Application and Performance Measurement of Total Productive Maintenance: Case study of a Food Industries Company in Egypt

Ragab Eid. Ragab
Al awel for food Company
Helwan University

Sabreen A. Abdelwahab
Production Technology Dep.,
Helwan University

Gamal H.Shehata
Mechanical Engineering Dep.,
Helwan University

NaglaaAbd El Samed
Curricula Dep.,
Helwan University

Saleh Kaytbay
Mechanical Engineering Dep., Benha University
Higher Institute of Engineering Technology
Mahalla Al – Kubra

Walid Mahmoud Elnahas
Production Technology Dep
Helwan University

Abstract

The maintenance activity is as important as the production activity. In order to reduce production cost and increase production efficiency, Total Productive Maintenance (TPM) is employed. TPM has several key principles; 5S, self-maintenance, continuous improvement, planned maintenance, education and training, quality maintenance, occupational safety and health, senior management support and participation of all departments. By implementing these principles, productivity can be improved by reducing downtime, improving quality, adhering to specified delivery times, improving working conditions, and increasing employee morale. This research focuses on the effective role of the TPM principles in achieving the objectives of the industrial companies, enhancing the cooperation and coordination between different departments of the company, especially the participation of all workers in the production and maintenance process, 6th October City has been selected for

application and measurement. A program has been designed and implemented in the form of checklists to measure TPM performance within industrial plants.

The aims of research are: first, to reduce the gap between production and maintenance which is usually found in the standard independent maintenance.

Second, to put a clear plan for predictive maintenance and provide adequate training for the company staff to apply TPM principles. Improvement in the Mean and Standard Deviation of applying the TPM which are 6% and 5.29% respectively have been achieved by applying TPM program.

Keywords: Total Productive Maintenance; TPM principles; TPM Implementation; Overall Equipment Effectiveness; Autonomous maintenance ; Kaizen; MTBF ; MTTR.

1. Introduction

Total Productive Maintenance (TPM) is a productivity improvement practice analogous to the use of total quality management (TQM). It is a Japanese concept of equipment management that allows a facility to improve decisively the equipment performance in the manufacturing area with the help and involvement of all employees. Nakajima concludes that TPM activities focus on eliminating the six major losses; equipment failure, set-up and adjustment time, idling and minor stoppages, reduced speed, defects in process, and reduced yield. According to the objectives of TPM, which are continuously improving the availability and prevent the degradation of equipment to achieve maximum effectiveness [1], these objectives require strong management support as well as continuous use of work teams and small group activities to achieve incremental improvements.

TPM has several principles; the first is Autonomous Maintenance (AM): In this system, the operator is responsible for performing minor maintenance tasks, such as re-connecting screws, lubricating and cleaning the equipment, or other maintenance tasks that do not require specialized technician. The second principle is 5S: This is an abbreviation for five Japanese words "Seiri- Seiton- Seiso- Seiketsu- Shitsuke", these mean (Sorting - Set in Order- Shining – Standardize - Sustain) respectively. Organized and clean work environment make problems easily observed, resulting in high efficiency, productivity and improved product quality. The third principle is Continuous Improvement (CI): It means to make small improvements that are carried out on an ongoing basis with the participation of all employees of the facility in order to reduce costs and time spent in workplace that impact efficiency. The fourth principle is Planned Maintenance (PM): Scheduling maintenance based on the historical failure rate of the equipment taking into account that maintenance done during

the low production periods in order to reduce maintenance during the production peaks. The fifth principle is Quality Maintenance (QM): It is intended to determine the conditions of equipment that cause the reduction of product quality in order to achieve customer satisfaction by achieving the highest quality rates through the manufacturing of defect-free products. The sixth principle is Education & Training (ET): Improve employees' knowledge and techniques and create a self-learning work environment with multi-skilled workers to enable them to solve problems within the company. The seventh principle is Health, Safety & Environment (HSE): Focuses on creating a safe working environment and to create awareness among employees regarding safety, health and environment. Finally, the eighth principle is TPM in the Office: It is intended to establish an administrative structure to maintain the overall productivity within the company to distribute jobs and roles to the employees and to follow up the implementation of TPM.

A TPM is a fundamental component of world-class manufacturing which has been recognized as one of the significant operation strategy to regain the production losses resulting from equipment inefficiency; this is illustrated by the following research studies. In a study conducted in the food industry in South India, implementation and performance factors are compared to those in the industry that have been applied TPM and an important relationship has been found. The results helped the management team to focus on areas of improvement to the production process [2]. In another study in Malaysia, they evaluated the TPM through the study of the relationship between TPM practices and manufacturing performance. It investigated the moderating effect of the level of technical complexity in the production process in the TPM practices and manufacturing performance relationships as well. Significant relationships were found between TPM practices and cost. The moderating effect of technical complexity in the production process on the relationship between TPM practices and manufacturing performance was found [3]. One of the challenges in the implementation of TPM in manufacturing industry is the slow managerial decision-making to respond to the condition in the factory. Investigates the answers of these challenges by analyzing and modeling the equipment condition and the response of actions required in a wooden door manufacturing industry TPM implementation in this company has deployed the Overall Equipment Effectiveness (OEE) measurement as an indicator [4]of the equipment utilization and condition. Through analysis and modeling of the OEE value obtained from the factory, the formulation of Association Rule Mining (ARM) aims to find a rule that shows the well computed relationship between measurable indicators of OEE with the response of action required to take in certain condition of machine utilization. Results obtained from ARM

accelerate the decision to establish an appropriate TPM management strategy based on the rules. The generated dynamic rules form and facilitate the process of decision-making by related stakeholders. The development of an effective TPM model to improve the maintenance system at a chemical manufacturing company in Zambia was the main focus of TPM [5]. The researchers set objectives to assess the current maintenance system, to determine the overall equipment effectiveness and to identify key performance indicators and success factors of TPM. Data relevant to the research was collected using designed questionnaires, structured interviews, direct observations and company records the researchers then designed a TPM model which would result in effective implementation of TPM for higher competitiveness in the dynamic business environment. To improve the accessibility of the existing equipment and in consequence curtail the further capital investment using TPM, a case study [6] has been carried out at cotton spinning plant to identify the extensive deficiency associated with equipment effectiveness. The paper intents on analyzing the practical problems accomplishing TPM program and improved the effectiveness for critical machine by significant value. Another paper studied the implementation of TPM which is done by performing machine wise breakdown analysis. TPM is a medical science of machine which improves the performance of maintenance activity, product and process quality, employee morale and job satisfaction. The study establishes that focused on section wise breakdown analysis, breakdown types wise and equipment wise breakdown analysis to avoid delay in manufacturing process [7]. TPM was also implemented in a machine shop area in a manufacturing industry (Yamuna m/c works ltd.) and to evaluate OEE of individual machines placed in machine shop area. The study is conducted in a food industry in South India which is engaged in the manufacturing of egg related products. The implementation factors and performance are compared with that in TPM awarded industry and the correlation is found significant. The aim of the study was to help improve the system through training, awareness and improving the performance of employees by comparing performance and implementation factors [8].

In the case study under consideration; (Al Awael Food Industries Co., 6th of October City, Egypt) many problems were detected as a great loss in maintenance time operations, lack of proper training for workers in the maintenance management, shortage of spare parts, lack of coordination planned maintenance, lack of AM and increase of maintenance costs. Therefore, many objectives were set for this study such as designing a program to measure the performance of TPM within the industrial facilities, apply the principles of TPM in the required manner, and reduce the maintenance management costs through the application of the principles of TPM.

This paper contains five sections; the first is the introduction section, the second is the experimental work, the third is results and discussions, the fourth is the conclusion section, the last section is the References section.

2. Experimental work

In this work a TPM evaluation program will be designed to detect the current TPM implementation in the factory, and then the eight principals of TPM will be implemented on the factory, after that the TPM will be evaluated again and be compared to the first value, this is done by the following steps;

A. TPM Evaluation Program Design

A Questionnaire preparation: A questionnaire consisting of a set of checklists for the principles of TPM has been prepared. Each list contains a set of questions for the main items of each principle. The items are measured before and after the application.

