AM in 2017.

CNC Workshop

CNC # 1

Table 5 compares the OEE of CNC#1 at 2016 before implementing AM and at 2017 after implementing AM. The average OEE at 2016 and 2017 was respectively 82.7% and 83.8%. The increase was about 1.1%. The standard deviation at 2016 was 1.3%, while at 2017 it was 0.3%. The planned production time increased from 30,080 minutes to 30,225 minutes. The breakdown time in 2016 was 60 minutes, while it was 0 in 2017. The set-up time increased from 2,853 minutes to 2,926 minutes. Set-up time refers to the time that operators adjusted the machine's running parameters to make the products reaching the quality standard. The PF&D time decreased from 665 minutes to 650 minutes. PF&D time refers to a Personal Time, Fatigue, and Delay factor (U.S. Department of Labor, 2008). The run time increased from 26,502 minutes to 26,649 minutes. The total count product increased from 100,956 pieces to 102,516 pieces. The defect decreased from 1,477 pieces to 1,255 pieces

Table 5.

CNC#1 OEE and performance parameters.

	2016	2017
Mean of OEE	82.7%	83.8%
Standard Deviation	1.3%	0.3%
Planned Production Time	30,080 mins	30,225 mins
Breakdown Time	60 mins	0
Set-up Time	2,853 mins	2,926 mins
P, F, & D Time	665 mins	650 mins
Run Time	26,502 mins	26,649 mins
Ideal Cycle Time	0.25mins/piece	0.25mins/piece
Total Count	100,956 pieces	102,516 pieces
Defect	1,477 pieces	1,255 pieces

Figure 8 compares the OEE of CNC #1 before and after implementing AM. In June 2017, the OEE of CNC #1 was 83.9%, while in the same period of the previous year it was 82.3%. In July 2017, the OEE was 83.7%, while in July 2016, it was 82.8%.

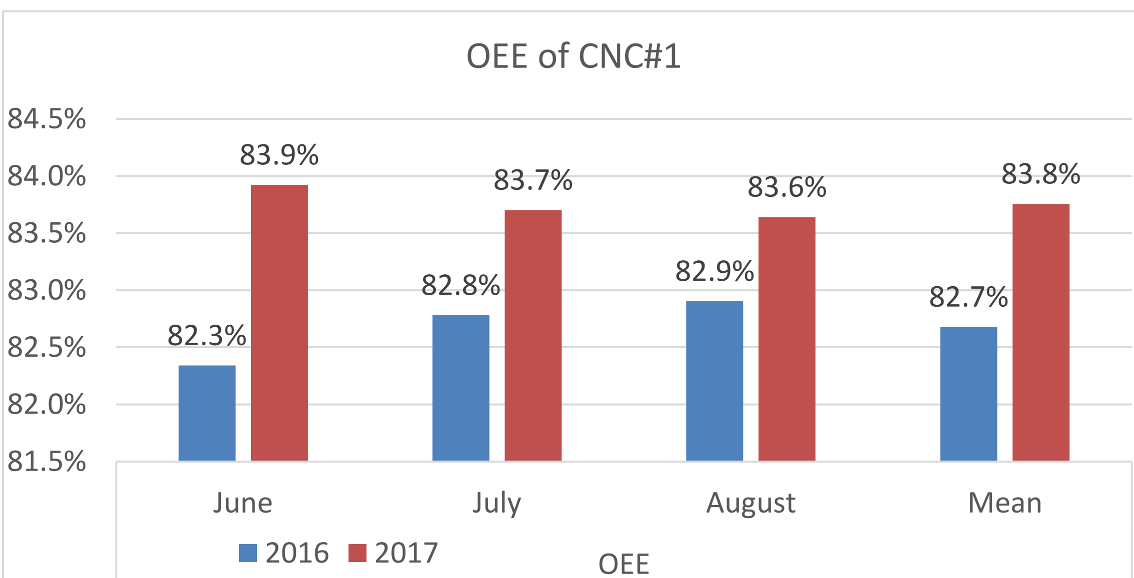

Figure 8. OEE of CNC #1.

In August 2017, the OEE was 83.6%, while in August 2016 it was 82.9%. The increase in each month was at least 0.7%.

Figure 9, Figure 10, and Figure 11 show the details of availability, performance, and quality rate, which directly showed their contribution to OEE. Figure 9 shows the performance of CNC #1 increased from 95.2% to 96.2%. Compared with 2016, the performance increased for all months.

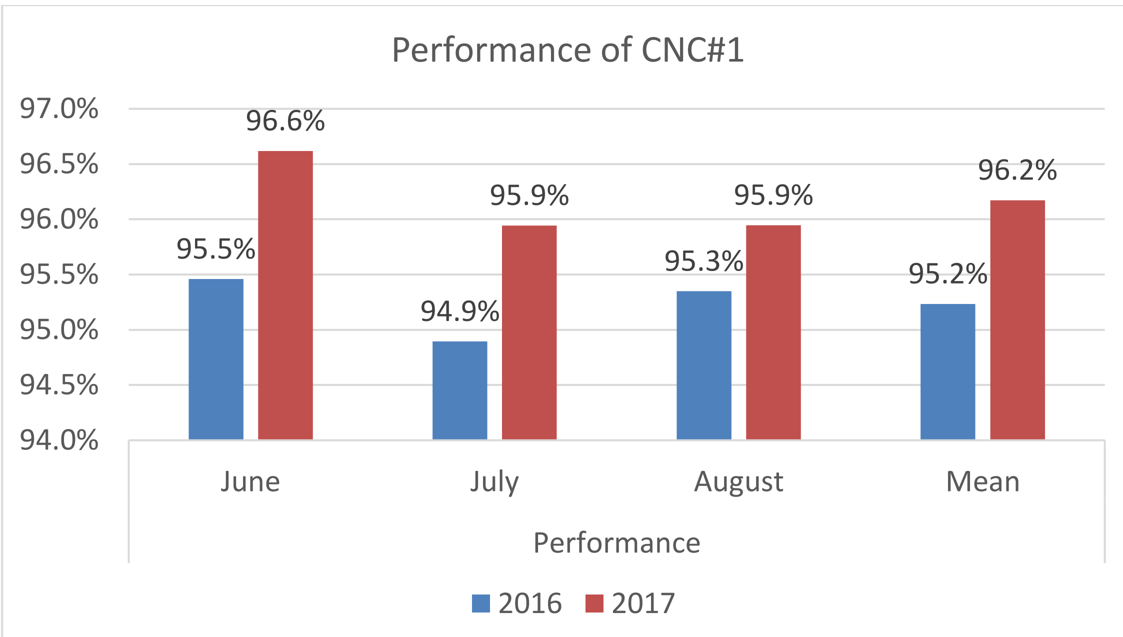

Figure 9. Performance of CNC #1.

Figure 10 shows the availability of CNC #1. There was virtually no change in availability after implementing AM. In addition, in July, the availability of CNC #1 decreased by 0.3%.

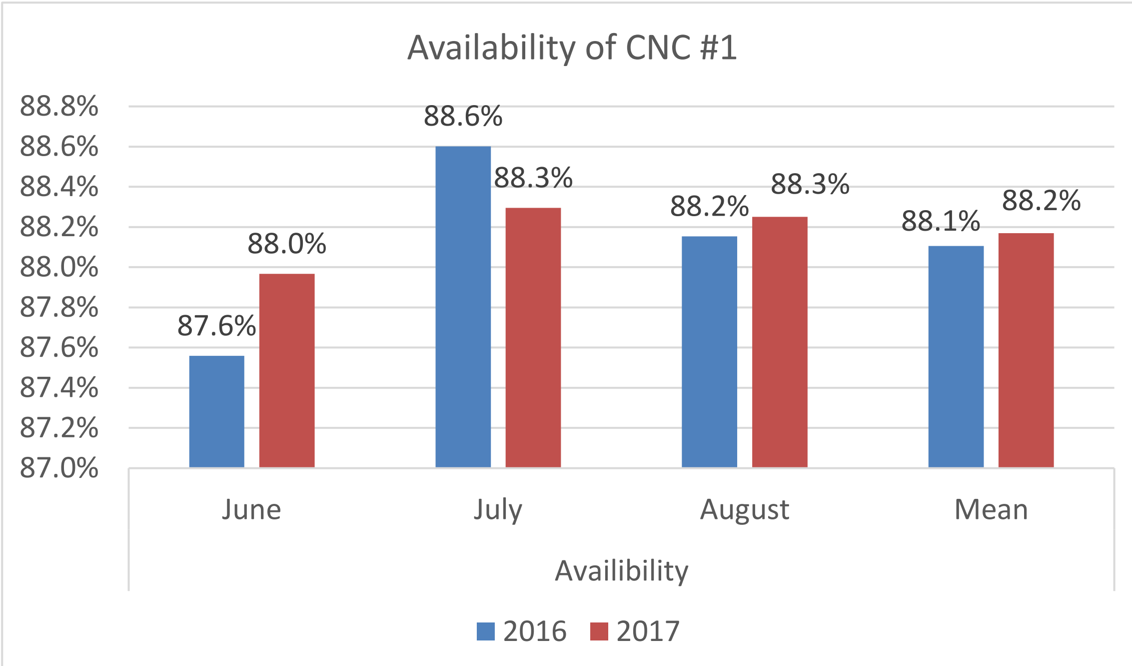

Figure 10. Availability of CNC #1.

Figure 11 showed CNC #1's quality rate increased from 98.5% to 98.8%. The increase of quality was about 0.2%. In the three selected months, AM made a slight positive impact on the quality part.

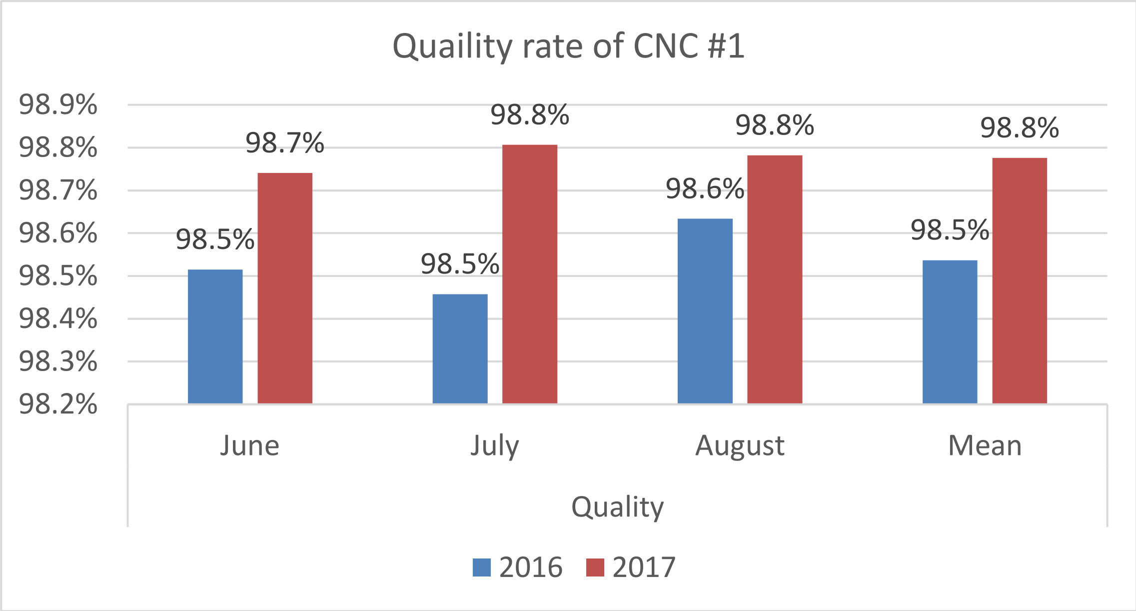

Figure 11. Quality rate of CNC #1.

The results indicated that AM made a positive contribution to the performance and the quality of CNC #1 while having a negligible impact on the availability. In addition, AM resulted in greater stability of OEE for CNC #1 as evidenced by the OEE's standard deviation.

CNC # 2

Table 6 shows the OEE mean and standard deviation for CNC #2. The mean increased by 0.8% from 82.9% in 2016 to 83.7% in 2017. The standard deviation declined from 1.5% to 0.3%. The breakdown time decreased from 48 minutes to 0. The set-up time decreased from 2,938 minutes to 2,842 minutes. The PF&D time decreased from 665 minutes to 650 minutes. The run time increased from 26,429 minutes to 26,733 minutes. The total count increased from 101,269 pieces to 102,528 pieces. The defect decreased from 1,511 pieces to 1,358 pieces.

Table 6.

CNC#2 OEE, and performance parameters of CNC #2.

	2016	2017
Mean of OEE	82.9%	83.7%
Standard Deviation	1.5%	0.3%
Planned Production Time	30,080 mins	30,225 mins
Breakdown Time	48min	0
Set-up Time	2,938 mins	2,842mins
PF&D Time	665 mins	650 mins
Run Time	26,429 mins	26,733 mins
Ideal Cycle Time	0.25mins/pics	0.25 mins/pics
Total Count	101,269 pics	102,528 pics
Defeat	1,511pics	1,358 pics

As shown in Figure 12, the OEE of CNC #2 increased from 82.7% to around 83.7%.

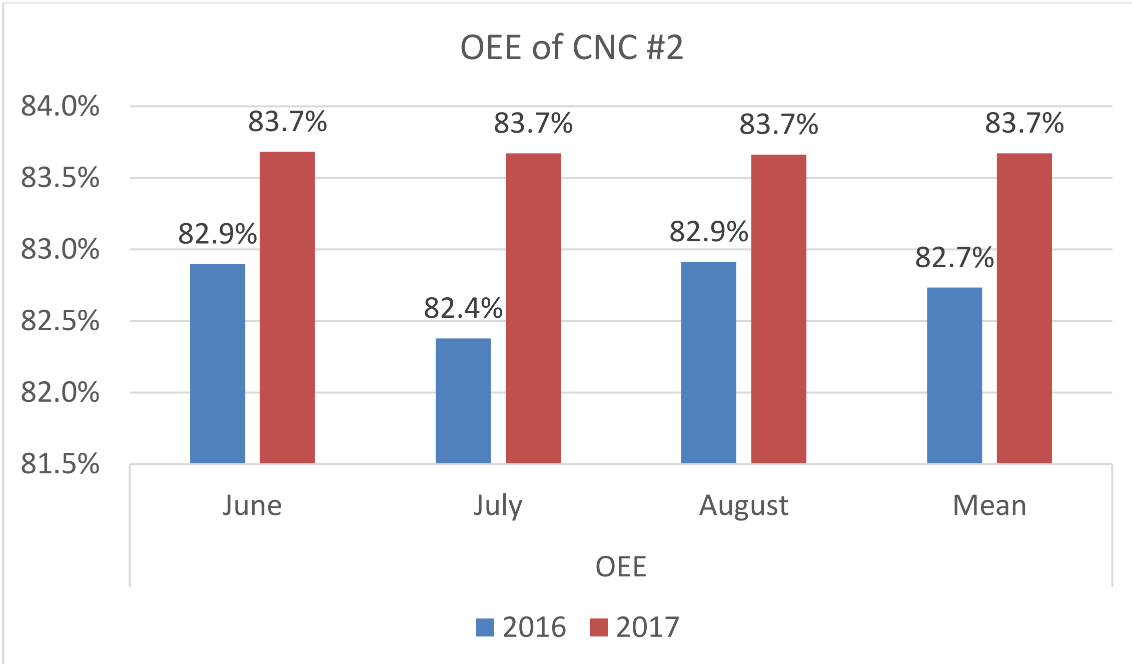

Figure 12. OEE of CNC #2.

As shown in Figure 13, the performance of CNC # 2 at June 2017 was 95.9%, while at same month of the last year 2016, it was 95.6%. The performance in July 2017 increased slightly by 0.6%, comparing with the data in July 2016. In August, the performance was rarely changed.

