An Integrated Framework for Investigating Relationship between Overall Equipment Effectiveness (OEE) and Downtime

Md. Ariful Haque, A M Almas Shahriyar Azad, Moumita Ghosh, Zarin Tasnim Oishi and Md. Mohibul Islam
Department of Industrial & Production Engineering
Rajshahi University of Engineering &Technology
Rajshahi-6204, Bangladesh.
arifulhaque.ruet@gmail.com, aaaarnab1234@gmail.com,moumitaghosh984@gmail.com,
oishi3892@gmail.com, mohibul@ipe.ruet.ac.bd

Abstract

Nowadays, proper utilization of the available equipment and machines is a high-priority task in every industry. The equipment's effectiveness can be enhanced and acquired through the proper implementation of overall equipment effectiveness (OEE). The equipment's effectiveness has been unfolded by measuring the OEE in this work. A top manufacturing company's data for six days from two shifts were examined to determine the current OEE standard, and downtime data was also gathered. This study emphasizes developing a correlation between OEE and downtime. The findings revealed a negative correlation between OEE and downtime. The critical causes of the downtime have been identified and how the application of total productive management (TPM) can decrease downtime resulting in an increase in OEE was illustrated. The influence of availability rate, performance rate, and quality rate on OEE was also discussed in the article. Availability rate has the closest relationship with OEE.One of the study's limitations is the lack of information on OEE improvement over the existing OEE following the implementation of TPM. This study is expected to guide practitioners in implementing OEE to improve productivity and profitability.

Keywords
Overall Equipment Effectiveness (OEE), Downtime and Total Productive Management (TPM).

1. Introduction
Every manufacturing system strives to enhance its effectiveness and quality. But assessing their current situation is crucial for them. The effectiveness measurement of that organization might be a means of self-evaluation in this discipline. The OEE of a manufacturing operation measures how effectively the equipment is utilized to its maximum capacity during the hours when it is scheduled to run (Muchiri and Pintelon 2008).In other words, OEE is a performance assessment technique used in the production sectors which serves as an initial key point for understanding equipment losses and developing solutions to remove them (Jonsson and Lesshammar1999). Therefore, evaluating the OEE of a production system may serve as both a benchmark for assessing the system's current state and a monitoring tool for tracking the system's development.OEE is also crucial in the manufacturing industry as it helps to improve quality, boost machine performance and quality rate, reduce breakdowns, and improve effectiveness(Kumar et al. 2014).The world-class standard for OEE is 85% and is based on three OEE factors: availability rate (90%), performance rate (95%) and quality rate (99%) (Fakhri et al. 2019). However, for the improvement of OEE, the most common barrier is downtime.

Downtime is the length of time that a manufacturing process is interrupted due to an unanticipated circumstance. The most terrifying thing that can happen in a manufacturing facility is that if one area gets behind schedule, it could cause other areas to get backlogged as well while they wait for parts to finish processing in other places. A tool for improvement is needed for removing impediments and properly maintaining the system in order to reduce downtime and raise OEE on the factory floor.TPM is used in this study as an OEE improvement and maintenance tool. However, in this study, implementation of TPM indicates the implementation of eight pillars (autonomous maintenance; focused improvement; planned maintenance; quality management; early equipment management; training and education; safety, health andenvironment; office TPM)of TPMreduce downtime from the beginning to ending of the process (Prabowo et al. 2018).

1.1 Scope of the Study
Numerous studies analyze a system's overall effectiveness (OEE) and its process of improvement. Again, there is a ton of research about system downtime reduction. However, a few studies identified downtime as one of the main issues for declining OEE. Additionally, it is crucial to identify the downtime reasons that have a particular impact on the system's OEE. In order to lessen the reasons for downtime and improve the system's OEE, a rigorous strategy is needed to correlate OEE with downtime.

1.2 Problem Statement
In the manufacturing system, there are a lot of machines working every day for producing a lot of products. Generally, the machines are operated in the same environment and in the same process. But their effectiveness for all days is not the same. Nevertheless, their availability, performance, and quality also fluctuate from one day to another. One of the major causes of these fluctuations is the system's downtime. This downtime is occurred by many planned and unplanned stoppages such as set up change and adjustment time, tool breakage and set up time, waiting time for tools and materials receiving etc. at the production periods. So, proper maintenance is also very essential for not only reducing downtime but also maximizing effectiveness.