Data entry stage: this program was implemented on the basis of the experienced staff within the factory to obtain the data. The data for the evaluation program shall be entered in the form of answers to the questions prepared for each main principle of TPM, with the possibility of modification or deletion of each question.

B. Evaluation of the current TPM situation

An evaluation of the workers within the Alawael for Food Industries is carried out through inspection lists for TPM. The answers values are chosen from 1 to 5, where 1 is the lowest rating and 5 is the highest rating according to Table 1:

Table 1: Evaluation values

Evaluation values				
1	2	3	4	5
(0 to 20)%	(21 to 40)%	(41 to 60)%	(61 to 80) %	(81 to 100)%

The program will calculate the TPM principles by equation NO. 1:

$$(\#)\% = \frac{(1*\sum N1)+(2*\sum N2)+(3*\sum N3)+(4*\sum N4)+(5*\sum N5)}{N*5} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where
: is the measured TPM principle,
N : is the number of questions,
N1, N2, N3, N4, and N5: are the evaluation values of each answer per principle.

C. TPM implementation

Training sessions will be conducted at the company's training department in order to improve the awareness of the principles of TPM. Then, second evaluation is carried out after applying the principles of TPM.

3. Results and discussions

Table 2 shows the questions checklist and the results of the **5S** principle evaluation before and after the application of the TPM principles. The 5S principle evaluation were 74.12% before applying the TPM principles, while the evaluation results after evaluating the TPM application were 80.11%. This is due to: Not all unnecessary items were removed but some of them were needed. Non-essential objects were not kept in a particular place but are placed randomly. There were no fixed rules to ensure cleanliness and order of work, but this is done as needed. The equipment is placed randomly, which takes considerable time to reach. After applying the principles of TPM, the Performance has been improved as shown in Table 2. The first assessment appears before and after application of the principles TPM of Figure 1.

Note: Bar charts from Figure 1 to Figure 8 show the **evaluation value** of the answer of each question (from 1 to 5) on the horizontal axis, and the **number of repeating each evaluation value** on the vertical axis. For example, the evaluation value of '5' is repeated 3 times before TPM implementation, and 5 times after TPM implementation as shown in Figure 1 and Table 2, which means an increase in TPM tasks done by the staff leading to an enhancement in the TPM performance evaluation for the 5S plan.

From Figure 1 it was found that the number of repeating of evaluation values 1 and 2 decreased while the number of repeating of the evaluation values 4 and 5 increased after the application of TPM 5S principle which indicates an improvement in performance.

Table 2: Evaluation of Principle of 5S (SSSSS)

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5

1	Is there a prior knowledge of the program of the 5S?				√					√
2	Does the 5s program apply as required?			√					√		
3	Are unnecessary items removed and only necessary items kept?			√						√	
4	Are unnecessary tools and objects kept in a designated space?		√							√	
5	Are employees trained on 5S principles?			√						√	
6	Is your workplace regularly cleaned?				√				√		
7	Are there rules and procedures to ensure the order and cleanliness of the place of work?		√					√			
8	Are employees committed to applying new workplace rules and standards and workplace procedures?				√					√	
9	Do you see that applying the 5S program is appropriate for your company?					√					√
10	Is there a company plan for applying 5S principles?				√					√	
11	Do employees have acceptance of the 5S program?					√					√
12	Can You train principals and leaders on 5S principles?				√						√
13	Are equipment classified within the facility?					√				√	
14	Do you provide all the necessary tools by the management to implement the 5S principles?					√					√
15	Is there participation and cooperation among the staff when applying 5S principles?				√					√	
16	Are there operating instructions for equipment and machinery?					√					√
17	Are unnecessary items arranged in easily accessible places?	√							√		
Total		1	2	3	6	5	0	1	3	7	6

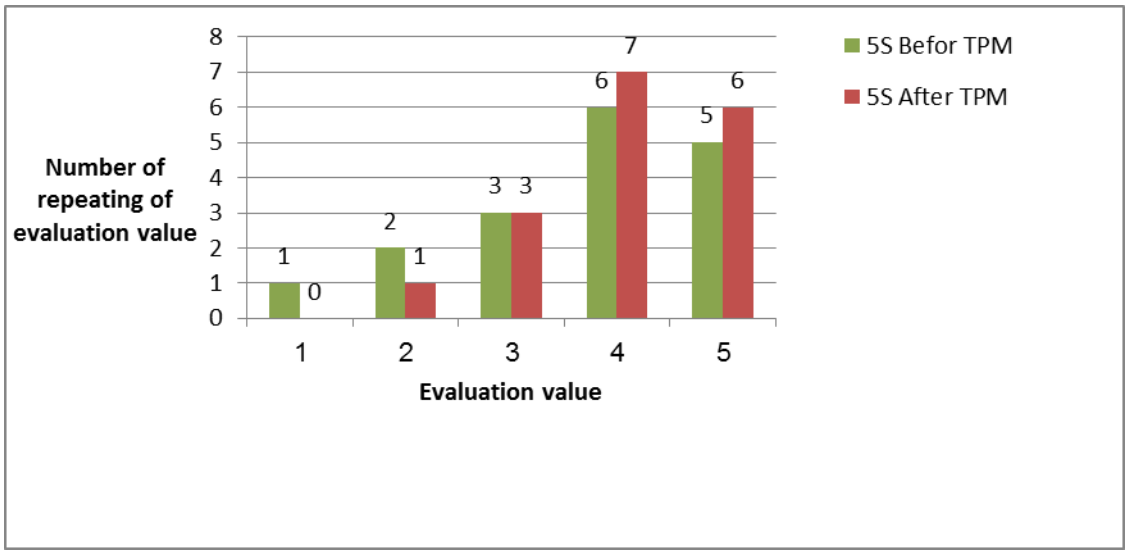

Figure 1: Measure of the principle of 5S before and after applying TPM

Table 3 shows the questions checklist and the results of the PM principle evaluation before and after the application of the TPM principles. The PM principle evaluation was 68.24% before applying the TPM principles, while the evaluation results after the TPM application were 76.47%. This is due to: There

is no system that analyzes the results obtained from maintenance operations, there is no predictive maintenance system, maintenance is not evaluated and maintenance plan is not implemented properly. After applying the principles of TPM, Table 2 shows the questions checklist and the results of the **5S** principle evaluation before and after the application of the TPM principles. The 5S principle evaluation were 74.12% before applying the TPM principles, while the evaluation results after evaluating the TPM application were 80.11%. This is due to: Not all unnecessary items were removed but some of them were needed. Non-essential objects were not kept in a particular place but are placed randomly. There were no fixed rules to ensure cleanliness and order of work, but this is done as needed. The equipment is placed randomly, which takes considerable time to reach. After applying the principles of TPM, From Figure 2 the number of repeating of evaluation values 1 and 2 decreased while the number of repeating of the evaluation values 3, 4 and 5 increased after the application of TPM PM Principle which indicates an improvement in performance.

Table 3: Evaluation of Principle of PM

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5
1	There an inventory of all machines and equipment?					√					√
2	Is there a maintenance information system that analyzes all data?	√							√		
3	Is there a plan for the in-house maintenance program?					√				√	
4	Is the plan implemented according to schedule?			√					√		
5	Is there a plan for lubrication and greases of equipment and machinery?					√				√	
6	Is the Lubrication and Lubrication Plan for Equipment and Machinery implemented at specified times?			√					√		
7	Is a system for predictive maintenance installed?	√						√			
8	Is all planned maintenance activities assessed?	√							√		
9	Are there procedures for early detection of malfunctions?		√							√	
10	Is there a specific approach to reducing repair times?	√							√		
11	Are All faults recorded for all equipment and machinery?				√					√	
12	Is there a plan to maintain the infrastructure of the facility?				√						√
13	Is there an inventory of all equipment catalogs within the facility?					√					√
14	Are You coding equipment?					√					√
15	Is there an inventory of all spare parts required for each stomach?				√					√	
16	Are there schedules to be implemented through preventive maintenance?					√					√
17	Are There instructions on and off for all equipment?				√				√		