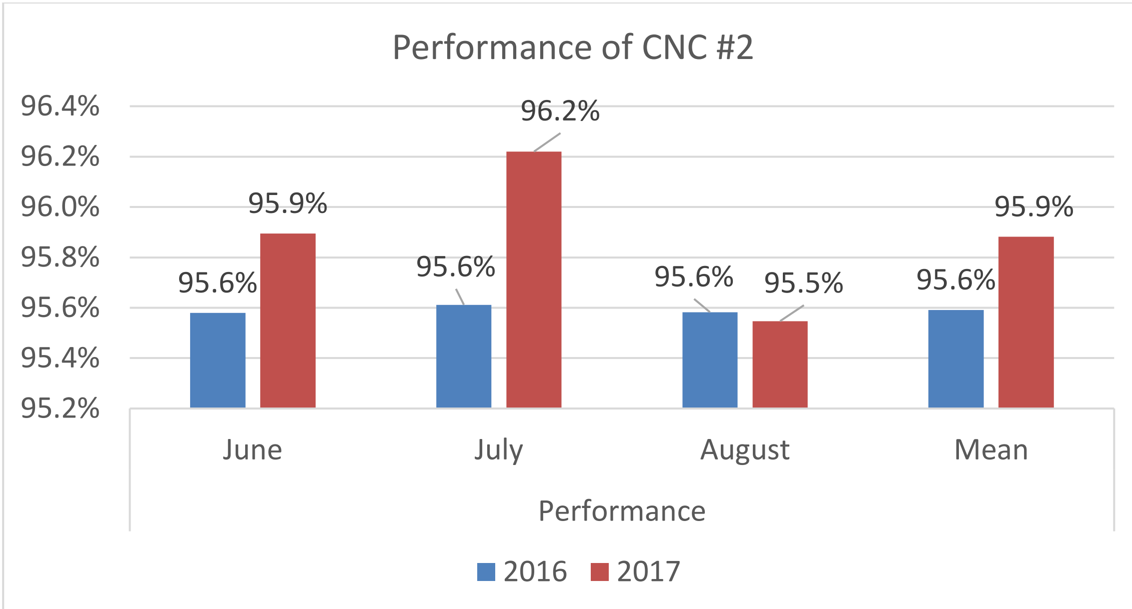

Figure 13. Performance of CNC #2.

In Figure 14, the availability of CNC #2 increased from 87.9% in 2016 to 88.5% in 2017. The availability increased to 88.5% in June 2017, from 88.1% in June 2016.

July showed growth of 0.7% relative to the same month of the previous year, from 87.5% to 88.2%. In August, it increased from 87.9% to 88.5%.

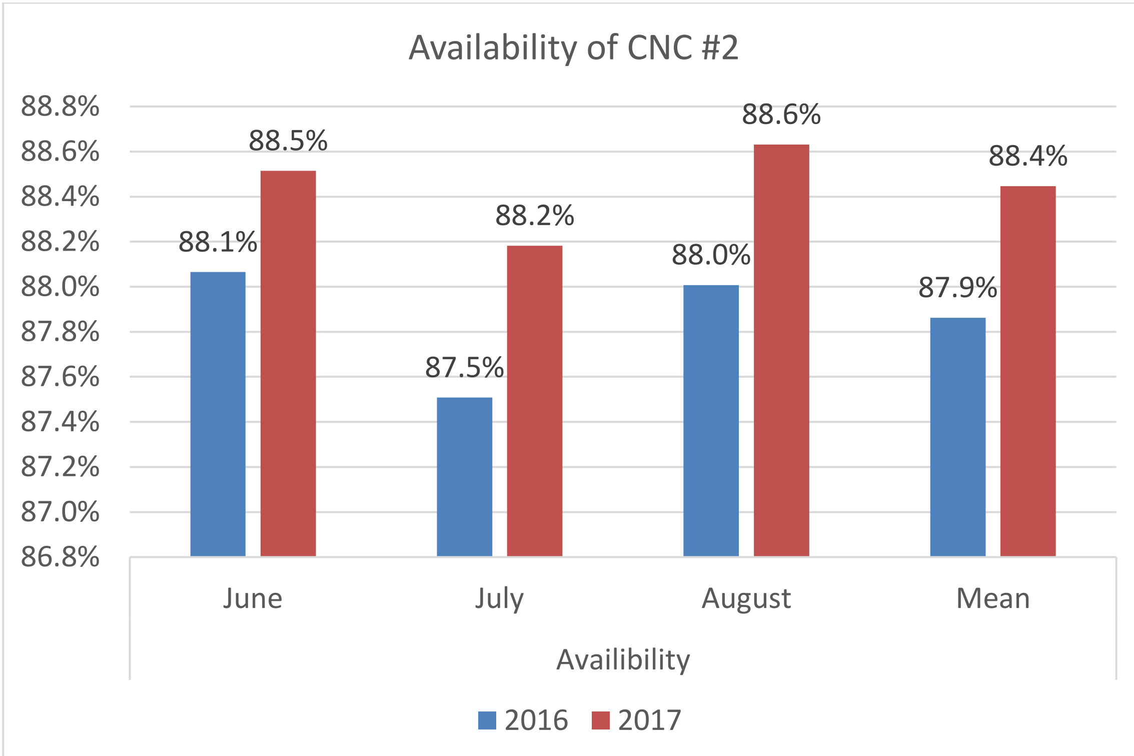

Figure 14. Availability of CNC #2.

Figure 15 shows the impacts on quality after implementing AM on CNC #2. The mean quality increased from 98.5% to 98.7%. The quality of CNC #2 in June 2017 was

98.6% compared to 98.4 % in 2016. The quality in July 2017 was 0.1% more than the rate in July 2016. The quality in August 2017 was 98.8% versus 98.6% in August 2016.

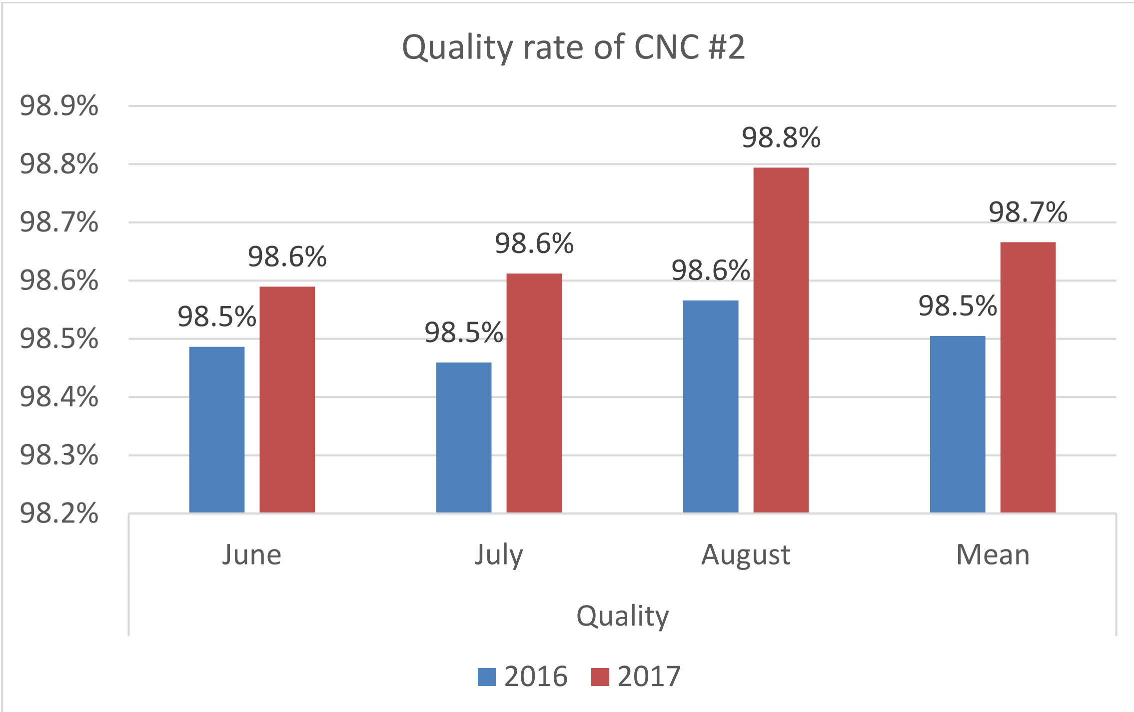

Figure 15. Quality rate of CNC #2.

The results indicated AM had a positive impact on performance, availability, and quality rate of CNC #2. The OEE increased. The variation of OEE for CNC #2 decreased.

CNC #19

As shown in Table 7, the OEE of CNC #19 in 2016 was 74.6%, while it in 2017 was 79.6%. The standard deviation of OEE of CNC #19 in 2016 was 3.2%, and it was decreased to 2.0% in 2017. The breakdown time decreased from 1,620 minutes to 75 minutes. The planned production time increased from 30,080 minutes to 30225 minutes. The set-up time increased from 2,708 minutes to 2,926 minutes. The PF&D time increased from 630 minutes to 650 minutes. The run time increased from 25,152 minutes to 26,574 minutes. The total count increased from 100,956 pieces to 102,516 pieces. The defect decreased from 1,477 pieces to 1,255 pieces.

Table 7.

CNC #19 OEE and performance parameters.

	2016	2017
OEE Average	74.6%	79.6%
Standard Deviation	3.2%	2.0%
Planned Production Time	30,080 mins	30,225 mins
Breakdown Time	1,620 mins	75 mins
Set-up Time	2,708 mins	2,926 mins
PF&D Time	630 mins	650 mins
Run Time	25,152 mins	26,574 mins
Ideal Cycle Time	0.25mins/pieces	0.25mins/pieces
Total Count	100,956 pieces	102,516 pieces
Defects	1,477 pieces	1,255 pieces

Figure 16 shows the OEE of CNC #19 in June, July, and August of 2016 was 69.8%, 74.7%, and 79.1%, respectively, and 79.2%, 79.8%, and 79.9% in 2017. The results showed the OEE of CNC #19 became more stability than it before implementation of AM.

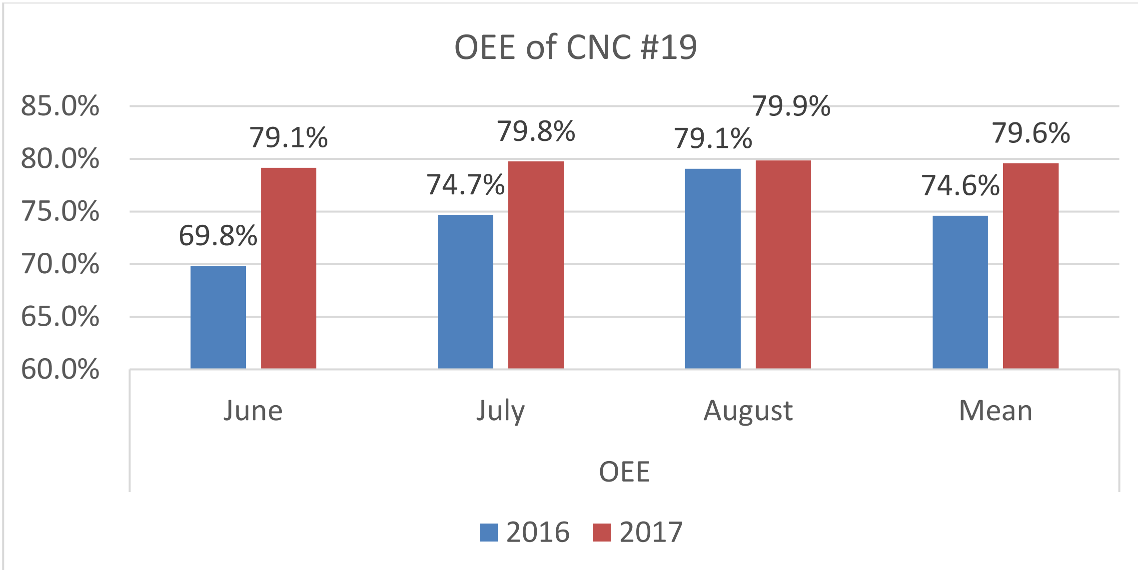

Figure 16. OEE of CNC #19.

As shown in Figure 17, the performance of CNC #19 in 2016 was 90.9%. After implementing AM, performance was increased to 92.1%. The performance of CNC #19 in June 2016 was 90.5%, and it increased to 92.2% in June 2017. In July 2017, it increased about 0.8% from July 2016. The performance grew from 91.3% in August 2016 to 92.1% in August 2017.

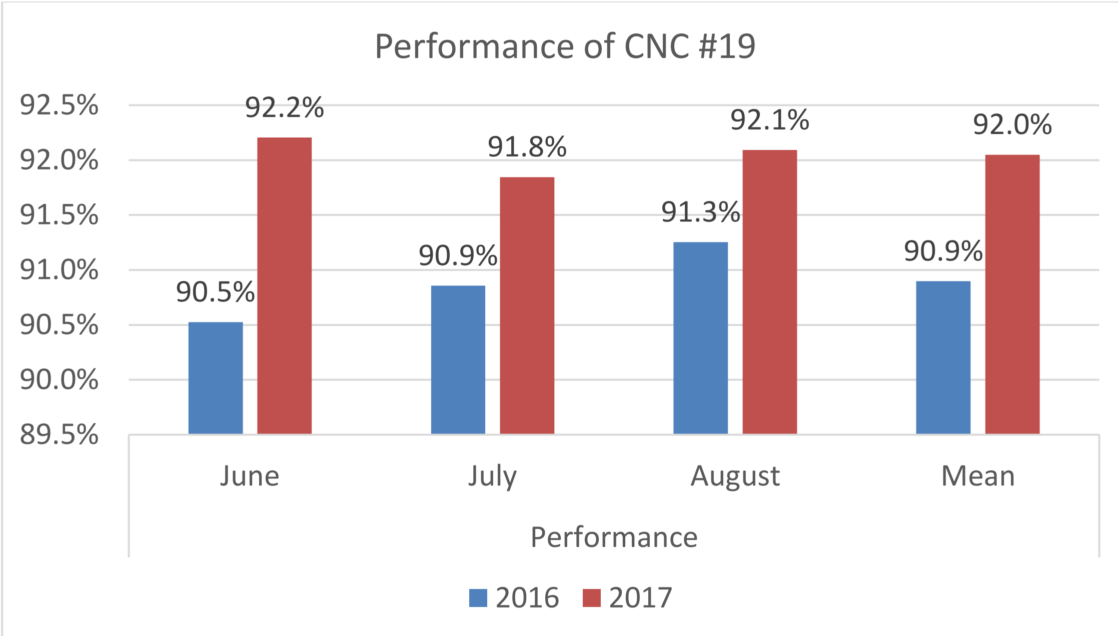

Figure 17. Performance of CNC #19.

Figure 18 indicates the availability of CNC #19 in June, July and August of 2016 and 2017. The mean of the performance of CNC #19 increased from 83.6% to 87.9%. There was an abnormal increase in the period of June, July, and August in 2016. The availability increased from 78.7% to 83.8% to 88.2%. Appendix C shows a breakdown of the results. The availability of CNC #19 in June, July, and August 2017 was more stable and close to 80.0% after implementing AM.

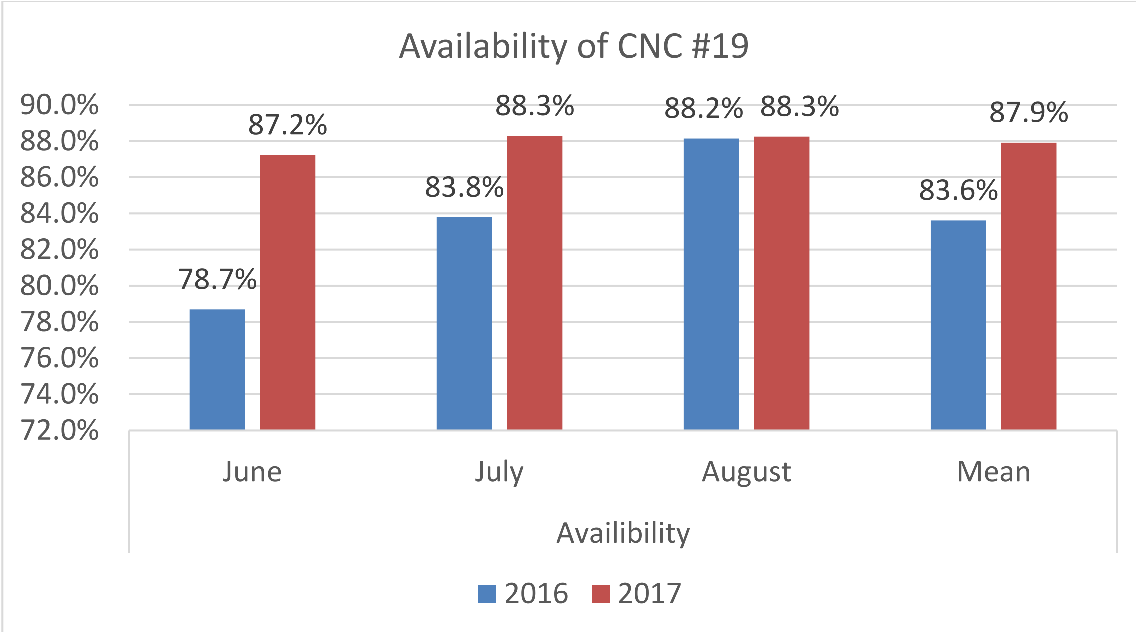

Figure 18. Availability of CNC #19.