1.3 Objectives
This study aims to measure the OEE of the machines of a manufacturing plant. It also observes the impacts of availability rate, performance rate and quality rate over OEE. Downtime is one of the main hindrances to smoothing the production system. It is one of the critical factors in decreasing the system's productivity. The cause analysis is performed behind the system's downtime. The regression analysis evaluates the relationship between downtime and OEE, to understand how the downtime affects the overall OEE of the system. Some solution approaches based on TPM to reduce downtime are also the concerns of the study.

2. Literature Review
In a competitive world, all manufacturing organizations are trying to improve day by day taking many strategies to their working field. For measuring the level of gradual improvement, some parameters are needed to be evaluated. For the production and manufacturing sectors, a machine's effectiveness plays an important role in the level of gradual improvement.OEE measurement is an effective way of analysing the effectiveness of a single machine or an integrated manufacturing system (Nakajima 1999). The OEE represents the machines' effectiveness in the production sector. Production downtime spread its impact on the machines' effectiveness. Proper maintenance is a must for the betterment of machines' effectiveness which is ensured by Total Productive Maintenance (TPM) implementation. TPM has been accepted as the most promising strategy for improving maintenance performance in order to succeed in a highly demanding market arena (Nakajima 1988). The TPM implementation methodology provides organizations with a guide to fundamentally transform their shop floor by integrating culture, process, and technology (Moore1997). They linked up machine deterioration, tool changeover costs and machine maintenance costs. This job-sequence method was unable to explicitly consider real-time machine failure.

Jonson and Lesshammar (1999) aimed to examine the generality of the dimensions and characteristics of a comprehensive system of measuring OMP and the contribution of the OEE measure tothe fulfilment of the dimensions and characteristics. A common weakness of the systems was that they did not measure flow orientation or external effectiveness to any great extent. Field experiments in the studied organizations showed that the use of OEE in combination with an open and decentralized organization design could improve weaknesses. Dal et al. (2000) tried to measure overall equipment effectiveness (OEE) in automobile industries. Its implementation and use within the operational environment were described and analyzed. OEE provides an excellent perspective on production improvement. Kiureghan et al. (2005) developed closed-form expressions for steady-state availability, mean rate of failure, mean duration of downtime of a general system with randomly repairable components. These closed-form solutions upgrade the performance of the system by altering the mean failure rates or mean repair durations of the individual components. These closed-form expressions provide a convenient framework for identifying important components within the system.

Sharma et al. (2006) used an approach to implement TPM by using four main activity stages e.g.,the preparatory stage, introduction stage, introduction-execution stage, failure analysis and countermeasures. After the collection of the data related to failure and maintenance aspects, a thorough analysis was carried out. OEE was measured before TPM implementation and after TPM implementation to justify the TPM office goal. Considerable improvements in availability, performance effectiveness and quality rate were obtained after the implementation of TPM. Pascual et al. (2006) proposed a non-linear mixed integer model to improve the effectiveness of the production system by minimizing the expected overall cost rate concerning repair, overhaul and replacement times. This model develops an approach to solve the non-convex nature of the global cost with the combinatorial nature of integer variables. Kleef and Rooij (2006) analysed downtime data for both employees and the company by using Pareto analysis. This analysis tries to find the root causes and sources of the errors. The corrective actions for reducing downtime by first defining priorities based on Pareto analysis and secondly by creating projects to ensure a solid approach. Ahuja and Khamba (2008) tried to evaluate the challenges before Indian manufacturing organizations for adopting proactive total productive maintenance (TPM). They surveyed traditional Indian manufacturing organizations to identify the conditions of TPM. The maintenance and human factors are considered neglected areas in traditional Indian manufacturing organizations. Maintenance is treated as an unnecessary issue. The difficulties faced by the organizations have been categorized into organizational, cultural, behavioral, technological, operational, financial, and departmental obstacles. The top management's contributions to successful TPM implementation have been found.

Garza et al. (2010) provided evidence of the connection between OEE and process capability to aid in assessing a process' eligibility to satisfy the necessary quality requirements. OEE is the result obtained by multiplying all three variables, specifically: accessibility, effectiveness, and quality. As a result, any advancements achieved in the capability measure will benefit OEE. Vivekprabhu et al. (2014) used a Genetic Algorithm in their paper to optimize Overall Equipment Effectiveness (OEE) to achieve the best utilization of plant resources. The effectiveness of a production system is assessed using a performance metric called overall equipment effectiveness (OEE), which takes into account variables like availability rate, performance rate, and quality rate. The paper suggests that emphasizing performance rate improvement will lead to a considerable improvement in OEE. Shagful et al. (2014) present a review of maintenance management methodologies and their application to positional error calibration decision making. Predictive calibration is a technique that helps to facilitate greater control of manufacturing accuracy issues. Tabikh (2014) surveyed Swedish manufacturing firms that show that the estimated cost constitutes 23.9% of the total manufacturing cost ratio and 13.3% of planned production time. They applied a preventive maintenance strategy. By using OEE, the hidden production plant capacity by revealing six losses. This represents a sample of how Swedish manufacturing companies approach downtime cost analysis and its reduction.