Total	4	1	2	4	6	0	1	6	5	5

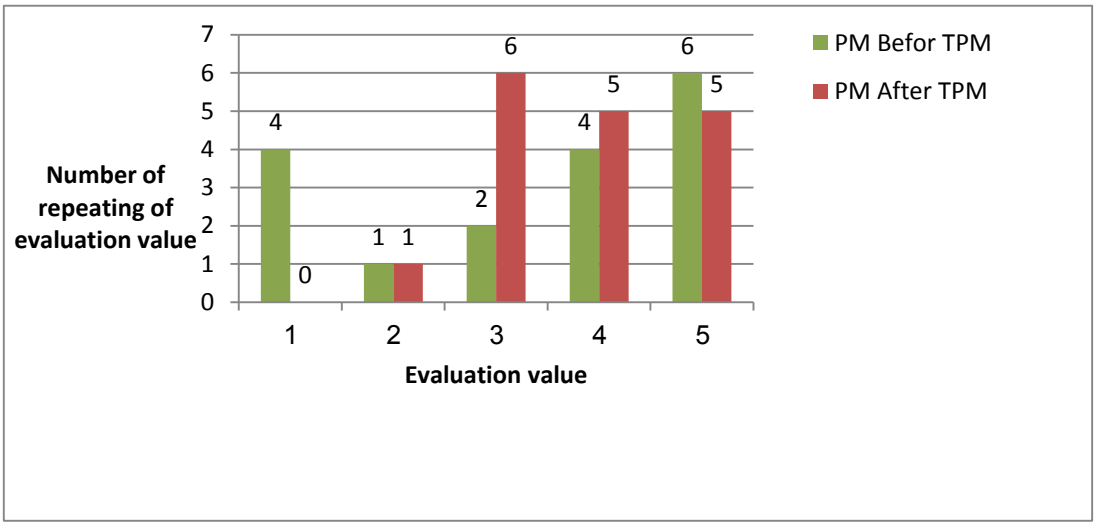

Figure 2: Measure of the principle of PM before and after applying TPM

Table 4 shows the questions checklist and the results of the AM principle evaluation before and after the application of the TPM principles. The results of the AM evaluation before application of the TPM principles were 28.24%, while the evaluation results after the TPM application were 56.47%. This is due to: The staff did not have sufficient knowledge of the AM principles. There is a constant difference of views between maintenance and production management about self-maintenance. The employees do not perform any of the AM operations and do not lubricate and grease regularly, they do only during maintenance, which requires more time. After applying the principles of TPM, the Table 2 shows the questions checklist and the results of the **5S** principle evaluation before and after the application of the TPM principles. The 5S principle evaluation were 74.12% before applying the TPM principles, while the evaluation results after evaluating the TPM application were 80.11%. This is due to: Not all unnecessary items were removed but some of them were needed. Non-essential objects were not kept in a particular place but are placed randomly. There were no fixed rules to ensure cleanliness and order of work, but this is done as needed. The equipment is placed randomly, which takes considerable time to reach. After applying the principles of TPM, the Performance has been improved as shown in Table 4. From Figure 3 it was found that the number of repeating of evaluation value 1 decreased while the number of repeating of the evaluation values 3, 4 and 5 increased after the application of TPM AM principle which indicates an improvement in performance.

Table 4: Evaluation of Principle of AM

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5
1	Do you arrange all the equipment and tools you deal with?	√							√		
2	Are employees being taught the benefits of TPM through training?	√						√			
3	Do operators continuously improve the performance of the equipment and reduce the time required for cleaning operations?	√							√		
4	Has the importance of applying the self-maintenance system been clarified?		√					√			
5	Is it scheduled to clean the equipment thoroughly by the operators?	√							√		
6	Have You sufficient knowledge of how to lubricate and grease the stomach?		√					√			
7	Do you remove excess stains and grease from machinery and equipment?	√						√			
8	Have steps been taken to facilitate cleaning of equipment?			√					√		
9	Is the machine cleaned in a way that prevents the formation of dust and dirt on it?	√								√	
10	Are Autonomous Maintenance schedules scheduled and executed accurately?	√						√			
11	Does the AM schedule include inspection, cleaning, lubrication and other details (such as when, why, and how to schedule)?	√					√				
12	Where Do you training on the general operator of equipment such as inspection, lubrication, electrical inspection, safety and others?	√									√
13	Are The technical skills of operators improved on how to use the screening tools correctly?	√								√	
14	Are the technical know-how acquired by operators among them?		√							√	
15	Do the cleaning and lubrication methods used are updated?	√							√		
16	Is the operator cooperating with the supervisor to prepare self-examination of the machine scheduling?	√						√			
17	Does the operator delete the parts that do not need continuous checking from the list of parts when performing the general			√					√		
Total		12	3	2	0	0	1	6	6	3	1

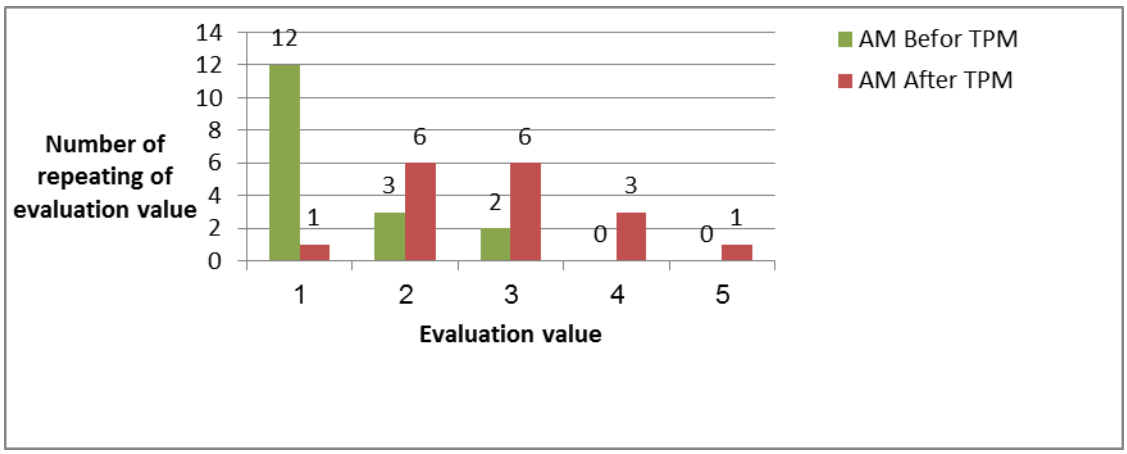

Figure 3: Measure of the principle of AM before and after applying TPM

Table 5 shows the questions checklist and the results of the ET principle evaluation before and after the application of the TPM principles. The results of the ET evaluation before application of the TPM principles were 56.47%, while the evaluation results after the TPM application were 77.65%. This is due to: The situation of the current technicians and operators was not determined before training to determine the training needs. The plan was not implemented as planned and specific mechanisms were not developed to define the training plan. Training on how to develop technicians and operators' skills were not adopted. After applying the principles of TPM, the Performance has been improved as shown in Table 5. The first assessment appears before and after application of the principles TPM in Figure 4.

Table 5: Evaluation of Principle of ET

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5
1	Is there an ET plan?					√					√
2	Is the current status of ET verified for operators and technicians working in the maintenance department?	√								√	
3	Are specific timetables for the training plan established?			√							√
4	Is the ET plan implemented as expected?		√						√		
5	Is there training to upgrade the training skills and maintenance plan?				√					√	
6	Are priorities for the implementation of training programs set for maintenance (mechanical, electrical, educating new operators, etc.)?	√							√		
7	Can engineers and managers be trained in the maintenance department to suit their responsibilities?	√							√		
8	Is the course program implemented at the work site by the company's engineers and technicians?					√				√	
9	Are all workers trained with equipment from operators, on concepts, objectives, and principles of TPM?		√								√
10	Is the training required for all new people assigned to the maintenance department?	√								√	
11	Is there a way to evaluate and assess trainees?				√					√	
12	Is there a possibility of training outside the facility if necessary?					√					√
13	Is there continuous improvement under the training plan?				√				√		
14	Are Trainers very skilled and efficient?				√					√	
15	Is there a possibility of exchanging information among trainees?				√					√	
16	Is there a processing of the work environment for ET?	√							√		
17	Can You staff training facility staff on how to acquire skills in their fields?	√							√		
Total		6	2	1	5	3	0	0	6	7	4