In the quality of CNC #19, the mean increased slightly from 98.1% to 98.3%. The quality of CNC #19 was above 98% both before and after AM.

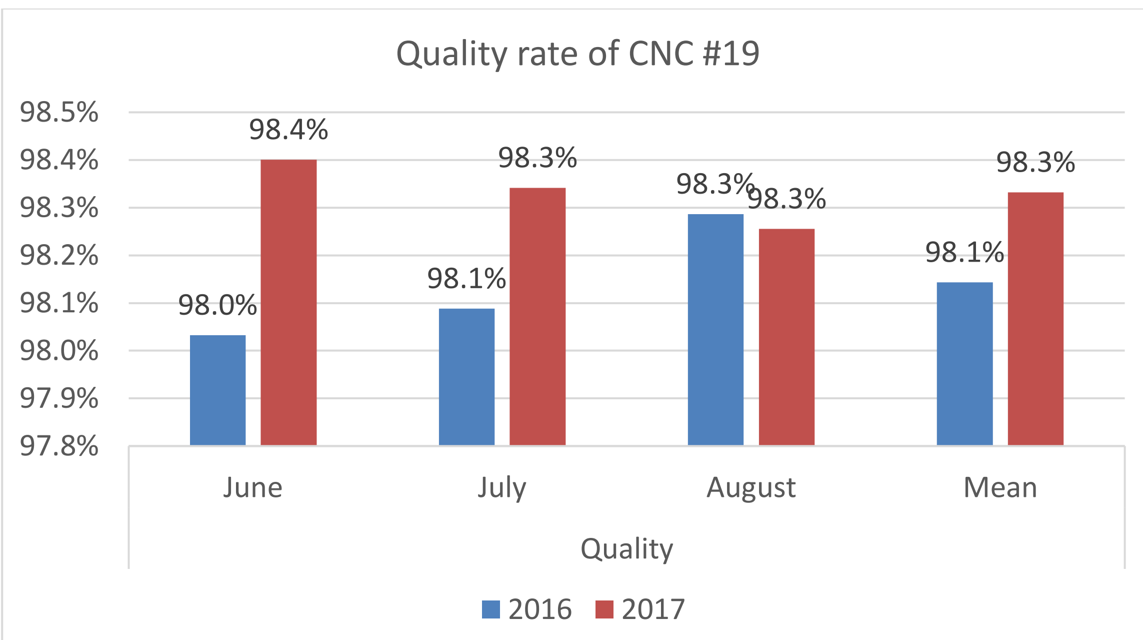

Figure 19. Quality rate of CNC #19.

The results indicated that AM has a positive impact on performance and quality rate. There were more than 1600 minutes of breakdown time in 2016, which made the availability low. Through implementing AM measure, the availability of CNC #19 trended upwards to a stable range around 98.3%. Therefore, AM directly or indirectly decreased breakdowns, which could be related to the increase of availability of CNC #19. AM also increased the stability and reduced the variation of OEE for CNC #19 through comparing the standard deviation of OEE of CNC #19.

Modeling Workshop

Modeling Group #2

As illustrated in Table 8, the OEE of group #2 in the Modeling Workshop increased by 6.5% from 69.8% in 2016 to 76.4% in 2017. The standard deviation decreased from 6.0% in 2016 to 2.1% in 2017. The planned production time increased from 29,440 minutes to 30,225 minutes. The breakdown time was 1,280 minutes in 2016, while it was 0 in 2017. The set-up time decreased from 6,188 minutes to 6,021 minutes. The PF&D time decreased from 615 minutes to 413 minutes. The run time increased from 21,397 minutes to 23,791 minutes. The total count increased from 1,165 pieces to 1,300 pieces. The defects decreased from 21 pieces to 17 pieces.

Table 8.

Modeling group #2 OEE and performance parameters.

	2016	2017
OEE Average	69.8%	76.4%
Standard Deviation	6.0%	2.1%
Planned Production Time	29,440 mins	30,225 mins
Breakdown Time	1,280 mins	0
Set-up Time	6,188 mins	6,021mins
PF&D Time	615 mins	413 mins
Run Time	21,397 mins	23,791 mins
Ideal Cycle Time	18 mins/piece	18 mins/piece
Total Count	1,165 pieces	1,300 pieces
Defects	21pieces	17 pieces

Figure 20 indicates that the OEE of group #2 in the Modeling Workshop had a significant increase in 2017 compared to 2016. The OEE increased from 71.6% in June 2016 to 76.0% in June 2017. It increased from 73.2% in July 2016 to 76.5% in July 2017, and from 65.28% in August 2016 to 76.72% in August 2017.

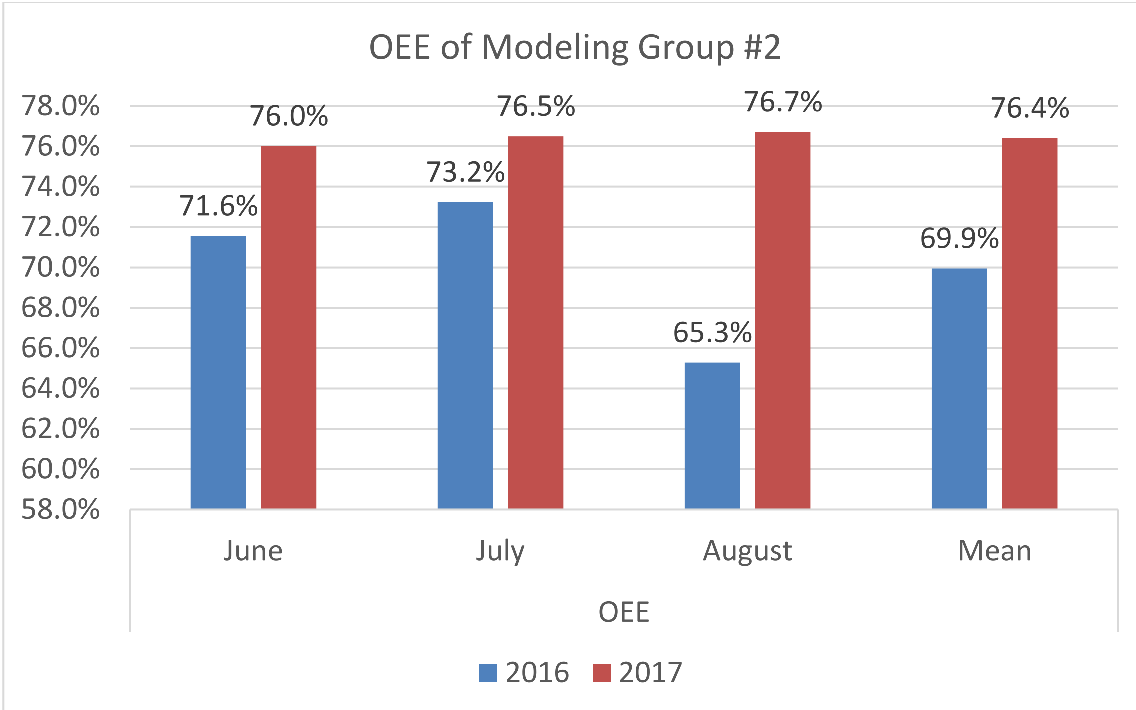

Figure 20. OEE of Modeling Group #2.

Figure 21 shows the details of performance for group #2 in the Modeling Workshop. The performance of group #2 in June 2017 was 98.2%, compared to 97.9% in June 2016. The performance in July 2017 was 98.6%, compared to 98.1% in July 2016. The performance in August 2017 was 98.31%, compared to 98.2% in August

2016.

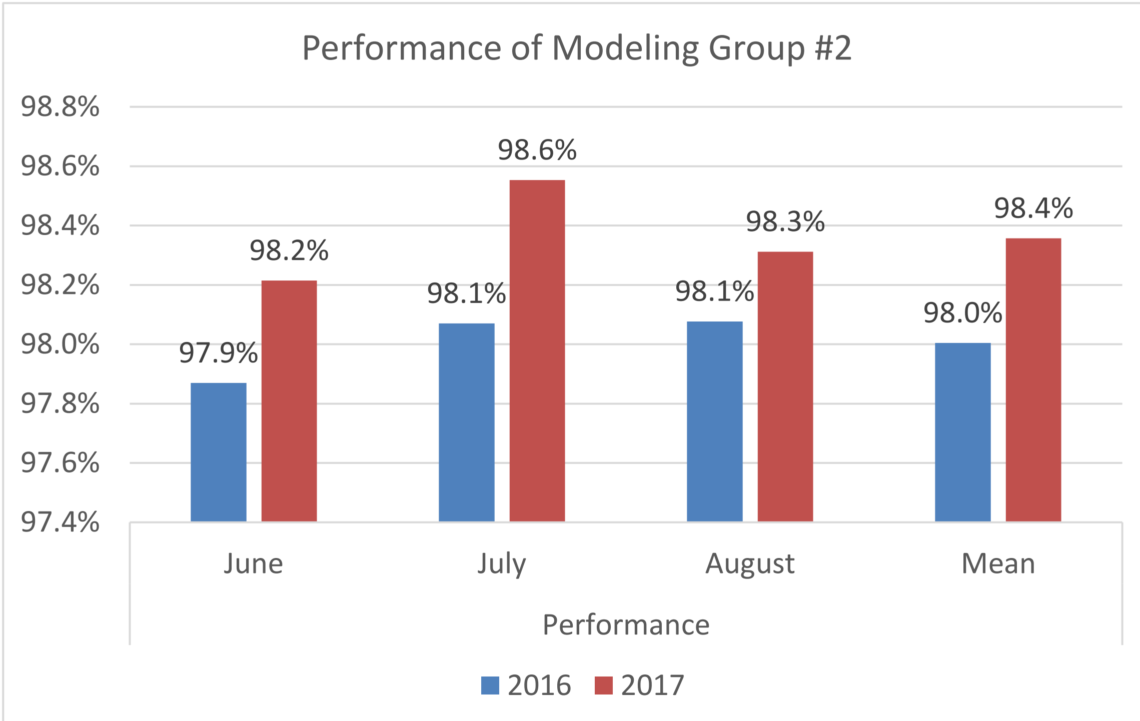

Figure 21. Performance of Modeling Group #2.

The availability for modeling group #2 changed a lot. The availability for June increased by 4.0%. The availability for July was increased by 2.9%. The availability for August increased by 10.9%.

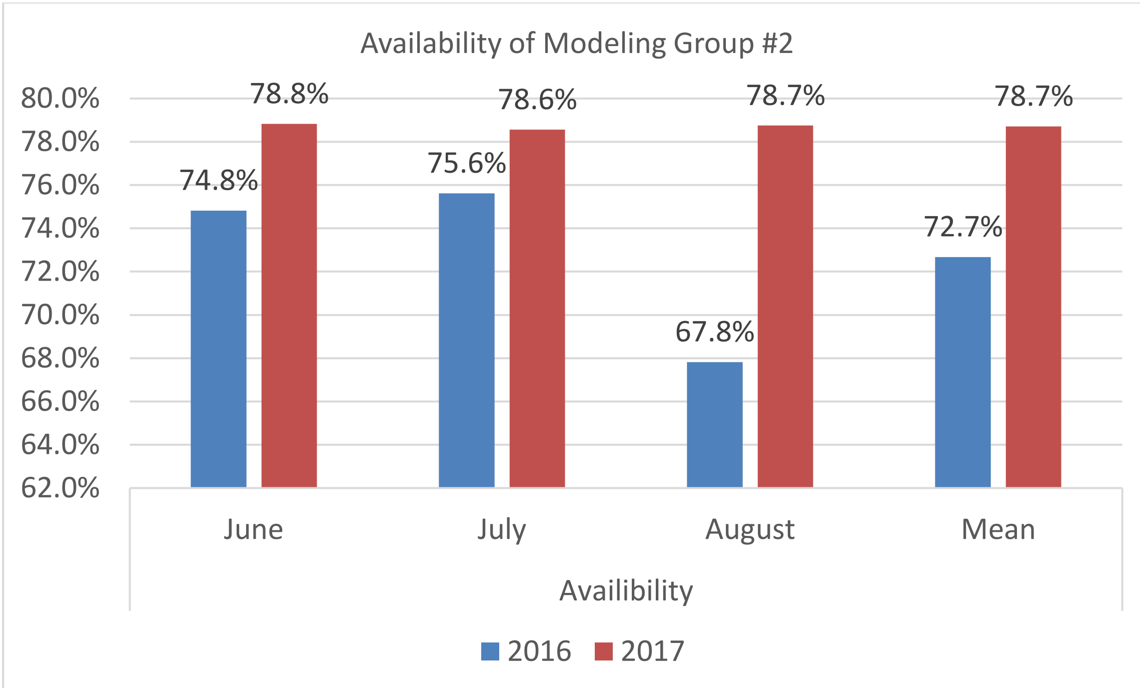

Figure 22. Availability of Modeling Group #2.

Figure 23 shows the change of quality of modeling group #2: the quality in June 2017 was 98.2% compared to 97.7% in June 2016. The quality in July 2017 was 98.8% compared to 98.7% in July 2016. The quality in August 2017 was 98.9% compared to 98.1% in August 2016.

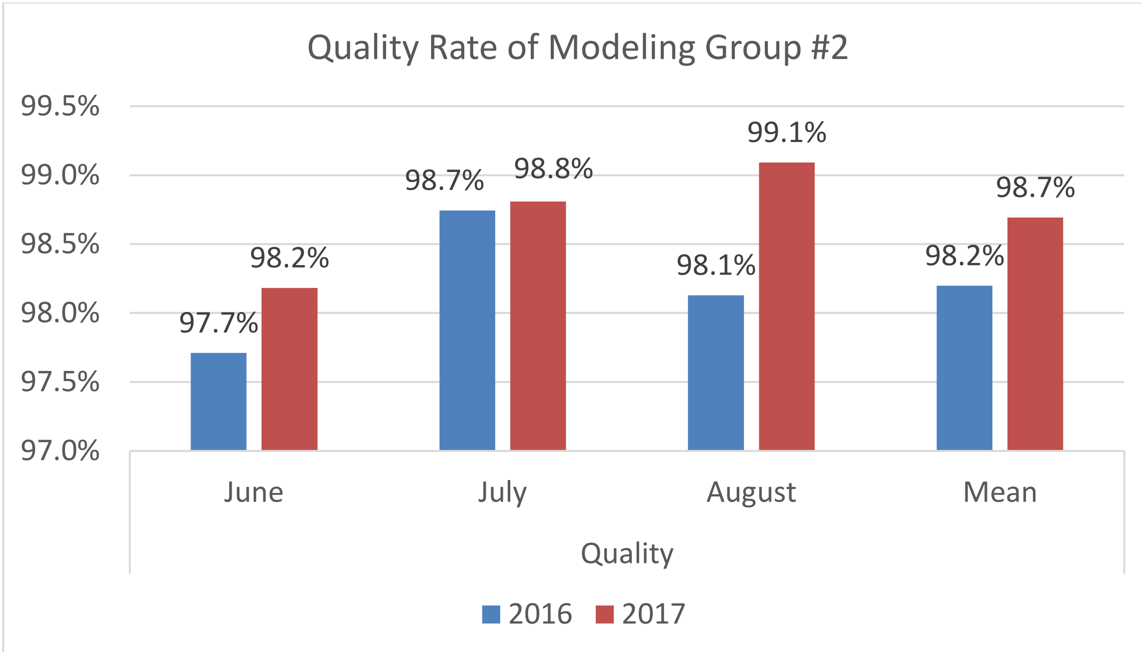

Figure 23. Quality of Modeling Group #2.

Implementing AM in modeling group #2 resulted in positive impacts on the OEE. While the changes in performance and quality were slight, the change in availability was significant. The main reason was the reduced breakdown shown in Table 8. In addition, the decrease of standard deviation indicated that the stability of OEE for the modeling group #2 become better after implementing AM.

Mixing Workshop

As illustrated in Table 9, the mean of OEE for mixing group #1 in 2016 was 64.4%, while it at 2017 was 77.6%. The standard deviation in 2016 was 1%, while it was 0.3% in 2017. The planned production time increased from 23,040 minutes to 24,960 minutes. The cleaning time decreased from 6,686 minutes to 6,088 minutes. The breakdown time decreased to 0. The set-up time decreased from 5,380 minutes to 5,145 minutes. The PF&D time decreased significantly from 3,174 minutes to 489 minutes.

The run time increased from 15,120 minutes to 19,500 minutes. The total count increased from 252 buckets to 325 buckets. In calculating the OEE parameters, it was found that both the quality and the performance of this workshop were at 100%. There was only change in availability. The change in the availability of mixing group #1 is shown in Figure 21.