Gupta and Vardhan (2015) investigated increasing sales volume by improving overall equipment efficiencies (OEE) of the machines, plant productivity and production cost through total productive maintenance.OEE enables organizations to benchmark and monitors their progress with simple and easy to understand metrics with the purpose to increase manufacturing performance. Machines having OEE less than or equal to 70% were first considered for improving their OEE. A good number of kaizen projects were carried out and the desired improvement in the OEE of these machines was achieved. Goyal and Jindal (2015) set up the target to evaluate the success of TPM based on improvement in overall equipment effectiveness. Some barriers to effective implementations of TPM, such as Lack of material exposure, and difficulty in understanding TPM methodology. Krzeminski (2016) developed a new model for minimizing construction team downtime. This model was designed especially for flow shop scheduling. The mathematical algorithm is based onan iterative algorithm to assist in generating the most significant downtime that is responsible for effectiveness losses. The model is easy to use by usingan effectiveness matrix. This model is noticeable for reducing worker downtime. Yazdi et al. (2018) selected OEE as the standard for measuring manufacturing productivity to highlight the impact of time. Time effectiveness in OEE has been considered to utilize the analytical methodology. The connection between time and energy use has been looked into in the study. The need for a competent industrial production system with a long period of functioning for time and energy consumption observation is necessary to overcome any potential challenges that may arise in determining the impact of the OEE percentage on manufacturing sustainability. Throughout this literature review, it is seen that OEE measures the effectiveness of the machines. Downtime reduction is considered an important issue for improving OEE. Many researchers pointed out that TPM implementation is ensured excellent manufacturing and they discussed the ways to implement TPM.

3. Methodology

OEE is a measure of the value added to production by a certain machine in a certain period. To maximize equipment effectiveness, OEE is used as a measure. It is a function of the availability rate, performance rate, and quality rate.

OEE= Availability rate* Performance rate* Quality rate

The 'Availability rate' indicates the relationship between the time that the machine could theoretically have been in operation (there was demand) and the time that there was actual output. It can be expressed by the ratio of operating time and loading time. The working time without the planned downtimes of a machine is called loading time.

Availability rate = {(Loading time- unplanned downtime)/ loading time} *100
Here, loading time= Working time - planned stoppages time
Unplanned downtime= Downtime due to unwanted stoppages

The output that the machine could have made in theory if the machine had operated at maximum speed during the time that it operated, is known as 'Performance rate'. This can be expressed by the ratio of produced quantity in a cycle time to the operating time of the machine. The working time of a machine without the overall downtime is called the operating time. Cycle time is the amount of time required to carry out repetitively one single processing operation.
Performance Rate= {(Cycle time* quantity produced)/ operating time} * 100
Operating time= Loading time – unplanned downtime

The ratio of good quantity to the produced quantity is called the quality rate.
Quality Rate = {(Produced quantity- rejected parts)/ produced quantity} *100(Muchiri and Pintelon 2008).

4. Data Collection

At the very beginning of analyzing a process, it was required to collect some relevant data from a practical process. For this reason, a production plant of a leading plastic manufacturing companyfrom Bangladesh has been chosen. From the production plant, a production floor, where 23 machines are available, was selected for the analysis. The operating time of the production floor is classified as shift A and shift B. Relevant data of the production system for six days for both shifts A and B were collected for the OEE measurement and overall analysis. For each machine, the produced products, cycle time, quality of the products, total operating time and other necessary data were collected for this study.

5. Result Analysis

This section deals with the representation of results based on methodology and collected data as mentioned in the previous section. At first, graphical and tabular analysis investigates the relationship of OEE with availability rate, performance rate, and quality rate. Later, linear regression is used to seek the impact of downtime over OEE.

5.1 Relationship of OEE with Machine Parameters

Parameters can be defined as the additional quantities that influence the behavior of a function. In another word, the definable, measurable, and constant or variable characteristics of a system or equipment are called its parameters. According to this definition, it can be said that availability rate, performance rate, and quality rate are some of the parameters of a machine. The three parameters and OEE were calculated as described in the previous section. Then the average of the three parameters of 23 machines along with OEE was calculated for each of the six days of shifts A and B to observe the impact of the parameters on OEE. The data are represented in Tables 1 and 2. Later graphical illustrations of the data are represented for better visualization in Figures 1 and 2.