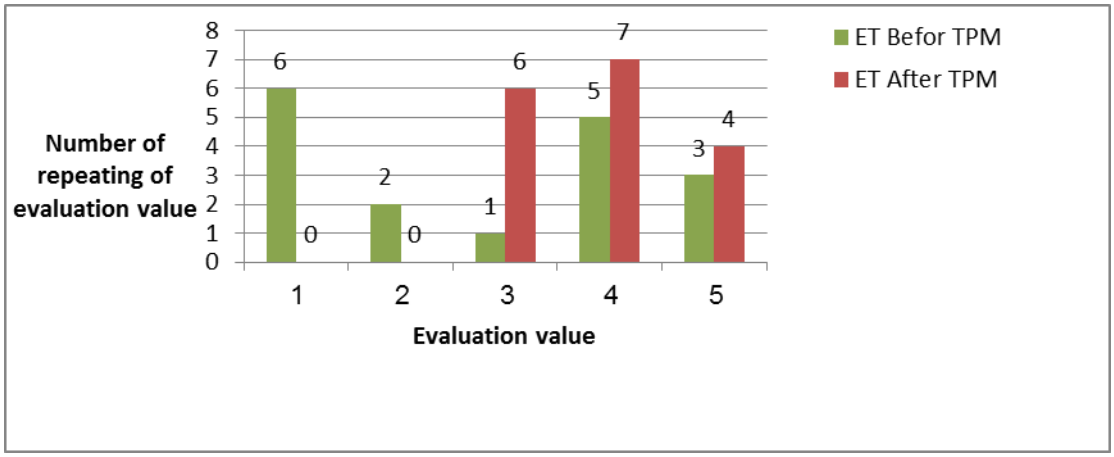

Figure 4: Measure of the principle of ET before and after applying TPM

Table 6 shows the questions checklist and the results of the SHE principle evaluation before and after the application of the TPM principles. The results of the SHE evaluation before application of the TPM principles were 71.76%, while the evaluation results after the TPM application were 80%. This is due to: From the previous results, it was noted that the performance of SHE is good to some extent and there are some shortcomings need to be improved to reach the optimum results. Procedures are not reviewed after emergency operations as required. No recommendations or proposals for improvement are made, they are done only by the Safety Committee without the participation of staff, and monitoring and measurement are not done as required. After applying the principles of TPM, the Performance has been improved as shown in Table 6. The first assessment appears before and after application of the principles TPM in Figure 5.

Table 6: Evaluation of Principle of SHE

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5
1	Are all roles, responsibilities and authorities of all parties involved are documented?				√					√	
2	Are process control documented?					√					√
3	Are documents approved before being issued by the Occupational Safety and Health Committee?		√							√	
4	Are Operations and activities are identified for significant risks and damage?				√					√	
5	Is there a procedure to prevent and respond to the risks and harms of occupational safety and health systems?				√					√	
6	Are the procedures reviewed and checked especially after the emergency?			√					√		
7	Do you monitor and measure the performance of occupational safety and health?					√					√

8	Is there a corrective and preventive system for occupational health and safety procedures?			√						√	
9	Do monitoring and measurements are compatible with the goals and objectives?				√					√	
10	Do monitoring and measurements are compatible with legal requirements?			√					√		
11	Is there a periodic assessment of occupational safety and health to ensure that the system complies with occupational safety and health requirements?				√					√	
12	Are there internal management reviews in which compliance with legislative requirements is assessed?					√					√
13	Are accident investigations saved?					√					√
14	Is there continuous improvement to prevent or reduce accidents?				√					√	
15	Are Records easy to reference and protected from damage?				√					√	
16	Are documents approved before they are issued?	√							√		
17	Are procedures reviewed and verified after an emergency?	√							√		
Total		2	1	3	7	4	0	0	4	9	4

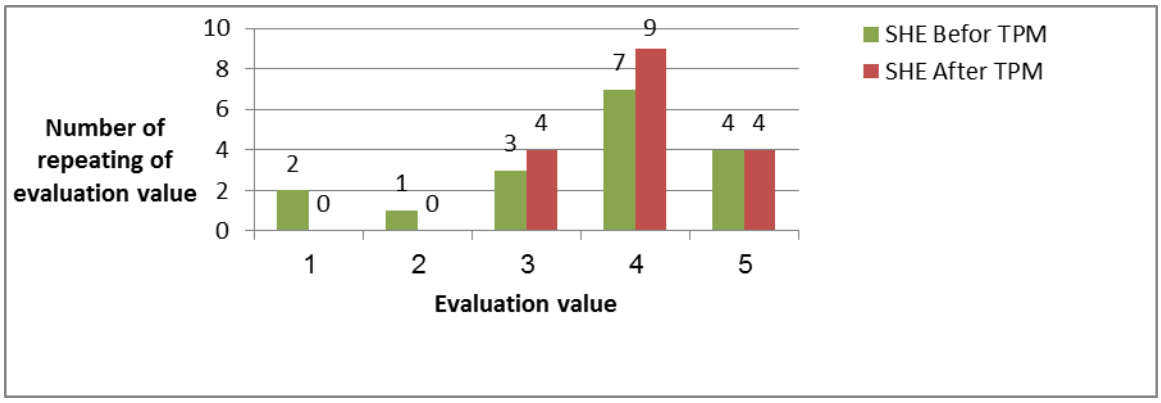

Figure 5: Measure of the principle of SHE before and after applying TPM

Table 7 shows the questions checklist and the results of CI principle evaluation before and after the application of the TPM principles. The results of the CI evaluation before application of the TPM principles were 58.82%, while the evaluation results after the TPM application were 72.94%. This is due to: There is no clear plan for any improvements to increase production efficiency, there is no plan to improve the management functions of the maintenance department, productive maintenance is not analyzed and the real reasons for wasting time in production and maintenance are not determined. After applying the principles of TPM, the Performance has been improved as shown in Table 7. The first assessment appears before and after application of the principles TPM in Figure 6.

Table 8 shows the questions checklist and the results of QM principle evaluation before and after the application of the TPM principles. The results of the QM evaluation before application of the TPM principles were 57.65%, while the evaluation results after the TPM application were 75.29%. This is due to: There are many factors that affect maintenance quality, including the use of raw materials that do not correspond to harmful substances, Specifications in machine mold, and The existence of old machines that require constant repair, and affect the quality of the product, special attention is paid to old machines and equipment, and the knowledge of independent maintenance activities by operators leads to frequent machine failures. After applying the principles of TPM, the Performance has been improved as shown in Table 8. The first assessment appears before and after application of the principles TPM in Figure 7.

Table 7: Evaluation of Principle of QM

NO	Questions	Results									
		Before					After				
		1	2	3	4	5	1	2	3	4	5
1	Is there a plan to implement quality maintenance in equipment to increase productivity efficiency?	√							√		
2	Do you use maintenance quality in all maintenance areas?	√								√	
3	Do you analyze why there is a lost time -, etc.)?		√						√		
4	Is there a plan to get rid of damaged and defective parts that cause wasting time when looking for parts?	√							√		
5	Is there a plan to raise the efficiency of the workers' maintenance department?			√						√	
6	Is there a continuous assessment of maintenance personnel to see how well the maintenance quality of the equipment is applied?					√					√
7	Is there a plan to eliminate all the surrounding conditions that accelerate the deterioration			√						√	
8	Is there a plan to try to achieve and maintain zero losses for minor stations?	√							√		
9	Is there a plan to try to apply the zero principle in all activities?				√					√	
10	Is there a plan for a constant effort to reduce the cost in all the resources of the company?				√					√	
11	Is there a plan for an ongoing effort to reduce the cost?					√					√
12	Is there a plan to achieve a permanent effort to increase the total plant efficiency of the refinery?				√					√	
13	Is there a plan to try to reduce the resulting output from the maintenance process through quality maintenance?					√					√
14	Does the organization have a role in applying the quality of maintenance?				√					√	
15	All the staff of the establishment can participate in quality maintenance currency				√					√	
16	Can all employees of the facility participate in the currency of continuous improvement?		√						√		
17	Does the quality of maintenance help in the process of improvement?	√						√			