Table 9.

Mixing group #1 OEE and performance parameters.

	2016	2017
OEE Average	64.4%	77.6%
Standard Deviation	1.0%	0.3%
Planned Production Time	23,040 mins	24,960 mins
Cleaning Time	6,686 mins	6,088 mins
Breakdown Time	360 mins	0
Set-up Time	5,380 mins	5,145 mins
PF&D Time	3,174 mins	489 mins
Run Time	15,120 mins	19,500 mins
Ideal Cycle Time	60 mins/ bucket	60 mins/bucket
Total Count	252 buckets	325 buckets
Defects	0	0

Figure 24 indicated that the availability of mixing group #1 each month in 2017 was close to 77.5%. The availability of mixing group #1 was 65.4% in June, and 64.1% in July, and 63.7% in August 2016.

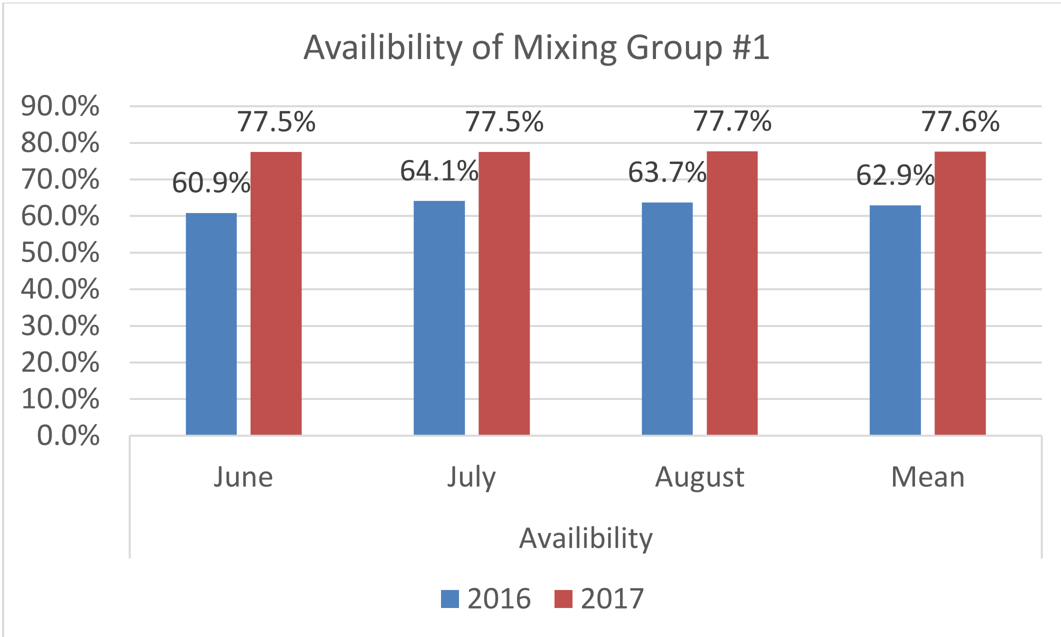

Figure 24. Availability of Mixing Group #1.

The results indicated that implementing AM in mixing group #1 had a positive impact on improving OEE. The main impact was availability. The reason for the reduction was PF&D time and the cleaning time. The PF&D time mainly included the operators' break time. Through implementing AM, the cleaning time was decreased by about 20 minutes per day. This reducation meant the operator could produce one more bucket per day. The high quality and performance benefited from that the Mixing Workshop is a no-dust workshop and the good status of machines.

Conclusion

The implementation of AM at PTFE plant improved the OEE of theses selected machines and processes. In the different workshop, when the operators applied AM, it required that working with the different actual approaches according to the different problems in that machine or group. For CNC Workshop, the operators implemented the daily inspection and cleaning. For Mixing Workshop, the operators not only implemented the daily inspection and cleaning but also adjusted the cleaning time, and planned production time, which made the time management more reasonable.

In the CNC workshop, operators increased the daily checking and cleaning time on the machines, while the number of small stops and the time of breakdowns was decreased, which increased the performance and availability of the machines. There were two situations in the CNC group. Although CNC #1 and #2's OEE were good, AM still had a positive contribution to OEE, but the degree of increase was slight. The other situation was that of CNC #19, for which was worse than 80%. AM resulted in positive improvement on its OEE.

In the Modeling Workshop, the number of machine faults decreased by implementing AM. More detailed and documented daily checking and cleaning supported the operators and made their work more accurate, which influenced availability.

In the Mixing Workshop, the main problem was the availability. There was much waste during the potential working time. In addition, the washing process could be simplified. For example, before implementing AM, the operators cleaned the machines by the experience. Sometimes, some cleaning events were repeated. However, through

AM, all the events of cleaning were recorded on the document, which decreased the cleaning time and increased the potential production time. Through adjusting the washing time and break time, the mixing group increased the actual running time per day. As a result, there was a positive impact on availability.

Summary

Autonomous maintenance is an important pillar in the implementation of TPM. It can improve the productivity of machines or processes. The project aimed to improve the productivity of selected machines and processes through implementation of autonomous maintenance. OEE is a primary metric to measure machines' and processes' productivities. OEE has three components: performance, availability, and quality. In this project, the researcher compared the OEE and its components before and after implementing autonomous maintenance.

The hypothesis for this project was that implementing autonomous maintenance in the case of a general product line of the PTFE plant would result in improved OEE on three CNC machines in the CNC Workshop, one group in the Modeling Workshop, and one group in the Mixing Workshop. Implementing AM on these machines and groups had a positive impact on the OEE confirming the hypothesis. Therefore, the OEE was improved through the implementation of AM in this case

Recommendation for Future Research

Recommendations for further researchers are the following:

1. Future research could involve a long-term study using inferential statistics. Implementation of TPM is a long-term journey.

2. When implementing autonomous maintenance, operators could do tasks, such as cleaning processes during working time, which would increase the process time availability. A study on the effects of these tasks on availability would be appropriate.
3. A study on the frequency of communication between the maintenance department and the production department. Getting managerial and technical support is important in the implementation of TPM and AM, and frequent communication is critical.

Appendix A: CNC #1's Production Data And Its OEE

CNC Workshop

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	PF&D time (min)	Run time (min)	Ideal cycle time （min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
# 1	2016 June	1	480	10	470	50		15	405	0.25	1,576	17	97.28%	86.17%	98.92%	82.93%
		2	480	10	470	45		10	415	0.25	1,580	23	95.18%	88.30%	98.54%	82.82%
		3	480	10	470	40		15	415	0.25	1,582	25	95.30%	88.30%	98.42%	82.82%
		4														
		5														
		6	480	10	470	40		10	420	0.25	1,584	23	94.29%	89.36%	98.55%	83.03%
		7	480	10	470	45		10	415	0.25	1,587	25	95.60%	88.30%	98.42%	83.09%
		8	480	10	470	50		10	410	0.25	1,589	27	96.89%	87.23%	98.30%	83.09%
		9														
		10	480	10	470	45		10	415	0.25	1,586	21	95.54%	88.30%	98.68%	83.24%
		11														
		12														
		13	480	10	470	45		10	415	0.25	1583	17	95.36%	88.30%	98.93%	83.30%
		14	480	10	470	40		10	420	0.25	1584	24	94.29%	89.36%	98.48%	82.98%

		15	480	10	470	45		10	415	0.25	1583	28	95.36%	88.30%	98.23%	82.71%
		16	480	10	470	50		15	405	0.25	1580	30	97.53%	86.17%	98.10%	82.45%
		17	480	10	470	50		10	410	0.25	1569	17	95.67%	87.23%	98.92%	82.55%
		18														
		19														
		20	480	10	470	35		15	420	0.25	1579	21	93.99%	89.36%	98.67%	82.87%
		21	480	10	470	40		15	415	0.25	1584	26	95.42%	88.30%	98.36%	82.87%
		22	480	10	470	42		15	413	0.25	1580	23	95.64%	87.87%	98.54%	82.82%
		23	480	10	470	45		10	415	0.25	1576	26	94.94%	88.30%	98.35%	82.45%
		24	480	10	470	46		15	409	0.25	1579	28	96.52%	87.02%	98.23%	82.50%
		25														
		26														
		27	480	10	470	50	60	0	360	0.25	1389	26	96.46%	76.60%	98.13%	72.50%
		28	480	10	470	45		10	415	0.25	1580	20	95.18%	88.30%	98.73%	82.98%
		29	480	10	470	45		10	415	0.25	1568	23	94.46%	88.30%	98.53%	82.18%
		30	480	10	470	40		10	420	0.25	1580	20	94.05%	89.36%	98.73%	82.98%
	July	1	480	10	470	45		10	415	0.25	1576	27	94.94%	88.30%	98.29%	82.39%
		2														
		3														
		4	480	10	470	40		10	420	0.25	1580	21	94.05%	89.36%	98.67%	82.93%
		5	480	10	470	40		10	420	0.25	1580	22	94.05%	89.36%	98.61%	82.87%
		6	480	10	470	45		10	415	0.25	1576	24	94.94%	88.30%	98.48%	82.55%
		7	480	10	470	50		10	410	0.25	1569	23	95.67%	87.23%	98.53%	82.23%
		8	480	10	470	50		10	410	0.25	1576	25	96.10%	87.23%	98.41%	82.50%
		9														
		10														
		11	480	10	470	45		10	415	0.25	1580	21	95.18%	88.30%	98.67%	82.93%

		12	480	10	470	40		10	420	0.25	1575	18	93.75%	89.36%	98.86%	82.82%
		13	480	10	470	40		10	420	0.25	1600	27	95.24%	89.36%	98.31%	83.67%
		14	480	10	470	40		10	420	0.25	1592	32	94.76%	89.36%	97.99%	82.98%
		15	480	10	470	45		10	415	0.25	1580	32	95.18%	88.30%	97.97%	82.34%
		16														
		17														
		18	480	10	470	45		10	415	0.25	1580	25	95.18%	88.30%	98.42%	82.71%
		19	480	10	470	50		10	410	0.25	1575	19	96.04%	87.23%	98.79%	82.77%
		20	480	10	470	45		10	415	0.25	1580	23	95.18%	88.30%	98.54%	82.82%
		21	480	10	470	40		10	420	0.25	1595	35	94.94%	89.36%	97.81%	82.98%
		22	480	10	470	40		10	420	0.25	1579	21	93.99%	89.36%	98.67%	82.87%
		23														
		24														
		25	480	10	470	40		10	420	0.25	1580	23	94.05%	89.36%	98.54%	82.82%
		26	480	10	470	40		10	420	0.25	1580	25	94.05%	89.36%	98.42%	82.71%
		27	480	10	470	45		10	415	0.25	1583	23	95.36%	88.30%	98.55%	82.98%
		28	480	10	470	45		10	415	0.25	1576	21	94.94%	88.30%	98.67%	82.71%
		29	480	10	470	45		10	415	0.25	1582	25	95.30%	88.30%	98.42%	82.82%
		30														
		31														
	August	1	480	10	470	50		10	410	0.25	1578	21	96.22%	87.23%	98.67%	82.82%
		2	480	10	470	45		10	415	0.25	1580	17	95.18%	88.30%	98.92%	83.14%
		3	480	10	470	45		10	415	0.25	1580	24	95.18%	88.30%	98.48%	82.77%
		4	480	10	470	40		10	420	0.25	1582	26	94.17%	89.36%	98.36%	82.77%
		5	480	10	470	45		10	415	0.25	1586	26	95.54%	88.30%	98.36%	82.98%
		6														
		7														

		8	480	10	470	45		10	415	0.25	1587	27	95.60%	88.30%	98.30%	82.98%
		9	480	10	470	45		10	415	0.25	1580	23	95.18%	88.30%	98.54%	82.82%
		10	480	10	470	45		10	415	0.25	1578	24	95.06%	88.30%	98.48%	82.66%
		11	480	10	470	50		10	410	0.25	1586	23	96.71%	87.23%	98.55%	83.14%
		12	480	10	470	45		10	415	0.25	1595	28	96.08%	88.30%	98.24%	83.35%
		13														
		14														
		15	480	10	470	45		10	415	0.25	1580	23	95.18%	88.30%	98.54%	82.82%
		16	480	10	470	40		10	420	0.25	1590	22	94.64%	89.36%	98.62%	83.40%
		17	480	10	470	40		10	420	0.25	1570	17	93.45%	89.36%	98.92%	82.61%
		18	480	10	470	45		10	415	0.25	1574	19	94.82%	88.30%	98.79%	82.71%
		19	480	10	470	50		10	410	0.25	1568	8	95.61%	87.23%	99.49%	82.98%
		20														
		21														
		22	480	10	470	45		10	415	0.25	1575	19	94.88%	88.30%	98.79%	82.77%
		23	480	10	470	45		10	415	0.25	1580	20	95.18%	88.30%	98.73%	82.98%
		24	480	10	470	45		10	415	0.25	1580	24	95.18%	88.30%	98.48%	82.77%
		25	480	10	470	50		10	410	0.25	1579	25	96.28%	87.23%	98.42%	82.66%
		26	480	10	470	50		10	410	0.25	1587	24	96.77%	87.23%	98.49%	83.14%
		27														
		28														
		29	480	10	470	45		10	415	0.25	1576	16	94.94%	88.30%	98.98%	82.98%
		30	480	10	470	50		10	410	0.25	1573	19	95.91%	87.23%	98.79%	82.66%
	2017 June	1	480	15	465	43		10	412	0.25	1588	28	96.36%	88.60%	98.24%	83.87%
		2	480	15	465	48		10	407	0.25	1580	24	97.05%	87.53%	98.48%	83.66%
		3														
		4														

		5	480	15	465	45		10	410	0.25	1584	18	96.59%	88.17%	98.86%	84.19%
		6	480	15	465	48		10	407	0.25	1585	21	97.36%	87.53%	98.68%	84.09%
		7	480	15	465	49		10	406	0.25	1590	19	97.91%	87.31%	98.81%	84.46%
		8	480	15	465	39		10	416	0.25	1586	20	95.31%	89.46%	98.74%	84.19%
		9	480	15	465	50		10	405	0.25	1580	24	97.53%	87.10%	98.48%	83.66%
		10														
		11														
		12	480	15	465	44		10	411	0.25	1580	23	96.11%	88.39%	98.54%	83.71%
		13	480	15	465	43		10	412	0.25	1586	16	96.24%	88.60%	98.99%	84.41%
		14	480	15	465	49		10	406	0.25	1580	18	97.29%	87.31%	98.86%	83.98%
		15	480	15	465	40		10	415	0.25	1580	14	95.18%	89.25%	99.11%	84.19%
		16	480	15	465	42		10	413	0.25	1584	19	95.88%	88.82%	98.80%	84.14%
		17														
		18														
		19	480	15	465	48		10	407	0.25	1568	21	96.31%	87.53%	98.66%	83.17%
		20	480	15	465	50		10	405	0.25	1571	23	96.98%	87.10%	98.54%	83.23%
		21	480	15	465	46		10	409	0.25	1576	22	96.33%	87.96%	98.60%	83.55%
		22	480	15	465	44		10	411	0.25	1582	17	96.23%	88.39%	98.93%	84.14%
		23	480	15	465	46		10	409	0.25	1584	20	96.82%	87.96%	98.74%	84.09%
		24														
		25														
		26	480	15	465	48		10	407	0.25	1578	21	96.93%	87.53%	98.67%	83.71%
		27	480	15	465	49		10	406	0.25	1584	17	97.54%	87.31%	98.93%	84.25%
		28	480	15	465	50		10	405	0.25	1569	19	96.85%	87.10%	98.79%	83.33%
		29	480	15	465	47		10	408	0.25	1580	21	96.81%	87.74%	98.67%	83.82%
		30	480	15	465	43		10	412	0.25	1584	13	96.12%	88.60%	99.18%	84.46%
	July	1														