Total	5	2	2	5	3	0	1	5	8	3

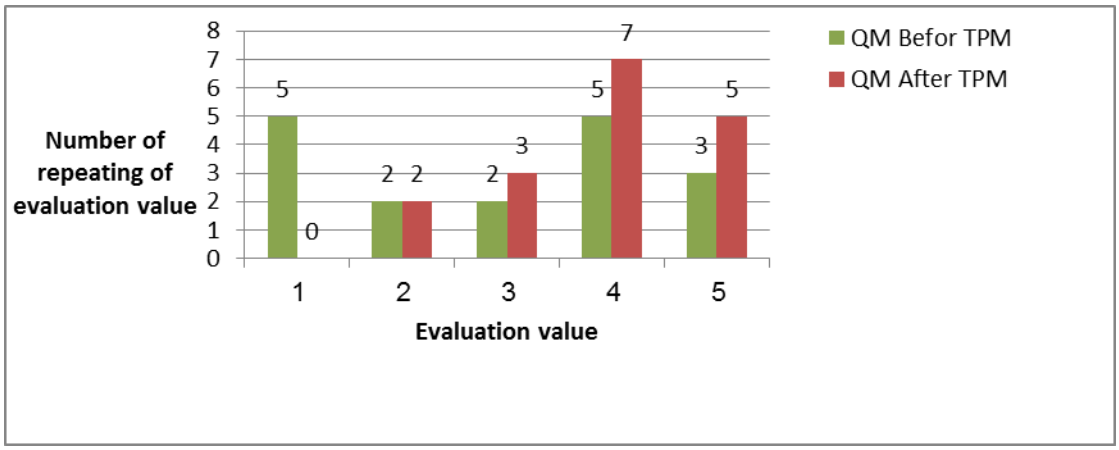

Figure 6: Measure of the principle of QM before and after applying TPM

Table 9 presents the checklist of questions and the results of the evaluation of the principle of the Comprehensive Productivity Office (SM) before and after the application of TPM principles. SM evaluation results before application of TPM principles reached 31.76%, while the evaluation results after application of TPM 74.11%. This is due to: This principle focuses on the establishment of a comprehensive production maintenance office to carry out the tasks or activities listed in the checklist. Maintenance activities are planned by the maintenance department to purchase spare parts from local markets due to the difficulty of obtaining them from foreign markets. This leads to the fact that many spare parts do not meet the required specifications, and some of the work is ignored by senior management under the pretext of saving expenses such as the lack of participation of senior technical management. To increase production efficiency, after applying the TPM principles, the performance is improved as shown in Table 9. The first assessment appears before and after the application of the TPM principles in Figure8.

The evaluation results of principle of SM=58.82%

The average results before applying TPM were 55.88%, while the average results after applying TPM were 74.13%, which means that the percentage of improvement is 18.25.

Figure 9 represents the contribution of each TPM principle to how much improvement has been made.

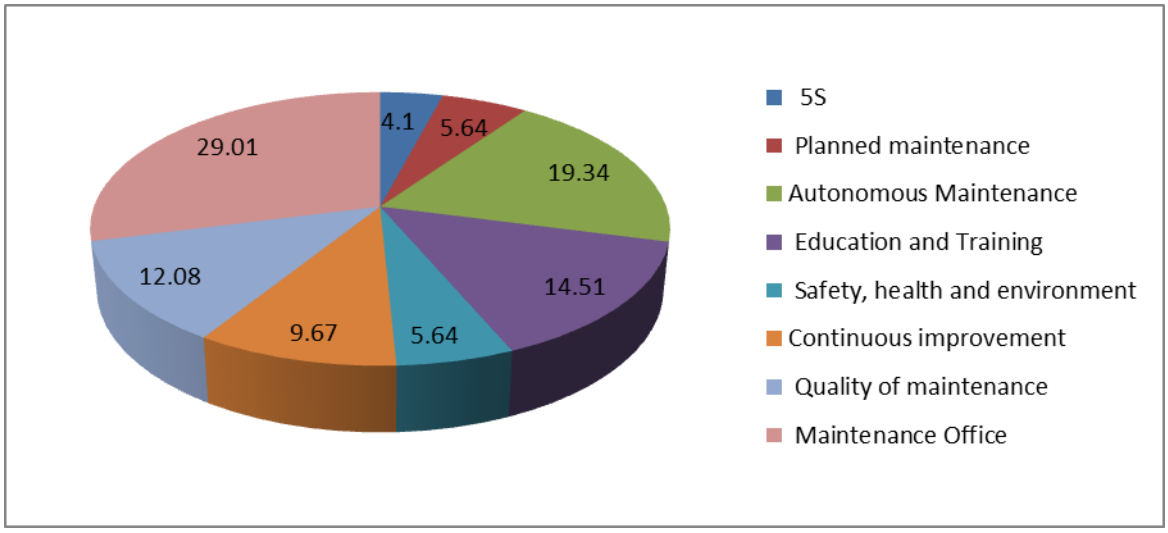

Figure 7: The contribution of each TPM principle in total improvement of TPM

Figure 9 represents the contribution of each TPM principle to the overall amount of improvement achieved, the overall improvement of total product maintenance performance is 18.25%. Each principle shared in this improvement as in Figure 9, for example contribution of 5S was 4.1% of the overall value (18.25%). The SM principle has the highest improvement share value (29.01%), and all of AM, ET, QM, and CI have a high share in the overall improvement value, these are 19.34, 14.51, 12.08 and 9.67 respectively. On the contrary, both of PM and SHE have a small share in the overall improvement value, these are 5.64 and 4.1 respectively.

The measures of dispersion calculation such as mean and standard deviation are presented in Table 10 for the TPM principles elements before and after TPM application.

Table 8: Mean and standard deviation

The principles	Mean before	Std. Deviation before	Mean after	Std. Deviation after
SSSSS	3.71	1.213	3.89	1.088
PM	3.41	1.622	3.59	1.549
AM	2.82	1.629	2.29	.470
ET	1.41	.712	4.00	.466
SHE	3.41	1.228	3.59	1.278
CI	2.94	1.560	3.76	1.348

QM	2.94	1.560	3.06	1.298
SM	3.72	1.328	2.41	1.238

The application of the TPM principles had a positive impact on the factory as follows: The mean of the principles of TPM before application was between (1.41: 3.71) which means that the performance was between (10%: 70%), while the arithmetic mean after applying the principles of TPM was between (2.29: 4.06) which means that the performance was between (23%: 81%), which shows an improvement in performance about 60.9%. Further, when the standard deviation measure was applied, the results before the application were between (0.712 : 1.629) while standard drift values after application (0.470 : 1.549) indicating that the standard deviation values before applying the TPM are higher than the values after applying it, which confirms an improvement in performance because the deviation from natural values decreased.

Performance indicators were selected for each principle to measure performance improvement as follows:

Figures from Figure 10 to Figure 15 show both TPM implementation stage and performance evaluation values on the vertical axis where the values from 1 to 5 represent the TPM implementation stage (1: Preliminary stage, 2: Awareness primary stage, 3: Planning stage, 4: stage of implementation, 5: Full implementation), or represent the performance evaluation percentage (20%, 40%, 60%, 80%, and 100%). The horizontal axis represents the selected performance indicators which differ according to each principle.

Figure 10 shows the performance indicators selected to measure performance improvement in the 5S plan on the horizontal axis; these are the (extent of implementation, the extent of staff participation and cooperation, the extent to which managers accept the implementation of the 5S principles and the extent of participation in improvement and development the performance of the 5S). For example, with respect to the first performance indicator which is 'the extent of implementation' the implementation stage was 3.2 meaning it goes over the third stage of TPM implementation “Planning stage”, with performance evaluation of 3 from 5 which means it equals about 41% to 60%, and the average improvement in the performance of 5S in full is 6%, which is the same proportion of 5S performance before and after application as in Figure 1.