		2														
		3	480	15	465	45		10	410	0.25	1578	15	96.22%	88.17%	99.05%	84.03%
		4	480	15	465	45		10	410	0.25	1573	18	95.91%	88.17%	98.86%	83.60%
		5	480	15	465	48		10	407	0.25	1569	19	96.38%	87.53%	98.79%	83.33%
		6	480	15	465	42		10	413	0.25	1583	20	95.82%	88.82%	98.74%	84.03%
		7	480	15	465	46		10	409	0.25	1579	17	96.52%	87.96%	98.92%	83.98%
		8														
		9														
		10	480	15	465	47		10	408	0.25	1581	18	96.88%	87.74%	98.86%	84.03%
		11	480	15	465	48		10	407	0.25	1579	18	96.99%	87.53%	98.86%	83.92%
		12	480	15	465	42		10	413	0.25	1573	17	95.22%	88.82%	98.92%	83.66%
		13	480	15	465	44		10	411	0.25	1572	23	95.62%	88.39%	98.54%	83.28%
		14	480	15	465	42		10	413	0.25	1577	27	95.46%	88.82%	98.29%	83.33%
		15														
		16														
		17	480	15	465	48		10	407	0.25	1575	17	96.74%	87.53%	98.92%	83.76%
		18	480	15	465	39		10	416	0.25	1574	14	94.59%	89.46%	99.11%	83.87%
		19	480	15	465	42		10	413	0.25	1581	23	95.70%	88.82%	98.55%	83.76%
		20	480	15	465	43		10	412	0.25	1573	13	95.45%	88.60%	99.17%	83.87%
		21	480	15	465	42		10	413	0.25	1574	29	95.28%	88.82%	98.16%	83.06%
		22														
		23														
		24	480	15	465	47		10	408	0.25	1576	18	96.57%	87.74%	98.86%	83.76%
		25	480	15	465	46		10	409	0.25	1578	20	96.45%	87.96%	98.73%	83.76%
		26	480	15	465	50		10	405	0.25	1576	21	97.28%	87.10%	98.67%	83.60%
		27	480	15	465	43		10	412	0.25	1576	22	95.63%	88.60%	98.60%	83.55%
		28	480	15	465	44		10	411	0.25	1568	8	95.38%	88.39%	99.49%	83.87%
		29														

		30														
		31	480	15	465	40		10	415	0.25	1574	18	94.82%	89.25%	98.86%	83.66%
	August	1	480	15	465	42		10	413	0.25	1577	21	95.46%	88.82%	98.67%	83.66%
		2	480	15	465	44		10	411	0.25	1582	22	96.23%	88.39%	98.61%	83.87%
		3	480	15	465	43		10	412	0.25	1574	24	95.51%	88.60%	98.48%	83.33%
		4	480	15	465	49		10	406	0.25	1578	23	97.17%	87.31%	98.54%	83.60%
		5														
		6														
		7	480	15	465	43		10	412	0.25	1572	15	95.39%	88.60%	99.05%	83.71%
		8	480	15	465	47		10	408	0.25	1577	17	96.63%	87.74%	98.92%	83.87%
		9	480	15	465	45		10	410	0.25	1574	18	95.98%	88.17%	98.86%	83.66%
		10	480	15	465	43		10	412	0.25	1573	19	95.45%	88.60%	98.79%	83.55%
		11	480	15	465	48		10	407	0.25	1572	21	96.56%	87.53%	98.66%	83.39%
		12														
		13														
		14	480	15	465	50		10	405	0.25	1575	23	97.22%	87.10%	98.54%	83.44%
		15	480	15	465	45		10	410	0.25	1573	20	95.91%	88.17%	98.73%	83.49%
		16	480	15	465	43		10	412	0.25	1580	17	95.87%	88.60%	98.92%	84.03%
		17	480	15	465	42		10	413	0.25	1574	16	95.28%	88.82%	98.98%	83.76%
		18	480	15	465	43		10	412	0.25	1575	15	95.57%	88.60%	99.05%	83.87%
		19														
		20														
		21	480	15	465	48		10	407	0.25	1571	17	96.50%	87.53%	98.92%	83.55%
		22	480	15	465	39		10	416	0.25	1570	13	94.35%	89.46%	99.17%	83.71%
		23	480	15	465	45		10	410	0.25	1574	19	95.98%	88.17%	98.79%	83.60%
		24	480	15	465	45		10	410	0.25	1575	20	96.04%	88.17%	98.73%	83.60%
		25	480	15	465	42		10	413	0.25	1575	25	95.34%	88.82%	98.41%	83.33%

		26														
		27														
		28	480	15	465	47		10	408	0.25	1573	21	96.38%	87.74%	98.66%	83.44%
		29	480	15	465	44		10	411	0.25	1578	17	95.99%	88.39%	98.92%	83.92%
		30	480	15	465	45		10	410	0.25	1576	19	96.10%	88.17%	98.79%	83.71%

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	PF&D time (min)	Run time (min)	Ideal cycle time (min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
2016	June		10080	210	9870	933	60	235	8642	0.25	32998	490	95.46%	87.56%	98.52%	82.34%
	July		10080	210	9870	915	0	210	8745	0.25	33194	512	94.89%	88.60%	98.46%	82.78%
	August		10560	220	10340	1005	0	220	9115	0.25	34764	475	95.35%	88.15%	98.63%	82.90%
	Total		30720	640	30080	2853	60	665	26502	0.25	100956	1477	95.23%	88.11%	98.54%	82.68%
2017	June		10560	330	10230	1011	0	220	8999	0.25	34779	438	96.62%	87.97%	98.74%	83.92%
	July		10080	315	9765	933	0	210	8622	0.25	33089	395	95.94%	88.29%	98.81%	83.70%
	August		10560	330	10230	982	0	220	9028	0.25	34648	422	95.95%	88.25%	98.78%	83.64%
	Total		31200	975	30225	2926	0	650	26649	0.25	102516	1255	96.17%	88.17%	98.78%	83.76%

Appendix B: CNC #2's Production Data And Its OEE

CNC Workshop

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	PF&&D time (min)	Run time (min)	Ideal cycle time (min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
# 2	2016 June	1	480	10	470	45		15	410	0.25	1,587	18	96.77%	87.23%	98.87%	83.46%
		2	480	10	470	45		10	415	0.25	1,590	28	95.78%	88.30%	98.24%	83.09%
		3	480	10	470	40		15	415	0.25	1,583	30	95.36%	88.30%	98.10%	82.61%
		4														
		5														
		6	480	10	470	48		10	412	0.25	1,584	26	96.12%	87.66%	98.36%	82.87%
		7	480	10	470	45		10	415	0.25	1,569	17	94.52%	88.30%	98.92%	82.55%
		8	480	10	470	50		10	410	0.25	1,574	29	95.98%	87.23%	98.16%	82.18%
		9														
		10	480	10	470	50		10	410	0.25	1,576	24	96.10%	87.23%	98.48%	82.55%
		11														
		12														
		13	480	10	470	50		10	410	0.25	1580	23	96.34%	87.23%	98.54%	82.82%
		14	480	10	470	50		10	410	0.25	1581	25	96.40%	87.23%	98.42%	82.77%
		15	480	10	470	45		10	415	0.25	1577	26	95.00%	88.30%	98.35%	82.50%
		16	480	10	470	45		15	410	0.25	1579	29	96.28%	87.23%	98.16%	82.45%
		17	480	10	470	45		10	415	0.25	1583	18	95.36%	88.30%	98.86%	83.24%
		18														

		19														
		20	480	10	470	35		15	420	0.25	1,585	23	94.35%	89.36%	98.55%	83.09%
		21	480	10	470	40		15	415	0.25	1590	27	95.78%	88.30%	98.30%	83.14%
		22	480	10	470	45		15	410	0.25	1583	30	96.52%	87.23%	98.10%	82.61%
		23	480	10	470	45		10	415	0.25	1586	23	95.54%	88.30%	98.55%	83.14%
		24	480	10	470	45		15	410	0.25	1585	27	96.65%	87.23%	98.30%	82.87%
		25														
		26														
		27	480	10	470	40		0	430	0.25	1587	20	92.27%	91.49%	98.74%	83.35%
		28	480	10	470	40		10	420	0.25	1586	21	94.40%	89.36%	98.68%	83.24%
		29	480	10	470	50		10	410	0.25	1582	21	96.46%	87.23%	98.67%	83.03%
		30	480	10	470	45		10	415	0.25	1584	18	95.42%	88.30%	98.86%	83.30%
	July	1	480	10	470	45		10	415	0.25	1583	24	95.36%	88.30%	98.48%	82.93%
		2														
		3														
		4	480	10	470	45		10	415	0.25	1584	23	95.42%	88.30%	98.55%	83.03%
		5	480	10	470	45		10	415	0.25	1585	24	95.48%	88.30%	98.49%	83.03%
		6	480	10	470	45		10	415	0.25	1585	31	95.48%	88.30%	98.04%	82.66%
		7	480	10	470	50		10	410	0.25	1583	27	96.52%	87.23%	98.29%	82.77%
		8	480	10	470	50		10	410	0.25	1582	13	96.46%	87.23%	99.18%	83.46%
		9														
		10														
		11	480	10	470	50		10	410	0.25	1584	27	96.59%	87.23%	98.30%	82.82%
		12	480	10	470	45		10	415	0.25	1582	18	95.30%	88.30%	98.86%	83.19%
		13	480	10	470	45		10	415	0.25	1584	19	95.42%	88.30%	98.80%	83.24%
		14	480	10	470	45		10	415	0.25	1581	28	95.24%	88.30%	98.23%	82.61%
		15	480	10	470	50		10	410	0.25	1588	26	96.83%	87.23%	98.36%	83.09%
		16														
		17														
		18	480	10	470	45		10	415	0.25	1579	23	95.12%	88.30%	98.54%	82.77%

		19	480	10	470	50	48	10	362	0.25	1369	24	94.54%	77.02%	98.25%	71.54%
		20	480	10	470	45		10	415	0.25	1584	27	95.42%	88.30%	98.30%	82.82%
		21	480	10	470	40		10	420	0.25	1580	24	94.05%	89.36%	98.48%	82.77%
		22	480	10	470	45		10	415	0.25	1584	29	95.42%	88.30%	98.17%	82.71%
		23														
		24														
		25	480	10	470	50		10	410	0.25	1581	21	96.40%	87.23%	98.67%	82.98%
		26	480	10	470	40		10	420	0.25	1584	27	94.29%	89.36%	98.30%	82.82%
		27	480	10	470	50		10	410	0.25	1584	22	96.59%	87.23%	98.61%	83.09%
		28	480	10	470	50		10	410	0.25	1585	28	96.65%	87.23%	98.23%	82.82%
		29	480	10	470	45		10	415	0.25	1581	24	95.24%	88.30%	98.48%	82.82%
		30														
		31														
	August	1	480	10	470	45		10	415	0.25	1583	17	95.36%	88.30%	98.93%	83.30%
		2	480	10	470	45		10	415	0.25	1584	23	95.42%	88.30%	98.55%	83.03%
		3	480	10	470	45		10	415	0.25	1584	25	95.42%	88.30%	98.42%	82.93%
		4	480	10	470	40		10	420	0.25	1582	28	94.17%	89.36%	98.23%	82.66%
		5	480	10	470	45		10	415	0.25	1585	29	95.48%	88.30%	98.17%	82.77%
		6														
		7														
		8	480	10	470	45		10	415	0.25	1578	27	95.06%	88.30%	98.29%	82.50%
		9	480	10	470	45		10	415	0.25	1580	23	95.18%	88.30%	98.54%	82.82%
		10	480	10	470	45		10	415	0.25	1582	19	95.30%	88.30%	98.80%	83.14%
		11	480	10	470	50		10	410	0.25	1579	27	96.28%	87.23%	98.29%	82.55%
		12	480	10	470	45		10	415	0.25	1584	16	95.42%	88.30%	98.99%	83.40%
		13														
		14														
		15	480	10	470	45		10	415	0.25	1585	23	95.48%	88.30%	98.55%	83.09%
		16	480	10	470	45		10	415	0.25	1583	27	95.36%	88.30%	98.29%	82.77%
		17	480	10	470	45		10	415	0.25	1580	29	95.18%	88.30%	98.16%	82.50%

		18	480	10	470	50		10	410	0.25	1583	23	96.52%	87.23%	98.55%	82.98%
		19	480	10	470	50		10	410	0.25	1582	16	96.46%	87.23%	98.99%	83.30%
		20														
		21														
		22	480	10	470	50		10	410	0.25	1579	27	96.28%	87.23%	98.29%	82.55%
		23	480	10	470	45		10	415	0.25	1583	24	95.36%	88.30%	98.48%	82.93%
		24	480	10	470	50		10	410	0.25	1580	23	96.34%	87.23%	98.54%	82.82%
		25	480	10	470	45		10	415	0.25	1577	19	95.00%	88.30%	98.80%	82.87%
		26	480	10	470	45		10	415	0.25	1582	20	95.30%	88.30%	98.74%	83.09%
		27														
		28														
		29	480	10	470	50		10	410	0.25	1579	21	96.28%	87.23%	98.67%	82.87%
		30	480	10	470	50		10	410	0.25	1578	13	96.22%	87.23%	99.18%	83.24%
	2017 June	1	480	15	465	44		10	411	0.25	1574	26	95.74%	88.39%	98.35%	83.23%
		2	480	15	465	47		10	408	0.25	1579	24	96.75%	87.74%	98.48%	83.60%
		3														
		4														
		5	480	15	465	39		10	416	0.25	1582	25	95.07%	89.46%	98.42%	83.71%
		6	480	15	465	41		10	414	0.25	1578	21	95.29%	89.03%	98.67%	83.71%
		7	480	15	465	43		10	412	0.25	1576	28	95.63%	88.60%	98.22%	83.23%
		8	480	15	465	46		10	409	0.25	1580	26	96.58%	87.96%	98.35%	83.55%
		9	480	15	465	42		10	413	0.25	1582	25	95.76%	88.82%	98.42%	83.71%
		10														
		11														
		12	480	15	465	47		10	408	0.25	1583	23	97.00%	87.74%	98.55%	83.87%
		13	480	15	465	42		10	413	0.25	1573	24	95.22%	88.82%	98.47%	83.28%
		14	480	15	465	43		10	412	0.25	1578	24	95.75%	88.60%	98.48%	83.55%
		15	480	15	465	44		10	411	0.25	1577	23	95.92%	88.39%	98.54%	83.55%
		16	480	15	465	44		10	411	0.25	1581	26	96.17%	88.39%	98.36%	83.60%
		17														

		18														
		19	480	15	465	46		10	409	0.25	1568	15	95.84%	87.96%	99.04%	83.49%
		20	480	15	465	43		10	412	0.25	1573	23	95.45%	88.60%	98.54%	83.33%
		21	480	15	465	40		10	415	0.25	1578	25	95.06%	89.25%	98.42%	83.49%
		22	480	15	465	42		10	413	0.25	1581	15	95.70%	88.82%	99.05%	84.19%
		23	480	15	465	41		10	414	0.25	1580	19	95.41%	89.03%	98.80%	83.92%
		24														
		25														
		26	480	15	465	46		10	409	0.25	1589	23	97.13%	87.96%	98.55%	84.19%
		27	480	15	465	41		10	414	0.25	1589	22	95.95%	89.03%	98.62%	84.25%
		28	480	15	465	44		10	411	0.25	1576	17	95.86%	88.39%	98.92%	83.82%
		29	480	15	465	45		10	410	0.25	1572	19	95.85%	88.17%	98.79%	83.49%
		30	480	15	465	45		10	410	0.25	1584	17	96.59%	88.17%	98.93%	84.25%
	July	1														
		2														
		3	480	15	465	48		10	407	0.25	1578	24	96.93%	87.53%	98.48%	83.55%
		4	480	15	465	47		10	408	0.25	1583	23	97.00%	87.74%	98.55%	83.87%
		5	480	15	465	42		10	413	0.25	1579	25	95.58%	88.82%	98.42%	83.55%
		6	480	15	465	48		10	407	0.25	1580	19	97.05%	87.53%	98.80%	83.92%
		7	480	15	465	51		10	404	0.25	1575	18	97.46%	86.88%	98.86%	83.71%
		8														
		9														
		10	480	15	465	46		10	409	0.25	1579	19	96.52%	87.96%	98.80%	83.87%
		11	480	15	465	41		10	414	0.25	1583	23	95.59%	89.03%	98.55%	83.87%
		12	480	15	465	45		10	410	0.25	1577	24	96.16%	88.17%	98.48%	83.49%
		13	480	15	465	43		10	412	0.25	1578	21	95.75%	88.60%	98.67%	83.71%
		14	480	15	465	43		10	412	0.25	1577	18	95.69%	88.60%	98.86%	83.82%
		15														
		16														
		17	480	15	465	41		10	414	0.25	1575	19	95.11%	89.03%	98.79%	83.66%

		18	480	15	465	44		10	411	0.25	1579	20	96.05%	88.39%	98.73%	83.82%
		19	480	15	465	41		10	414	0.25	1582	24	95.53%	89.03%	98.48%	83.76%
		20	480	15	465	47		10	408	0.25	1578	27	96.69%	87.74%	98.29%	83.39%
		21	480	15	465	46		10	409	0.25	1572	21	96.09%	87.96%	98.66%	83.39%
		22														
		23														
		24	480	15	465	50		10	405	0.25	1576	22	97.28%	87.10%	98.60%	83.55%
		25	480	15	465	43		10	412	0.25	1580	22	95.87%	88.60%	98.61%	83.76%
		26	480	15	465	52		10	403	0.25	1582	24	98.14%	86.67%	98.48%	83.76%
		27	480	15	465	42		10	413	0.25	1576	27	95.40%	88.82%	98.29%	83.28%
		28	480	15	465	41		10	414	0.25	1573	24	94.99%	89.03%	98.47%	83.28%
		29														
		30														
		31	480	15	465	43		10	412	0.25	1580	16	95.87%	88.60%	98.99%	84.09%
	August	1	480	15	465	41		10	414	0.25	1568	20	94.69%	89.03%	98.72%	83.23%
		2	480	15	465	40		10	415	0.25	1572	21	94.70%	89.25%	98.66%	83.39%
		3	480	15	465	43		10	412	0.25	1576	19	95.63%	88.60%	98.79%	83.71%
		4	480	15	465	48		10	407	0.25	1567	18	96.25%	87.53%	98.85%	83.28%
		5														
		6														
		7	480	15	465	42		10	413	0.25	1573	17	95.22%	88.82%	98.92%	83.66%
		8	480	15	465	43		10	412	0.25	1575	19	95.57%	88.60%	98.79%	83.66%
		9	480	15	465	41		10	414	0.25	1572	23	94.93%	89.03%	98.54%	83.28%
		10	480	15	465	43		10	412	0.25	1579	20	95.81%	88.60%	98.73%	83.82%
		11	480	15	465	45		10	410	0.25	1577	13	96.16%	88.17%	99.18%	84.09%
		12														
		13														
		14	480	15	465	37		10	418	0.25	1578	15	94.38%	89.89%	99.05%	84.03%
		15	480	15	465	39		10	416	0.25	1578	18	94.83%	89.46%	98.86%	83.87%
		16	480	15	465	40		10	415	0.25	1575	23	94.88%	89.25%	98.54%	83.44%

		17	480	15	465	42		10	413	0.25	1579	20	95.58%	88.82%	98.73%	83.82%
		18	480	15	465	44		10	411	0.25	1582	20	96.23%	88.39%	98.74%	83.98%
		19														
		20														
		21	480	15	465	44		10	411	0.25	1570	14	95.50%	88.39%	99.11%	83.66%
		22	480	15	465	39		10	416	0.25	1571	26	94.41%	89.46%	98.35%	83.06%
		23	480	15	465	46		10	409	0.25	1575	20	96.27%	87.96%	98.73%	83.60%
		24	480	15	465	48		10	407	0.25	1573	19	96.62%	87.53%	98.79%	83.55%
		25	480	15	465	42		10	413	0.25	1580	20	95.64%	88.82%	98.73%	83.87%
		26														
		27														
		28	480	15	465	43		10	412	0.25	1582	15	96.00%	88.60%	99.05%	84.25%
		29	480	15	465	48		10	407	0.25	1576	17	96.81%	87.53%	98.92%	83.82%
		30	480	15	465	45		10	410	0.25	1575	21	96.04%	88.17%	98.67%	83.55%

			Shift time (min)	Cleaning time (min)	Planned production time(min)	Set-up time (min)	Breakdown time (min)	PF&D time (min)	Run time (min)	Ideal cycle time （min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
2016	June		10080	210	9870	943	0	235	8692	0.25	33231	503	95.58%	88.06%	98.49%	82.90%
	July		10080	210	9870	975	48	210	8637	0.25	33032	509	95.61%	87.51%	98.46%	82.38%
	August		10560	220	10340	1020	0	220	9100	0.25	34792	499	95.58%	88.01%	98.57%	82.91%
	Total		30720	640	30080	2938	48	665	26429	0.25	101055	1511	95.59%	87.86%	98.50%	82.73%
2017	June		10560	330	10230	955	0	220	9055	0.25	34733	490	95.89%	88.51%	98.59%	83.68%
	July		10080	315	9765	944	0	210	8611	0.25	33142	460	96.22%	88.18%	98.61%	83.67%
	August		10560	330	10230	943	0	220	9067	0.25	34653	418	95.55%	88.63%	98.79%	83.66%
	Total		31200	975	30225	2842	0	650	26733	0.25	102528	1368	95.88%	88.45%	98.67%	83.67%

Appendix C: CNC #19's Production Data And Its OEE

CNC Workshop

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time(min)	Breakdown time(min)	PF&D time (min)	Run time (min)	Ideal cycle time (min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
# 19	2016 June	1	480	10	470	50		15	405	0.28	1,334	19	92.23%	86.17%	98.58%	78.34%
		2	480	10	470	45		10	415	0.28	1,346	26	90.81%	88.30%	98.07%	78.64%
		3	480	10	470	40		15	415	0.28	1,343	27	90.61%	88.30%	97.99%	78.40%
		4														
		5														
		6	480	10	470	40		10	420	0.28	1,337	32	89.13%	89.36%	97.61%	77.74%
		7	480	10	470	45		10	415	0.28	1,363	31	91.96%	88.30%	97.73%	79.35%
		8	480	10	470	50		10	410	0.28	1,354	27	92.47%	87.23%	98.01%	79.06%
		9														
		10	480	10	470	45		10	415	0.28	1,343	24	90.61%	88.30%	98.21%	78.58%
		11														
		12														
		13	480	10	470	45		10	415	0.28	1343	27	90.61%	88.30%	97.99%	78.40%
		14	480	10	470	40		10	420	0.28	1352	28	90.13%	89.36%	97.93%	78.88%
		15	480	10	470	45	60	10	355	0.28	1130	30	89.13%	75.53%	97.35%	65.53%
		16	480		470		480		0	0.28						
		17	480		470		480		0	0.28						
		18														

		19														
		20	480	10	470	35		15	420	0.28	1354	26	90.27%	89.36%	98.08%	79.11%
		21	480	10	470	40		15	415	0.28	1357	27	91.56%	88.30%	98.01%	79.23%
		22	480	10	470	42		15	413	0.28	1346	21	91.25%	87.87%	98.44%	78.94%
		23	480	10	470	45		10	415	0.28	1345	25	90.75%	88.30%	98.14%	78.64%
		24	480	10	470	46		15	409	0.28	1354	26	92.69%	87.02%	98.08%	79.11%
		25														
		26														
		27	480	10	470	50	60	0	360	0.28	1043	24	81.12%	76.60%	97.70%	60.71%
		28	480	10	470	45		10	415	0.28	1365	25	92.10%	88.30%	98.17%	79.83%
		29	480	10	470	45		10	415	0.28	1345	29	90.75%	88.30%	97.84%	78.40%
		30	480	10	470	40		10	420	0.28	1357	20	90.47%	89.36%	98.53%	79.65%
	July	1	480	10	470	45		10	415	0.28	1341	27	90.48%	88.30%	97.99%	78.28%
		2														
		3														
		4	480	10	470	40		10	420	0.28	1356	23	90.40%	89.36%	98.30%	79.41%
		5	480	10	470	40		10	420	0.28	1345	25	89.67%	89.36%	98.14%	78.64%
		6	480	10	470	45		10	415	0.28	1348	23	90.95%	88.30%	98.29%	78.94%
		7	480	10	470	50		10	410	0.28	1351	26	92.26%	87.23%	98.08%	78.94%
		8	480	10	470	50		10	410	0.28	1349	21	92.13%	87.23%	98.44%	79.11%
		9								0.28						
		10														
		11	480	10	470	45		10	415	0.28	1348	19	90.95%	88.30%	98.59%	79.17%
		12	480	10	470	40		10	420	0.28	1366	18	91.07%	89.36%	98.68%	80.31%
		13	480	10	470	40		10	420	0.28	1337	31	89.13%	89.36%	97.68%	77.80%
		14	480	10	470	40	60	10	360	0.28	1172	34	91.16%	76.60%	97.10%	67.80%
		15	480	10	470		480		0	0.28	0	0				
		16														
		17														
		18	480	10	470	45		10	415	0.28	1366	30	92.16%	88.30%	97.80%	79.59%

		19	480	10	470	50		10	410	0.28	1357	23	92.67%	87.23%	98.31%	79.47%
		20	480	10	470	45		10	415	0.28	1344	25	90.68%	88.30%	98.14%	78.58%
		21	480	10	470	40		10	420	0.28	1351	26	90.07%	89.36%	98.08%	78.94%
		22	480	10	470	40		10	420	0.28	1355	29	90.33%	89.36%	97.86%	79.00%
		23														
		24														
		25	480	10	470	40		10	420	0.28	1342	25	89.47%	89.36%	98.14%	78.46%
		26	480	10	470	40		10	420	0.28	1346	26	89.73%	89.36%	98.07%	78.64%
		27	480	10	470	45		10	415	0.28	1355	27	91.42%	88.30%	98.01%	79.11%
		28	480	10	470	45		10	415	0.28	1352	28	91.22%	88.30%	97.93%	78.88%
		29	480	10	470	45		10	415	0.28	1354	27	91.35%	88.30%	98.01%	79.06%
		30														
		31														
	August	1	480	10	470	50		10	410	0.28	1349	22	92.13%	87.23%	98.37%	79.06%
		2	480	10	470	45		10	415	0.28	1346	26	90.81%	88.30%	98.07%	78.64%
		3	480	10	470	45		10	415	0.28	1340	20	90.41%	88.30%	98.51%	78.64%
		4	480	10	470	40		10	420	0.28	1346	23	89.73%	89.36%	98.29%	78.82%
		5	480	10	470	45		10	415	0.28	1342	26	90.54%	88.30%	98.06%	78.40%
		6														
		7														
		8	480	10	470	45		10	415	0.28	1354	20	91.35%	88.30%	98.52%	79.47%
		9	480	10	470	45		10	415	0.28	1348	18	90.95%	88.30%	98.66%	79.23%
		10	480	10	470	45		10	415	0.28	1349	27	91.02%	88.30%	98.00%	78.76%
		11	480	10	470	50		10	410	0.28	1361	25	92.95%	87.23%	98.16%	79.59%
		12	480	10	470	45		10	415	0.28	1358	25	91.62%	88.30%	98.16%	79.41%
		13														
		14														
		15	480	10	470	45		10	415	0.28	1346	23	90.81%	88.30%	98.29%	78.82%
		16	480	10	470	40		10	420	0.28	1343	25	89.53%	89.36%	98.14%	78.52%
		17	480	10	470	40		10	420	0.28	1348	23	89.87%	89.36%	98.29%	78.94%

		18	480	10	470	45		10	415	0.28	1358	26	91.62%	88.30%	98.09%	79.35%
		19	480	10	470	50		10	410	0.28	1362	30	93.01%	87.23%	97.80%	79.35%
		20														
		21														
		22	480	10	470	45		10	415	0.28	1352	23	91.22%	88.30%	98.30%	79.17%
		23	480	10	470	45		10	415	0.28	1366	22	92.16%	88.30%	98.39%	80.07%
		24	480	10	470	45		10	415	0.28	1346	24	90.81%	88.30%	98.22%	78.76%
		25	480	10	470	50		10	410	0.28	1357	20	92.67%	87.23%	98.53%	79.65%
		26	480	10	470	50		10	410	0.28	1359	19	92.81%	87.23%	98.60%	79.83%
		27														
		28														
		29	480	10	470	45		10	415	0.28	1329	18	89.67%	88.30%	98.65%	78.10%
		30	480	10	470	50		10	410	0.28	1347	24	91.99%	87.23%	98.22%	78.82%
	2017 June	1	480	15	465	43		10	412	0.28	1364	18	92.70%	88.60%	98.68%	81.05%
		2	480	15	465	48		10	407	0.28	1353	19	93.08%	87.53%	98.60%	80.33%
		3														
		4														
		5	480	15	465	45		10	410	0.28	1342	14	91.65%	88.17%	98.96%	79.97%
		6	480	15	465	48		10	407	0.28	1347	19	92.67%	87.53%	98.59%	79.97%
		7	480	15	465	49		10	406	0.28	1352	17	93.24%	87.31%	98.74%	80.39%
		8	480	15	465	39		10	416	0.28	1343	22	90.39%	89.46%	98.36%	79.54%
		9	480	15	465	50	75	10	330	0.28	1089	25	92.40%	70.97%	97.70%	64.07%
		10														
		11														
		12	480	15	465	44		10	411	0.28	1343	20	91.49%	88.39%	98.51%	79.66%
		13	480	15	465	43		10	412	0.28	1345	21	91.41%	88.60%	98.44%	79.72%
		14	480	15	465	49		10	406	0.28	1347	19	92.90%	87.31%	98.59%	79.97%
		15	480	15	465	40		10	415	0.28	1348	24	90.95%	89.25%	98.22%	79.72%
		16	480	15	465	42		10	413	0.28	1342	23	90.98%	88.82%	98.29%	79.42%
		17														

		18														
		19	480	15	465	48		10	407	0.28	1346	25	92.60%	87.53%	98.14%	79.54%
		20	480	15	465	50		10	405	0.28	1347	26	93.13%	87.10%	98.07%	79.54%
		21	480	15	465	46		10	409	0.28	1343	20	91.94%	87.96%	98.51%	79.66%
		22	480	15	465	44		10	411	0.28	1342	18	91.43%	88.39%	98.66%	79.72%
		23	480	15	465	46		10	409	0.28	1349	17	92.35%	87.96%	98.74%	80.21%
		24														
		25														
		26	480	15	465	48		10	407	0.28	1348	24	92.74%	87.53%	98.22%	79.72%
		27	480	15	465	49		10	406	0.28	1352	26	93.24%	87.31%	98.08%	79.85%
		28	480	15	465	50		10	405	0.28	1350	23	93.33%	87.10%	98.30%	79.91%
		29	480	15	465	47		10	408	0.28	1344	27	92.24%	87.74%	97.99%	79.30%
		30	480	15	465	43		10	412	0.28	1351	23	91.82%	88.60%	98.30%	79.97%
	July	1														
		2														
		3	480	15	465	45		10	410	0.28	1345	21	91.85%	88.17%	98.44%	79.72%
		4	480	15	465	45		10	410	0.28	1339	14	91.44%	88.17%	98.95%	79.78%
		5	480	15	465	48		10	407	0.28	1338	21	92.05%	87.53%	98.43%	79.30%
		6	480	15	465	42		10	413	0.28	1343	23	91.05%	88.82%	98.29%	79.48%
		7	480	15	465	46		10	409	0.28	1346	17	92.15%	87.96%	98.74%	80.03%
		8														
		9														
		10	480	15	465	47		10	408	0.28	1343	19	92.17%	87.74%	98.59%	79.72%
		11	480	15	465	48		10	407	0.28	1350	24	92.87%	87.53%	98.22%	79.85%
		12	480	15	465	42		10	413	0.28	1348	21	91.39%	88.82%	98.44%	79.91%
		13	480	15	465	44		10	411	0.28	1341	22	91.36%	88.39%	98.36%	79.42%
		14	480	15	465	42		10	413	0.28	1345	23	91.19%	88.82%	98.29%	79.60%
		15														
		16														
		17	480	15	465	48		10	407	0.28	1353	14	93.08%	87.53%	98.97%	80.63%

		18	480	15	465	39		10	416	0.28	1345	28	90.53%	89.46%	97.92%	79.30%
		19	480	15	465	42		10	413	0.28	1348	29	91.39%	88.82%	97.85%	79.42%
		20	480	15	465	43		10	412	0.28	1349	23	91.68%	88.60%	98.30%	79.85%
		21	480	15	465	42		10	413	0.28	1352	26	91.66%	88.82%	98.08%	79.85%
		22														
		23														
		24	480	15	465	47		10	408	0.28	1347	23	92.44%	87.74%	98.29%	79.72%
		25	480	15	465	46		10	409	0.28	1352	25	92.56%	87.96%	98.15%	79.91%
		26	480	15	465	50		10	405	0.28	1349	23	93.26%	87.10%	98.30%	79.85%
		27	480	15	465	43		10	412	0.28	1346	25	91.48%	88.60%	98.14%	79.54%
		28	480	15	465	44		10	411	0.28	1351	20	92.04%	88.39%	98.52%	80.15%
		29														
		30														
		31	480	15	465	40		10	415	0.28	1352	28	91.22%	89.25%	97.93%	79.72%
	August	1	480	15	465	42		10	413	0.28	1352	24	91.66%	88.82%	98.22%	79.97%
		2	480	15	465	44		10	411	0.28	1351	21	92.04%	88.39%	98.45%	80.09%
		3	480	15	465	43		10	412	0.28	1358	25	92.29%	88.60%	98.16%	80.27%
		4	480	15	465	49		10	406	0.28	1355	23	93.45%	87.31%	98.30%	80.21%
		5														
		6														
		7	480	15	465	43		10	412	0.28	1348	23	91.61%	88.60%	98.29%	79.78%
		8	480	15	465	47		10	408	0.28	1353	25	92.85%	87.74%	98.15%	79.97%
		9	480	15	465	45		10	410	0.28	1355	21	92.54%	88.17%	98.45%	80.33%
		10	480	15	465	43		10	412	0.28	1346	28	91.48%	88.60%	97.92%	79.36%
		11	480	15	465	48		10	407	0.28	1343	24	92.39%	87.53%	98.21%	79.42%
		12														
		13														
		14	480	15	465	50		10	405	0.28	1346	24	93.06%	87.10%	98.22%	79.60%
		15	480	15	465	45		10	410	0.28	1349	25	92.13%	88.17%	98.15%	79.72%
		16	480	15	465	43		10	412	0.28	1341	25	91.14%	88.60%	98.14%	79.24%