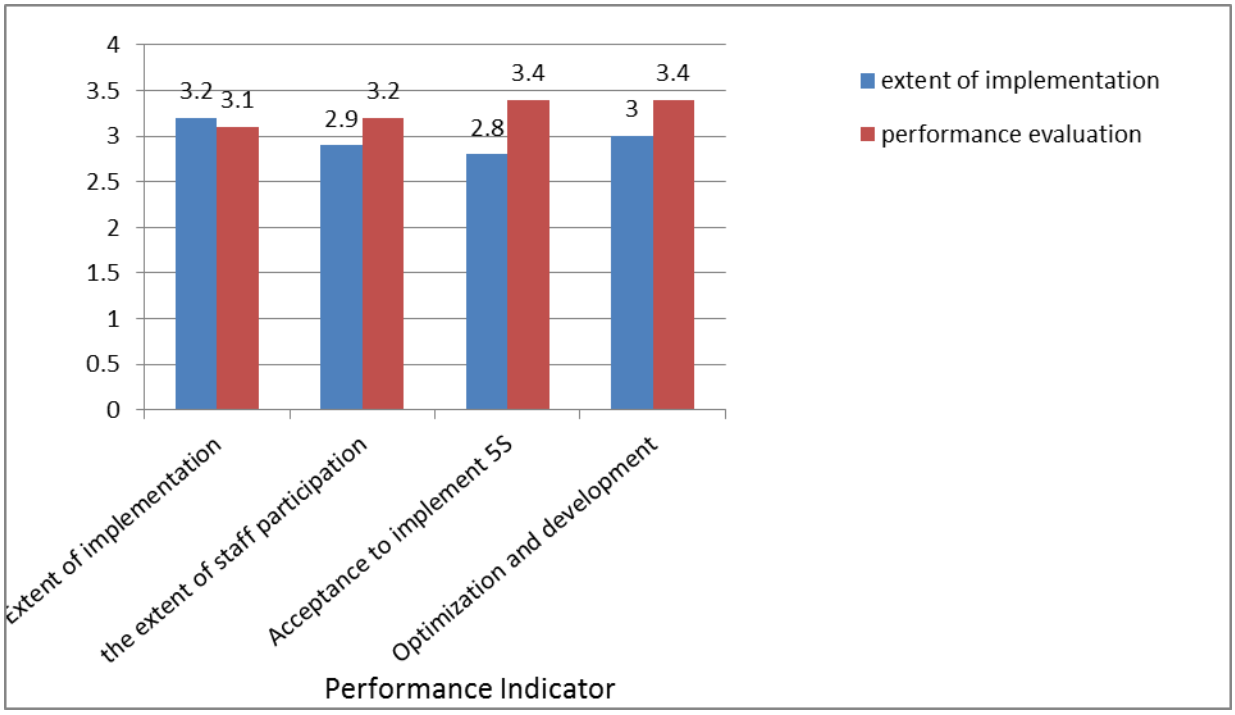

Figure 8: TPM implementation stage and performance evaluation against performance indicators of the 5S plan.

Figure 11 shows the selected performance indicators to measure the performance improvement in the general management plan on the horizontal axis (malfunction, setup, adjustment, shutdown, minor downtime and speed, operational faults and loss of losses). The average improvement rate in PM is ≈14.27%, which is the same as the improvement rate after TPM application, which is 14.23% as in Figure 2.

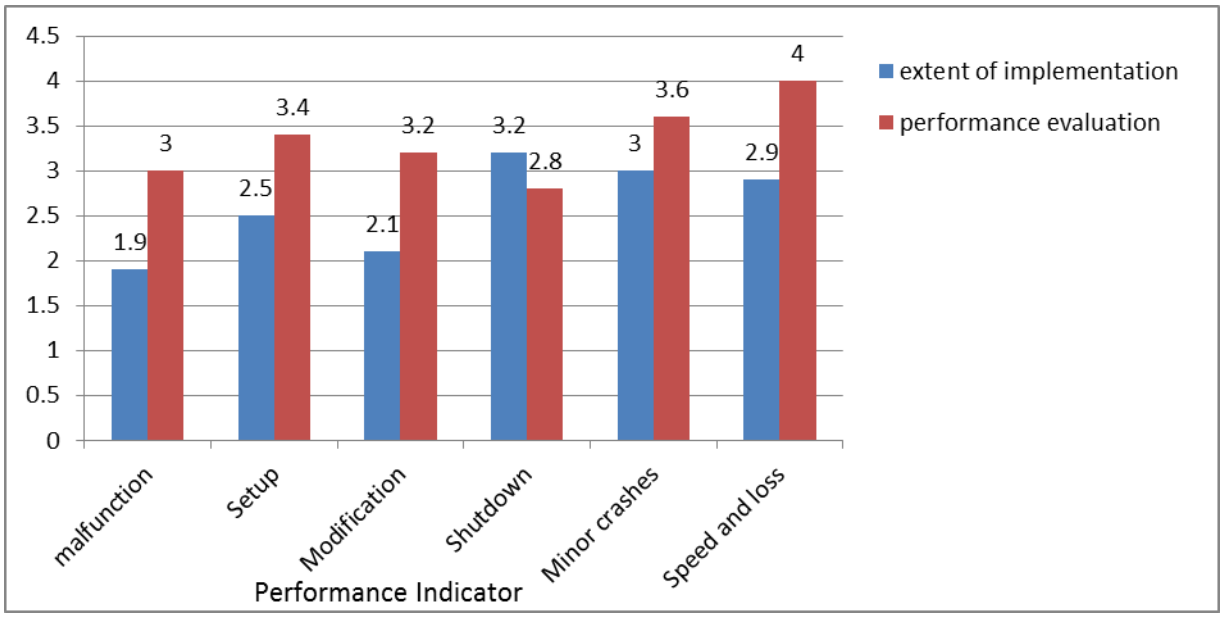

Figure 9: TPM implementation stage and performance evaluation against performance indicators of the PM plan.

Figure 12 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of AM plan and performance indicators (MTBF, MTTR, time reduction, unlimited time reduction, product reduction and maintenance machine) The average improvement rate in AM is ≈28.33%, which is the same as the improvement rate after TPM application, which is 28.23% as in Figure 3.

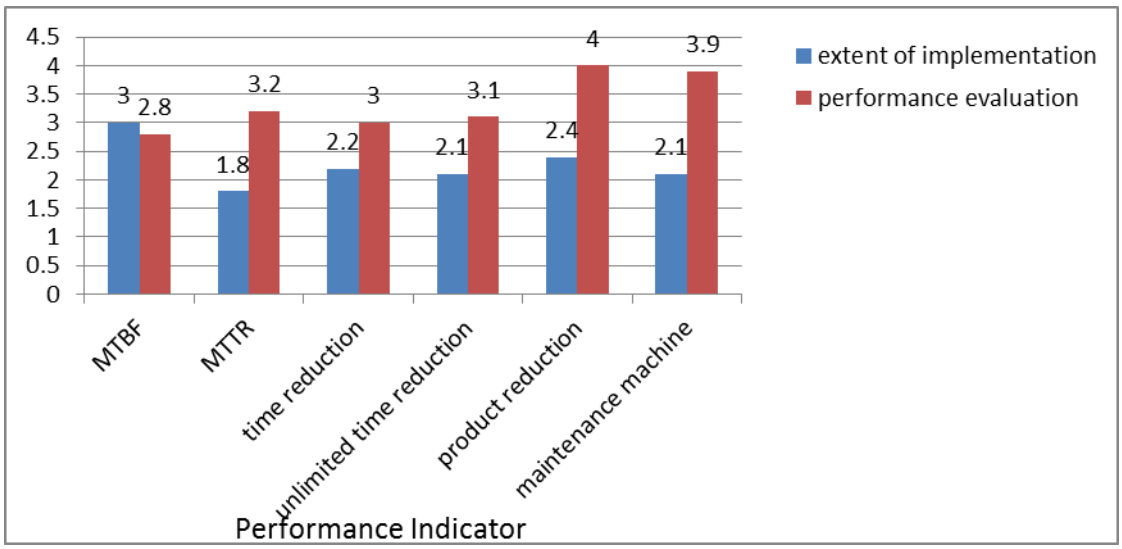

Figure 10: TPM implementation stage and performance evaluation against performance indicators of the AM plan.

Figure 13 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of ET plan and performance indicators (The extent to which the training plan has been implemented, The extent of staff response to the training plan, Improved performance of employees as a result of training and Effect of training on the production process). The average improvement rate in ET is ≈22%, which is the same as the improvement rate after TPM application, which is 21.18% as in Figure 4.

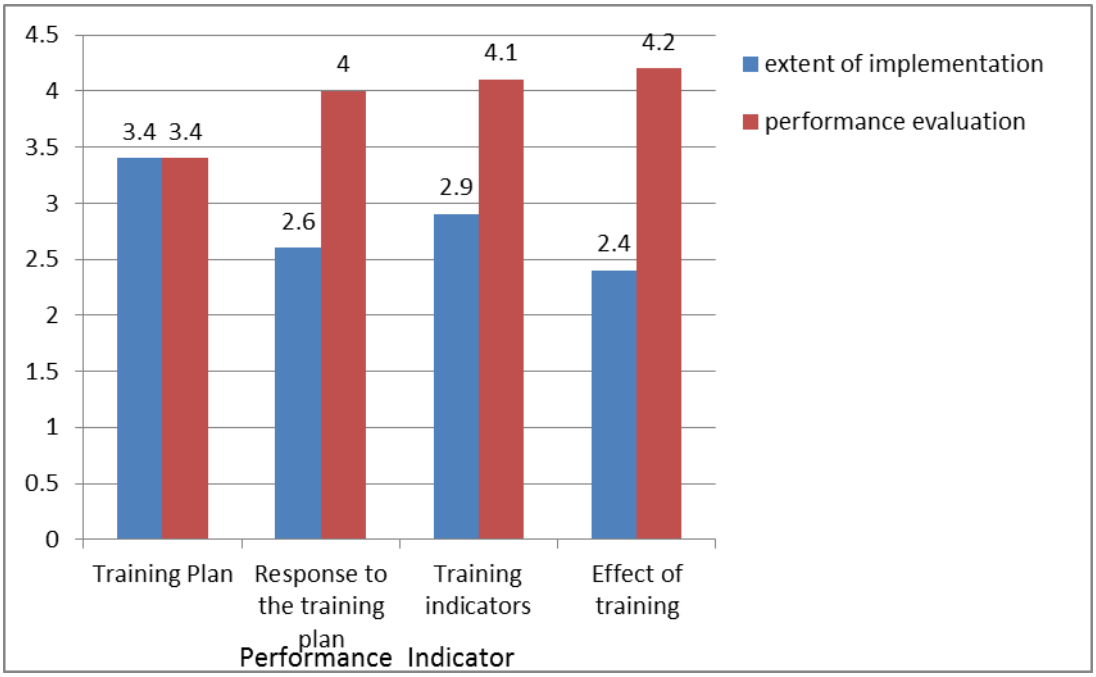

Figure 11: TPM implementation stage and performance evaluation against performance indicators of the ET plan.

Figure 14 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of SHE plan and performance indicators (Number of audit failures per total findings, Reduction in accidents, Monitoring and measurement compatibility with objectives and targets The effectiveness of improvements to the system and Effectiveness of safety, health and environment reports). The average improvement rate in SHE is ≈8.2%, which is the same as the improvement rate after TPM application, which is 8.24% as in Figure 5.

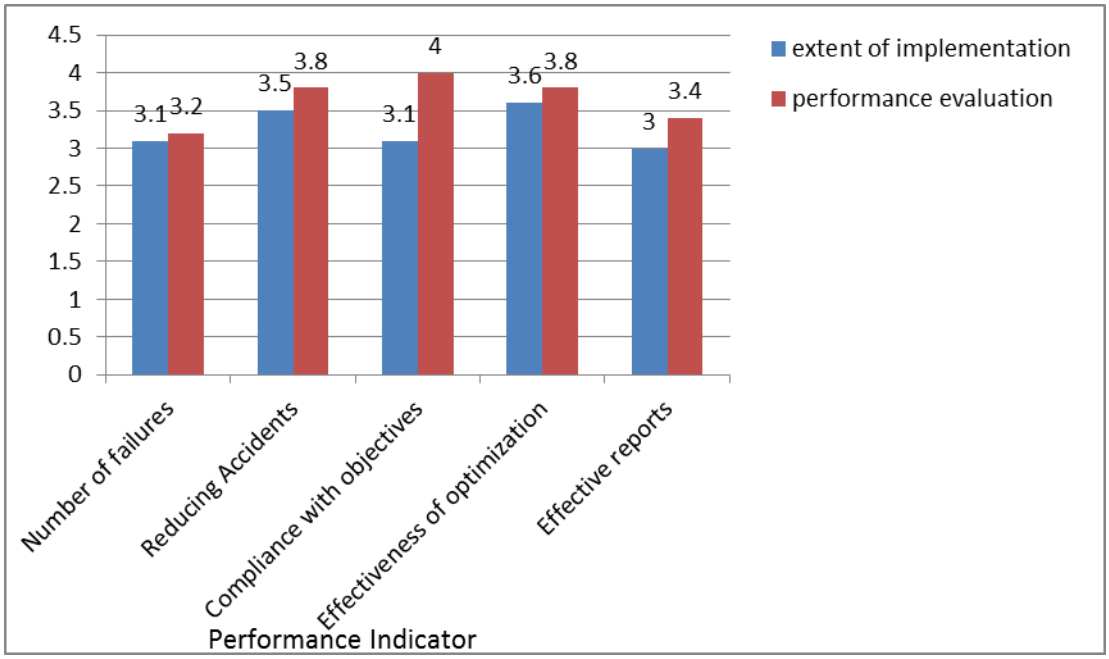

Figure 12: TPM implementation stage and performance evaluation against performance indicators of the SHE plan.

Figure 15 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of CI plan and performance indicators (Extent of implementation of the improvement plan developed, Reduced costs, Impact of improvements on spare parts reduction, Effective participation of employees in the improvement process, the impact of the optimization plan, and reduction in overtime work). The average improvement rate in CI is ≈14.67%, which is the same as the improvement rate after TPM application, which is 14.12% as in Figure 6.

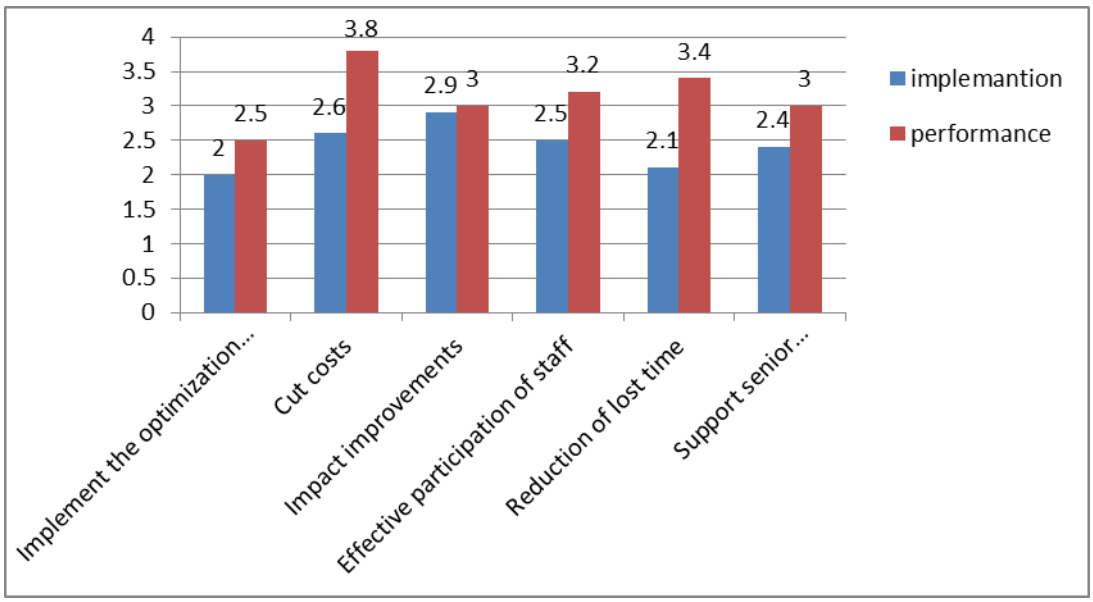

Figure 13: TPM implementation stage and performance evaluation against performance indicators of the CI plan.

Figure 16 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of QM plan and performance indicators (Quality level, zero defect area and zero customer complaint area). The average improvement rate in QM is ≈18%, which is the same as the improvement rate after TPM application, which is 17.64% as in Figure 7.