		17	480	15	465	42		10	413	0.28	1347	22	91.32%	88.82%	98.37%	79.78%
		18	480	15	465	43		10	412	0.28	1344	34	91.34%	88.60%	97.47%	78.88%
		19														
		20														
		21	480	15	465	48		10	407	0.28	1352	19	93.01%	87.53%	98.59%	80.27%
		22	480	15	465	39		10	416	0.28	1355	16	91.20%	89.46%	98.82%	80.63%
		23	480	15	465	45		10	410	0.28	1348	25	92.06%	88.17%	98.15%	79.66%
		24	480	15	465	45		10	410	0.28	1351	20	92.26%	88.17%	98.52%	80.15%
		25	480	15	465	42		10	413	0.28	1348	25	91.39%	88.82%	98.15%	79.66%
		26														
		27														
		28	480	15	465	47		10	408	0.28	1347	24	92.44%	87.74%	98.22%	79.66%
		29	480	15	465	44		10	411	0.28	1350	22	91.97%	88.39%	98.37%	79.97%
		30	480	15	465	45		10	410	0.28	1354	23	92.47%	88.17%	98.30%	80.15%

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time(min)	Breakdown time(min)	PF&D time (min)	Run time (min)	Ideal cycle time (min/pieces)	Total count(piece)	Defect (piece)	Performance	Availability	Quality rate	OEE
2016	June		10080	190	9870	833	1080	210	7767	0.28	25111	494	90.53%	78.69%	98.03%	69.84%
	July		10080	210	9870	870	540	200	8270	0.28	26835	513	90.86%	83.79%	98.09%	74.67%
	August		10560	220	10340	1005	0	220	9115	0.28	29706	509	91.25%	88.15%	98.29%	79.06%
	Total		30720	620	30080	2708	1620	630	25152	0.28	81652	1516	90.90%	83.62%	98.14%	74.59%
2017	June		10560	330	10230	1011	75	220	8924	0.28	29387	470	92.20%	87.23%	98.40%	79.15%
	July		10080	315	9765	933	0	210	8622	0.28	28282	469	91.85%	88.29%	98.34%	79.75%
	August		10560	330	10230	982	0	220	9028	0.28	29693	518	92.09%	88.25%	98.26%	79.85%
	Total		31200	975	30225	2926	75	650	26574	0.28	87362	1457	92.05%	87.92%	98.33%	79.58%

Appendix D: Modeling Group #2's Production Data And Its OEE

Modeling Workshop

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	PF&D time (min)	Run time (min)	Ideal cycle time (min/count)	Total count(count)	Defect (count)	Performance	Availability	Quality rate	OEE
Group #2	2016 June	1	480	20	460	97		15	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		2	480	20	460	96		14	350	18	19	1	97.71%	76.09%	94.74%	70.43%
		3	480	20	460	103		10	347	18	19	0	98.56%	75.43%	100.00%	74.35%
		4														
		5														
		6	480	20	460	102		10	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		7	480	20	460	98		1	361	18	20	1	99.72%	78.48%	95.00%	74.35%
		8	480	20	460	99		12	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		9														
		10	480	20	460	94		18	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		11														
		12														
		13	480	20	460	96		14	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		14	480	20	460	90		17	353	18	19	0	96.88%	76.74%	100.00%	74.35%
		15	480	20	460	92		2	366	18	20	1	98.36%	79.57%	95.00%	74.35%
		16	480	20	460	117	90	-5	258	18	14	0	97.67%	56.09%	100.00%	54.78%
		17	480	20	460	115		-3	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		18														

		19														
		20	480	20	460	103		7	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		21	480	20	460	92		12	356	18	19	0	96.07%	77.39%	100.00%	74.35%
		22	480	20	460	92		-3	371	18	20	2	97.04%	80.65%	90.00%	70.43%
		23	480	20	460	100		8	352	18	19	0	97.16%	76.52%	100.00%	74.35%
		24	480	20	460	103	120	-5	242	18	13	2	96.69%	52.61%	84.62%	43.04%
		25														
		26														
		27	480	20	460	93		18	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		28	480	20	460	96		16	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		29	480	20	460	96		-3	367	18	20	1	98.09%	79.78%	95.00%	74.35%
		30	480	20	460	104		-11	367	18	20	1	98.09%	79.78%	95.00%	74.35%
	July	1	480	20	460	97		15	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		2														
		3														
		4	480	20	460	98		13	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		5	480	20	460	103		9	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		6	480	20	460	100		13	347	18	19	0	98.56%	75.43%	100.00%	74.35%
		7	480	20	460	106	30	-10	334	18	18	1	97.01%	72.61%	94.44%	66.52%
		8	480	20	460	87		25	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		9														
		10														
		11	480	20	460	95		14	351	18	19	0	97.44%	76.30%	100.00%	74.35%
		12	480	20	460	95		17	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		13	480	20	460	98		-3	365	18	20	1	98.63%	79.35%	95.00%	74.35%
		14	480	20	460	101		10	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		15	480	20	460	96		13	351	18	19	0	97.44%	76.30%	100.00%	74.35%
		16														
		17														
		18	480	20	460	103		8	349	18	19	0	97.99%	75.87%	100.00%	74.35%

		19	480	20	460	95		15	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		20	480	20	460	99		13	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		21	480	20	460	106		6	348	18	19	1	98.28%	75.65%	94.74%	70.43%
		22	480	20	460	100		10	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		23														
		24														
		25	480	20	460	98		16	346	18	19	0	98.84%	75.22%	100.00%	74.35%
		26	480	20	460	97		13	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		27	480	20	460	120		11	329	18	18	0	98.48%	71.52%	100.00%	70.43%
		28	480	20	460	107		5	348	18	19	2	98.28%	75.65%	89.47%	66.52%
		29	480	20	460	101		10	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		30														
		31														
	August	1	480	20	460	94		20	346	18	19	0	98.84%	75.22%	100.00%	74.35%
		2	480	20	460	98		13	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		3	480	20	460	100		10	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		4	480	20	460	103		10	347	18	19	1	98.56%	75.43%	94.74%	70.43%
		5	480	20	460	100		12	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		6														
		7														
		8	480	20	460	96	120	20	224	18	12	0	96.43%	48.70%	100.00%	46.96%
		9	480		460		460	20								
		10	480		460		460	20								
		11	480	20	460	119		-6	347	18	19	1	98.56%	75.43%	94.74%	70.43%
		12	480	20	460	107		6	347	18	19	1	98.56%	75.43%	94.74%	70.43%
		13														
		14														
		15	480	20	460	105		8	347	18	19	0	98.56%	75.43%	100.00%	74.35%
		16	480	20	460	103		11	346	18	19	1	98.84%	75.22%	94.74%	70.43%
		17	480	20	460	99		11	350	18	19	1	97.71%	76.09%	94.74%	70.43%

		18	480	20	460	103		9	348	18	19	0	98.28%	75.65%	100.00%	74.35%
		19	480	20	460	91		19	350	18	19	0	97.71%	76.09%	100.00%	74.35%
		20														
		21														
		22	480	20	460	98		13	349	18	19	0	97.99%	75.87%	100.00%	74.35%
		23	480	20	460	116		-5	349	18	19	1	97.99%	75.87%	94.74%	70.43%
		24	480	20	460	101		8	351	18	19	0	97.44%	76.30%	100.00%	74.35%
		25	480	20	460	92		14	354	18	19	1	96.61%	76.96%	94.74%	70.43%
		26	480	20	460	80		13	367	18	20	0	98.09%	79.78%	100.00%	78.26%
		27														
		28														
		29	480	20	460	103		10	347	18	19	0	98.56%	75.43%	100.00%	74.35%
		30	480	20	460	100		12	348	18	19	0	98.28%	75.65%	100.00%	74.35%
	2017 June	1	480	15	465	92		6	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		2	480	15	465	93		6	366	18	20	1	98.36%	78.71%	95.00%	73.55%
		3														
		4														
		5	480	15	465	95		3	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		6	480	15	465	95		2	368	18	20	0	97.83%	79.14%	100.00%	77.42%
		7	480	15	465	98		0	367	18	20	1	98.09%	78.92%	95.00%	73.55%
		8	480	15	465	100		-5	370	18	20	1	97.30%	79.57%	95.00%	73.55%
		9	480	15	465	97		4	364	18	20	1	98.90%	78.28%	95.00%	73.55%
		10														
		11														
		12	480	15	465	94		5	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		13	480	15	465	90		9	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		14	480	15	465	89		9	367	18	20	1	98.09%	78.92%	95.00%	73.55%
		15	480	15	465	94		5	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		16	480	15	465	90		8	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		17														

		18														
		19	480	15	465	84		15	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		20	480	15	465	78		20	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		21	480	15	465	94		5	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		22	480	15	465	90		8	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		23	480	15	465	105		-6	366	18	20	2	98.36%	78.71%	90.00%	69.68%
		24														
		25														
		26	480	15	465	93		6	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		27	480	15	465	95		5	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		28	480	15	465	90		8	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		29	480	15	465	91		7	367	18	20	1	98.09%	78.92%	95.00%	73.55%
		30	480	15	465	89		10	366	18	20	0	98.36%	78.71%	100.00%	77.42%
	July	1														
		2														
		3	480	15	465	91		7	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		4	480	15	465	94		6	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		5	480	15	465	97		4	364	18	20	0	98.90%	78.28%	100.00%	77.42%
		6	480	15	465	99		2	364	18	20	1	98.90%	78.28%	95.00%	73.55%
		7	480	15	465	90		6	369	18	20	0	97.56%	79.35%	100.00%	77.42%
		8														
		9														
		10	480	15	465	92		7	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		11	480	15	465	93		7	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		12	480	15	465	90		8	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		13	480	15	465	100		0	365	18	20	2	98.63%	78.49%	90.00%	69.68%
		14	480	15	465	94		8	363	18	20	0	99.17%	78.06%	100.00%	77.42%
		15														
		16														
		17	480	15	465	90		7	368	18	20	0	97.83%	79.14%	100.00%	77.42%

		18	480	15	465	95		6	364	18	20	0	98.90%	78.28%	100.00%	77.42%
		19	480	15	465	97		5	363	18	20	1	99.17%	78.06%	95.00%	73.55%
		20	480	15	465	94		7	364	18	20	1	98.90%	78.28%	95.00%	73.55%
		21	480	15	465	92		7	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		22														
		23														
		24	480	15	465	95		6	364	18	20	0	98.90%	78.28%	100.00%	77.42%
		25	480	15	465	105		-4	364	18	20	0	98.90%	78.28%	100.00%	77.42%
		26	480	15	465	93		7	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		27	480	15	465	93		6	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		28	480	15	465	90		8	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		29														
		30														
		31	480	15	465	92		8	365	18	20	0	98.63%	78.49%	100.00%	77.42%
	August	1	480	15	465	94		7	364	18	20	0	98.90%	78.28%	100.00%	77.42%
		2	480	15	465	88		11	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		3	480	15	465	89		10	366	18	20	1	98.36%	78.71%	95.00%	73.55%
		4	480	15	465	93		7	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		5														
		6														
		7	480	15	465	97		3	365	18	20	1	98.63%	78.49%	95.00%	73.55%
		8	480	15	465	88		10	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		9	480	15	465	93		6	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		10	480	15	465	90		7	368	18	20	0	97.83%	79.14%	100.00%	77.42%
		11	480	15	465	87		12	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		12														
		13														
		14	480	15	465	92		6	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		15	480	15	465	97		2	366	18	20	1	98.36%	78.71%	95.00%	73.55%
		16	480	15	465	88		10	367	18	20	0	98.09%	78.92%	100.00%	77.42%

		17	480	15	465	90		7	368	18	20	0	97.83%	79.14%	100.00%	77.42%
		18	480	15	465	85		14	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		19														
		20														
		21	480	15	465	94		6	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		22	480	15	465	92		7	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		23	480	15	465	99		0	366	18	20	1	98.36%	78.71%	95.00%	73.55%
		24	480	15	465	89		8	368	18	20	0	97.83%	79.14%	100.00%	77.42%
		25	480	15	465	88		10	367	18	20	0	98.09%	78.92%	100.00%	77.42%
		26														
		27														
		28	480	15	465	91		9	365	18	20	0	98.63%	78.49%	100.00%	77.42%
		29	480	15	465	93		6	366	18	20	0	98.36%	78.71%	100.00%	77.42%
		30	480	15	465	92		7	366	18	20	0	98.36%	78.71%	100.00%	77.42%

			Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	PF&D time (min)	Run time (min)	Ideal cycle time (min/count)	Total count(count)	Defect	Performance	Availability	Quality rate	OEE
2016	June		10080	420	9660	2078	210	144	7228	18	393	9	97.87%	74.82%	97.71%	71.55%
	July		10080	420	9660	2102	30	223	7305	18	398	5	98.07%	75.62%	98.74%	73.23%
	August		10560	400	10120	2008	1040	248	6864	18	374	7	98.08%	67.83%	98.13%	65.28%
	Total		30720	1240	29440	6188	1280	615	21397	18	1165	21	98.00%	72.68%	98.20%	69.95%
2017	June		10560	330	10230	2036	0	130	8064	18	440	8	98.21%	78.83%	98.18%	76.01%
	July		10080	315	9765	1976	0	118	7671	18	420	5	98.55%	78.56%	98.81%	76.50%
	August		10560	330	10230	2009	0	165	8056	18	440	4	98.31%	78.75%	99.09%	76.72%
	Total		31200	975	30225	6021	0	413	23791	18	1300	17	98.36%	78.71%	98.69%	76.41%

Appendix E: Mixing Group #1's Production Data And Its OEE

Mixing Workshop

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	Run time (min)	PF&D time (min)	Ideal cycle time	Total count(bucket)	Defect	Performance	Availability	Quality rate	OEE
Mixing group 1	2016 June	1	480	115	365	90		240	35	1	4	0	100.00%	65.75%	100.00%	65.75%
		2	480	110	370	85		240	45	1	4	0	100.00%	64.86%	100.00%	64.86%
		3	480	110	370	86		240	44	1	4	0	100.00%	64.86%	100.00%	64.86%
		4														
		5														
		6	480	112	368	86		240	42	1	4	0	100.00%	65.22%	100.00%	65.22%
		7	480	107	373	85		240	48	1	4	0	100.00%	64.34%	100.00%	64.34%
		8	480	111	369	76		240	53	1	4	0	100.00%	65.04%	100.00%	65.04%
		9														
		10	480	108	372	90		240	42	1	4	0	100.00%	64.52%	100.00%	64.52%
		11														
		12														
		13	480	105	375	92		240	43	1	4	0	100.00%	64.00%	100.00%	64.00%
		14	480	103	377	90		240	47	1	4	0	100.00%	63.66%	100.00%	63.66%
		15	480	120	360	85		240	35	1	4	0	100.00%	66.67%	100.00%	66.67%
		16	480	117	363	83		240	40	1	4	0	100.00%	66.12%	100.00%	66.12%
		17	480	115	365	83		240	42	1	4	0	100.00%	65.75%	100.00%	65.75%
		18														

		19														
		20	480	118	362	85		240	37	1	4	0	100.00%	66.30%	100.00%	66.30%
		21	480		480		360		120	1						
		22	480	112	368	82		240	46	1	4	0	100.00%	65.22%	100.00%	65.22%
		23	480	104	376	81		240	55	1	4	0	100.00%	63.83%	100.00%	63.83%
		24	480	103	377	84		240	53	1	4	0	100.00%	63.66%	100.00%	63.66%
		25														
		26														
		27	480	100	380	83		240	57	1	4	0	100.00%	63.16%	100.00%	63.16%
		28	480	105	375	85		240	50	1	4	0	100.00%	64.00%	100.00%	64.00%
		29	480	103	377	83		240	54	1	4	0	100.00%	63.66%	100.00%	63.66%
		30	480	115	365	82		240	43	1	4	0	100.00%	65.75%	100.00%	65.75%
	July	1	480	108	372	87		240	45	1	4	0	100.00%	64.52%	100.00%	64.52%
		2														
		3														
		4	480	120	360	87		240	33	1	4	0	100.00%	66.67%	100.00%	66.67%
		5	480	113	367	87		240	40	1	4	0	100.00%	65.40%	100.00%	65.40%
		6	480	108	372	88		240	44	1	4	0	100.00%	64.52%	100.00%	64.52%
		7	480	107	373	88		240	45	1	4	0	100.00%	64.34%	100.00%	64.34%
		8	480	101	379	87		240	52	1	4	0	100.00%	63.32%	100.00%	63.32%
		9														
		10														
		11	480	103	377	85		240	52	1	4	0	100.00%	63.66%	100.00%	63.66%
		12	480	98	382	83		240	59	1	4	0	100.00%	62.83%	100.00%	62.83%
		13	480	103	377	85		240	52	1	4	0	100.00%	63.66%	100.00%	63.66%
		14	480	105	375	86		240	49	1	4	0	100.00%	64.00%	100.00%	64.00%
		15	480	102	378	88		240	50	1	4	0	100.00%	63.49%	100.00%	63.49%
		16														
		17														
		18	480	104	376	83		240	53	1	4	0	100.00%	63.83%	100.00%	63.83%

		19	480	110	370	83		240	47	1	4	0	100.00%	64.86%	100.00%	64.86%
		20	480	107	373	92		240	41	1	4	0	100.00%	64.34%	100.00%	64.34%
		21	480	99	381	83		240	58	1	4	0	100.00%	62.99%	100.00%	62.99%
		22	480	100	380	87		240	53	1	4	0	100.00%	63.16%	100.00%	63.16%
		23														
		24														
		25	480	105	375	89		240	46	1	4	0	100.00%	64.00%	100.00%	64.00%
		26	480	107	373	79		240	54	1	4	0	100.00%	64.34%	100.00%	64.34%
		27	480	98	382	84		240	58	1	4	0	100.00%	62.83%	100.00%	62.83%
		28	480	111	369	88		240	41	1	4	0	100.00%	65.04%	100.00%	65.04%
		29	480	109	371	86		240	45	1	4	0	100.00%	64.69%	100.00%	64.69%
		30														
		31														
	August	1	480	105	375	85		240	50	1	4	0	100.00%	64.00%	100.00%	64.00%
		2	480	105	375	85		240	50	1	4	0	100.00%	64.00%	100.00%	64.00%
		3	480	111	369	86		240	43	1	4	0	100.00%	65.04%	100.00%	65.04%
		4	480	103	377	86		240	51	1	4	0	100.00%	63.66%	100.00%	63.66%
		5	480	99	381	85		240	56	1	4	0	100.00%	62.99%	100.00%	62.99%
		6														
		7														
		8	480	98	382	83		240	59	1	4	0	100.00%	62.83%	100.00%	62.83%
		9	480	103	377	85		240	52	1	4	0	100.00%	63.66%	100.00%	63.66%
		10	480	102	378	87		240	51	1	4	0	100.00%	63.49%	100.00%	63.49%
		11	480	107	373	88		240	45	1	4	0	100.00%	64.34%	100.00%	64.34%
		12	480	103	377	89		240	48	1	4	0	100.00%	63.66%	100.00%	63.66%
		13														
		14														
		15	480	110	370	83		240	47	1	4	0	100.00%	64.86%	100.00%	64.86%
		16	480	113	367	85		240	42	1	4	0	100.00%	65.40%	100.00%	65.40%
		17	480	104	376	86		240	50	1	4	0	100.00%	63.83%	100.00%	63.83%

		18	480	101	379	87		240	52	1	4	0	100.00%	63.32%	100.00%	63.32%
		19	480	107	373	89		240	44	1	4	0	100.00%	64.34%	100.00%	64.34%
		20														
		21														
		22	480	103	377	84		240	53	1	4	0	100.00%	63.66%	100.00%	63.66%
		23	480	103	377	83		240	54	1	4	0	100.00%	63.66%	100.00%	63.66%
		24	480	96	384	84		240	60	1	4	0	100.00%	62.50%	100.00%	62.50%
		25	480	105	375	84		240	51	1	4	0	100.00%	64.00%	100.00%	64.00%
		26	480	98	382	85		240	57	1	4	0	100.00%	62.83%	100.00%	62.83%
		27														
		28														
		29	480	100	380	85		240	55	1	4	0	100.00%	63.16%	100.00%	63.16%
		30	480	99	381	85		240	56	1	4	0	100.00%	62.99%	100.00%	62.99%
	2017 June	1	480	94	386	80		300	6	1	5	0	100.00%	77.72%	100.00%	77.72%
		2	480	93	387	81		300	6	1	5	0	100.00%	77.52%	100.00%	77.52%
		3														
		4														
		5	480	95	385	82		300	3	1	5	0	100.00%	77.92%	100.00%	77.92%
		6	480	92	388	84		300	4	1	5	0	100.00%	77.32%	100.00%	77.32%
		7	480	96	384	85		300	-1	1	5	0	100.00%	78.13%	100.00%	78.13%
		8	480	94	386	81		300	5	1	5	0	100.00%	77.72%	100.00%	77.72%
		9	480	94	386	79		300	7	1	5	0	100.00%	77.72%	100.00%	77.72%
		10														
		11														
		12	480	93	387	78		300	9	1	5	0	100.00%	77.52%	100.00%	77.52%
		13	480	94	386	80		300	6	1	5	0	100.00%	77.72%	100.00%	77.72%
		14	480	92	388	81		300	7	1	5	0	100.00%	77.32%	100.00%	77.32%
		15	480	94	386	80		300	6	1	5	0	100.00%	77.72%	100.00%	77.72%

		16	480	91	389	82		300	7	1	5	0	100.00%	77.12%	100.00%	77.12%
		17														
		18														
		19	480	93	387	83		300	4	1	5	0	100.00%	77.52%	100.00%	77.52%
		20	480	93	387	78		300	9	1	5	0	100.00%	77.52%	100.00%	77.52%
		21	480	92	388	81		300	7	1	5	0	100.00%	77.32%	100.00%	77.32%
		22	480	91	389	81		300	8	1	5	0	100.00%	77.12%	100.00%	77.12%
		23	480	90	390	81		300	9	1	5	0	100.00%	76.92%	100.00%	76.92%
		24														
		25														
		26	480	93	387	77		300	10	1	5	0	100.00%	77.52%	100.00%	77.52%
		27	480	93	387	84		300	3	1	5	0	100.00%	77.52%	100.00%	77.52%
		28	480	92	388	81		300	7	1	5	0	100.00%	77.32%	100.00%	77.32%
		29	480	94	386	80		300	6	1	5	0	100.00%	77.72%	100.00%	77.72%
		30	480	95	385	80		300	5	1	5	0	100.00%	77.92%	100.00%	77.92%
	July	1														
		2														
		3	480	95	385	76		300	9	1	5	0	100.00%	77.92%	100.00%	77.92%
		4	480	93	387	78		300	9	1	5	0	100.00%	77.52%	100.00%	77.52%
		5	480	94	386	79		300	7	1	5	0	100.00%	77.72%	100.00%	77.72%
		6	480	93	387	82		300	5	1	5	0	100.00%	77.52%	100.00%	77.52%
		7	480	93	387	77		300	10	1	5	0	100.00%	77.52%	100.00%	77.52%
		8														
		9														
		10	480	93	387	77		300	10	1	5	0	100.00%	77.52%	100.00%	77.52%
		11	480	93	387	80		300	7	1	5	0	100.00%	77.52%	100.00%	77.52%
		12	480	94	386	81		300	5	1	5	0	100.00%	77.72%	100.00%	77.72%
		13	480	93	387	82		300	5	1	5	0	100.00%	77.52%	100.00%	77.52%
		14	480	90	390	79		300	11	1	5	0	100.00%	76.92%	100.00%	76.92%
		15														

		16														
		17	480	91	389	83		300	6	1	5	0	100.00%	77.12%	100.00%	77.12%
		18	480	92	388	78		300	10	1	5	0	100.00%	77.32%	100.00%	77.32%
		19	480	89	391	78		300	13	1	5	0	100.00%	76.73%	100.00%	76.73%
		20	480	92	388	79		300	9	1	5	0	100.00%	77.32%	100.00%	77.32%
		21	480	97	383	80		300	3	1	5	0	100.00%	78.33%	100.00%	78.33%
		22														
		23														
		24	480	96	384	80		300	4	1	5	0	100.00%	78.13%	100.00%	78.13%
		25	480	95	385	82		300	3	1	5	0	100.00%	77.92%	100.00%	77.92%
		26	480	92	388	75		300	13	1	5	0	100.00%	77.32%	100.00%	77.32%
		27	480	93	387	78		300	9	1	5	0	100.00%	77.52%	100.00%	77.52%
		28	480	94	386	76		300	10	1	5	0	100.00%	77.72%	100.00%	77.72%
		29														
		30														
		31	480	92	388	76		300	12	1	5	0	100.00%	77.32%	100.00%	77.32%
	August	1	480	93	387	79		300	8	1	5	0	100.00%	77.52%	100.00%	77.52%
		2	480	95	385	75		300	10	1	5	0	100.00%	77.92%	100.00%	77.92%
		3	480	97	383	76		300	7	1	5	0	100.00%	78.33%	100.00%	78.33%
		4	480	96	384	78		300	6	1	5	0	100.00%	78.13%	100.00%	78.13%
		5														
		6														
		7	480	92	388	79		300	9	1	5	0	100.00%	77.32%	100.00%	77.32%
		8	480	93	387	75		300	12	1	5	0	100.00%	77.52%	100.00%	77.52%
		9	480	93	387	74		300	13	1	5	0	100.00%	77.52%	100.00%	77.52%
		10	480	95	385	80		300	5	1	5	0	100.00%	77.92%	100.00%	77.92%
		11	480	91	389	82		300	7	1	5	0	100.00%	77.12%	100.00%	77.12%
		12														
		13														
		14	480	96	384	78		300	6	1	5	0	100.00%	78.13%	100.00%	78.13%

		15	480	96	384	79		300	5	1	5	0	100.00%	78.13%	100.00%	78.13%
		16	480	96	384	79		300	5	1	5	0	100.00%	78.13%	100.00%	78.13%
		17	480	93	387	76		300	11	1	5	0	100.00%	77.52%	100.00%	77.52%
		18	480	92	388	81		300	7	1	5	0	100.00%	77.32%	100.00%	77.32%
		19														
		20														
		21	480	94	386	82		300	4	1	5	0	100.00%	77.72%	100.00%	77.72%
		22	480	93	387	73		300	14	1	5	0	100.00%	77.52%	100.00%	77.52%
		23	480	92	388	79		300	9	1	5	0	100.00%	77.32%	100.00%	77.32%
		24	480	95	385	76		300	9	1	5	0	100.00%	77.92%	100.00%	77.92%
		25	480	93	387	78		300	9	1	5	0	100.00%	77.52%	100.00%	77.52%
		26														
		27														
		28	480	92	388	75		300	13	1	5	0	100.00%	77.32%	100.00%	77.32%
		29	480	91	389	77		300	12	1	5	0	100.00%	77.12%	100.00%	77.12%
		30	480	96	384	79		300	5	1	5	0	100.00%	78.13%	100.00%	78.13%

Machine No.		Date	Shift time (min)	Cleaning time (min)	Planned production time (min)	Set-up time (min)	Breakdown time (min)	Run time (min)	PF&D time (min)	Ideal cycle time	Total count(bucket)	Defect	Performance	Availability	Quality rate	OEE
2016	June		10080	2193	7887	1696	360	4800	1031	1	80	0	100.00%	65.42%	100.00%	65.42%
	July		10080	2218	7862	1805	0	5040	1017	1	84	0	100.00%	64.11%	100.00%	64.11%
	August		10560	2275	8285	1879	0	5280	1126	1	88	0	100.00%	63.73%	100.00%	63.73%
	Total		30720	6686	24034	5380	360	15120	3174	1	252	0	100.00%	64.41%	100.00%	64.41%
2017	June		10560	2048	8512	1779	0	6600	133	1	110	0	100.00%	77.54%	100.00%	77.54%
	July		10080	1954	8126	1656	0	6300	170	1	105	0	100.00%	77.53%	100.00%	77.53%
	August		10560	2064	8496	1710	0	6600	186	1	110	0	100.00%	77.68%	100.00%	77.68%
	Total		31200	6066	25134	5145	0	19500	489	1	325	0	100.00%	77.58%	100.00%	77.58%

References

Ade, A. (2014). *TPM simplified*. Retrieved from http://www.aaglobalsoucing.com.

Amir, A. (2015). Evaluation improvement of production productivity performance using statistical process control, overall equipment efficiency, and autonomous maintenance. *Procedia Manufacturing*, *2*, 186-190. doi:10.1016/j.promfg.2015.07.032.

Cloves, W. T. F., & Jandecy, C. L. (2016). Applied autonomous maintenance in the improvement of production quality: a case study. Journal of Engineering and Technology for Industrial Applications, 2(7), 17-27. Retrieved from https://dx.doi.org/10.5935/2447-0228.20160026.

Chen, C. (2013). A developed autonomous preventive maintenance program using RCA and FMEA. *International Journal of Production Research, 51*(18), 5404-5412. Retrieved from http://dx.doi.org/10.1080/00207543.2013.775521.

Chris, A. O. (2015). *The TPM playbook: A step-by-step guideline for the lean practitioner.* Boca Raton, FL: CRC Press.

Edward, H., & Hartmann, P. E. (1992). *Successfully installing TPM in a non-Japanese plant.* Allison Park, PA: TPM press.

Hisamitsu, I. (1994). Early management. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.199-234). New York: Productivity Press.

Hisamitsu, I. (1994). Operating and maintenance skills training. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.261-282). New York: Productivity Press.

Ikuo, S. (1994). Building a safe, environmentally friendly system. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.323-350). New York: Productivity Press.

Ikuo, S. (1994). Quality maintenance. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.235-260). New York: Productivity Press.

Koichi, N. (1994). Autonomous maintenance. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.87-144). New York: Productivity Press.

Koichi, N. (1994). Focused improvement. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.45-84). New York: Productivity Press.

Tokutaro, S. (1994). Overview of TPM in process industry. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.1-13). New York: Productivity Press.

Kunio, S., & Seiichi, N. (1992). *TPM for supervisors.* Boca Raton, FL: CRC Press.

McCarthy, D., & Rich, N. (2015). *Lean TPM: A blueprint for change.* Waltham, MA: Butterworth-Heinemann. Makoto, H. (1994). TPM in administrative and support departments. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.283-322). New York: Productivity Press.

Makoto, S., & Hisao, M. (1994). Planned maintenance. In S. Tokutaro (Eds), *TPM-in process industries.* (pp.145-198). New York: Productivity Press.

Melesse, W. W., & Ananth, S. I. (2014). Autonomous maintenance: a case study on Assela Malt Factory. *Bonfring International Journal of Industial Engineering and Management Science, 4* (4), 170-178. doi:10.9756/BIJIEMS.10364.

Mnif, R., Ben, J., M., C., Kacem, N., H., & Elleuch, R., (2013). Impact of viscoelasticity on the tribological behavior of PTFE composites for valve seals application. *Transactions, 56*(5), 879-886.

Nicholas, J. M. (1998). *Competitive manufacturing management: continuous improvement, lean production, and customer-focused quality.* US: McGraw-Hill.

Roland Berger Strategy Consultants. (2016, September). Operational Excellence. Retrieved from https://www.rolandberger.com/publications/publication_pdf/roland_berger_operational_excellence_3.pdf.

Seiichi, N. (1991). In Alan R. (Ed.), *Continuous improvement in operations*. Cambridge, MA: Productivity Press.

Terry, W. (2004). *Total productive maintenance (*2nd ed.) New York city: Industrial Press.

Willmott, P., & McCarthy, D. (2001). *TPM- a route to a world-class performance*. Woburn, MA: Butterworth-Heinemann.

U.S. Office of Management and Budget. (1979, April 5). OMB circular #A109: a major system acquisitions. Retrieved from https://www.emcbc.doe.gov/pmo/supporting_files/omb_circular_a_109.pdf.

U.S Department of Labor. (2008, July). Fact sheet #39D: incorporating personal time, fatigue and delay (PF&D) allowances when determining piece rates to be paid workers with disabilities receiving special minimum wages under section 14(c) of the fair labor standards act. Retrieved from https://www.dol.gov/whd/regs/compliance/whdfs39d.pdf.