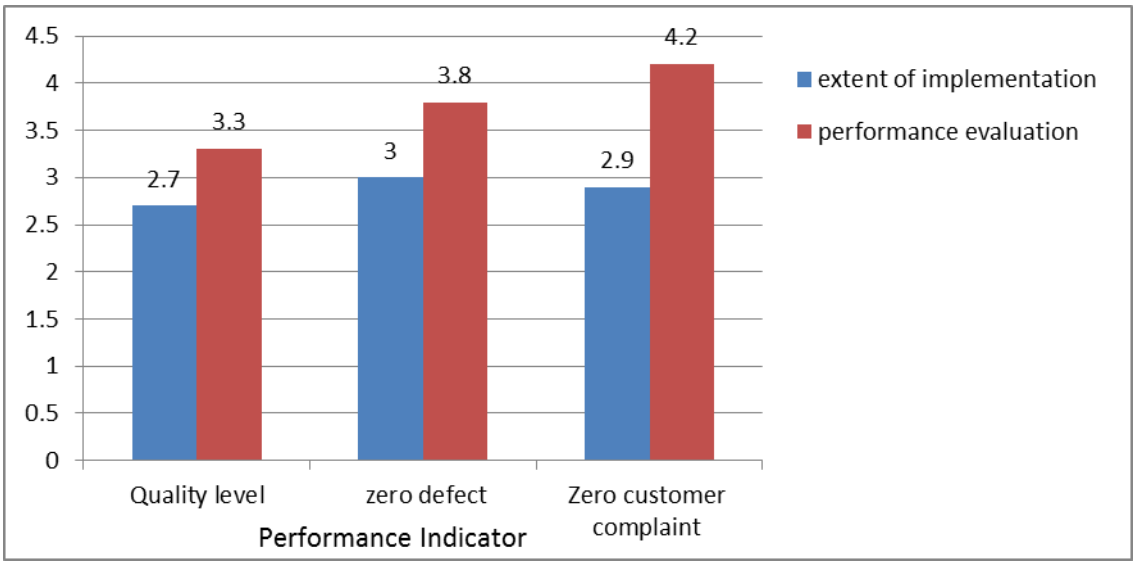

Figure 14: TPM implementation stage and performance evaluation against performance indicators of the QM plan.

Figure 15 shows the relation between both TPM implementation stage and performance evaluation values on the vertical axis and the selected performance indicators on the horizontal axis of Maintenance Office plan and performance indicators (SM impact of company performance, Reduced costs and increased productivity, Ability to analyze data, The extent of influence in decision-making and Provide spare parts in partnership with senior management). The average improvement rate in Maintenance Office is ≈43%, which is the same as the improvement rate after TPM application, which is 42.35% as in Figure 8.

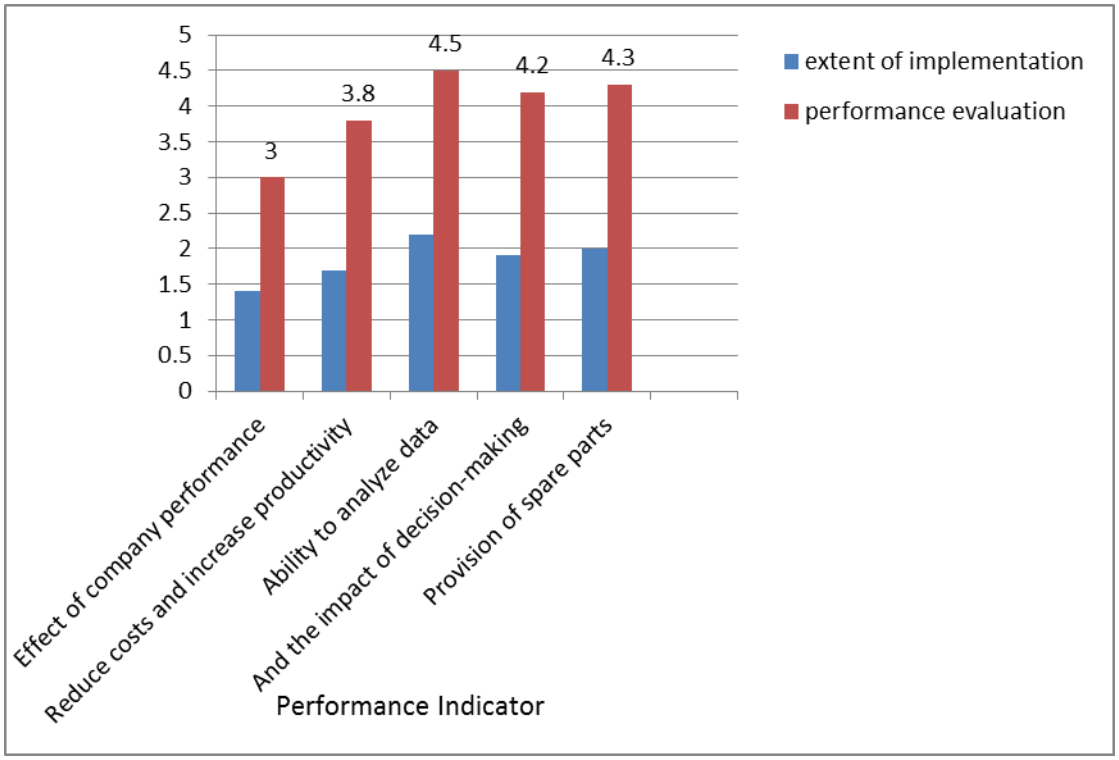

Figure 15: TPM implementation stage and performance evaluation against performance indicators of the SM plan.

The average evaluation of the TPM principles prior to application is due to weakness in the application of the TPM principles prior to implementation; particular (AM-SM-ET-CI) where the results were (28.24-31.76-56.47-57.65) respectively. While the application of TPM principles improved performance due to improvements in some principles of overall productive maintenance particularly (AM-SM-ET-CI) where the results were (56.47-74.11-77.65-72.94) was respectively. Figure 9 shows the improvement in the principles of TPM. These are illustrated in Table 11.

Table 9: Average evaluation of the TPM principles before and after application of TPM

Principles TPM	5S	PM	AM	ET	SHE	CI	QM	Maintenance Office
Before TPM	74.12%	68.24%	28.24%	56.47%	71.76%	58.82%	57.65%	31.76%
After TPM	80.11%	76.47%	56.47%	77.65%	80%	72.94%	75.29%	74.11%

4. Conclusions

Following the implementation of the evaluation process, determining the current status of the maintenance department and determining the application of the principles of productive maintenance, as well as analysis of the results of the evaluation process, a management improvement plan has been developed for the maintenance tasks as well as the tasks they perform, including equipment operators, workshops, training, quality control, safety, health and environment. It is the responsibility of the maintenance department to develop the improvement plan. Therefore, the researcher proposes to implement the two-stage improvement plan: Phase 1: Work on improving all functions for all eight principles of TPM. Phase 2: Work to improve the functions of the principles contained in the previous lists. These two phases help the company to apply the principle of continuous improvement gradually and incremental additions contribute to the creation of a new culture in the industrial companies and helps over time to strengthen them among all maintenance workers and prevents the followers of these phases from falling in a gap between the functions or activities of the maintenance section or other sections when not completing tasks and completing tasks.

The production and maintenance staff have been alerted to the importance of the 5S program and have initiated training courses to demonstrate the importance of implementing the 5S principles. A data storage and analysis system is being implemented to maintain and implement predictive procedures for early detection of defects,

The training of workers to transform them from production workers to production operators is carried out by: Maximizing the importance of teamwork between production and maintenance. The culture of teamwork, the building of trust between different departments had been promoted. A clear training development plan is developed for all employees in the establishment to record and analyze all small and large accidents leading to a plan to improve the technical and administrative functions of the maintenance department through training; the importance of cooperation with the production management department is emphasized.

Coordination between maintenance departments and production department management to ensure the application of self-maintenance, continuous coordination with the quality control department, responsible for determining the source, size and frequency of defects. Implementation of advanced training courses for technicians and engineers. Use of raw materials and backup materials conform to specifications.

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