Table 1 demonstrates the three machine parameters and OEE for six days of shift A. Among the three machine parameters availability rate is consistently lowest for shift A. For day 1, the availability rate was lowest resulting in the lowest OEE 48.62% in six days for this shift. On the other hand, on day 4, each of the three machine parameters was at its peak. Consequently, OEE was also highest at 70.79% on that day while the availability rate was 77.82%. From this data, it is observable that there is an issue with the availability rate of machines of shift A as a lower availability rate is affecting OEE on regular basis.

Table 1. OEE and other machine parameters of shift A for six days

Day	Availabilityrate (%)	Performance rate (%)	Quality rate (%)	OEE (%)
1	57.46	61.25	68.19	48.62
2	73.52	93.56	93.13	70.54
3	69.41	90.12	87.35	66.07
4	77.82	94.27	96.92	70.79
5	71.98	80.30	81.15	68.63
6	73.43	93.49	93.43	70.12

Figure 1 is obtained by plotting OEE against the three machining parameters of shift A. It is revealed from the figure that the OEE of each machine varies directly with the variation of eachparameter of machine e.g., availability rate, performance rate, and quality rate. For this shift, the availability rate has the closest relationship with OEE. The line of OEE is almost parallel to the line of availability rate while performance rate and quality rate are always better than the availability rate. So, the lower availability rate has a negative impact on OEE for this shift.

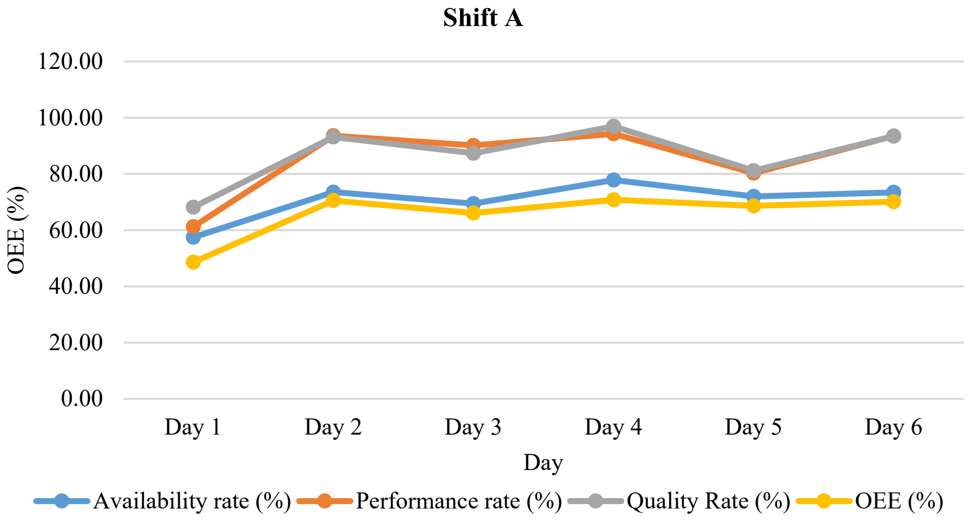

Figure 1. Graphical representation of OEE (%), availability rate (%), performance rate (%), quality rate (%)

The three machine parameters and OEE for shift B of six days are shown in Table 2. The availability rate for shift B is consistently the lower of the three machine metrics. Day 2 had the lowest availability rate, which led to this shift's lowest OEE (65.38%) in six days. This data makes it obvious that there is a problem with shift B's availability rate of machines which is affecting OEE, quite similar to shift A.

Table 2. OEE and other machine parameters of shift B for six days

Day	Availabilityrate (%)	Performance rate(%)	Quality rate(%)	OEE
1	82.61	81.22	80.73	79.37
2	75.18	84.71	85.58	65.38
3	77.93	97.92	97.61	74.79
4	86.32	93.58	94.25	83.12
5	79.41	97.42	97.63	76.73
6	90.79	92.99	93.79	86.46

Plotting OEE versus the three machining parameters of shift B yields Figure 2. The graphical lines represent that there is a close correlation between the availability rate and OEE for this shift. While performance rate and quality rate are always superior to the availability rate, the line of OEE is virtually parallel to the line of availability rate. Therefore, similar to shift A, OEE for this shift is negatively impacted by the reduced availability rate. Therefore, from the statistical data, it is evident that the availability rate, performance rate and quality rate have a great impact on the OEE of both shifts of the plant. The performance rate and quality rate are always satisfactory for both shifts of the plant. As a result, a lesser availability rate is a constraint for the productivity of the plant.

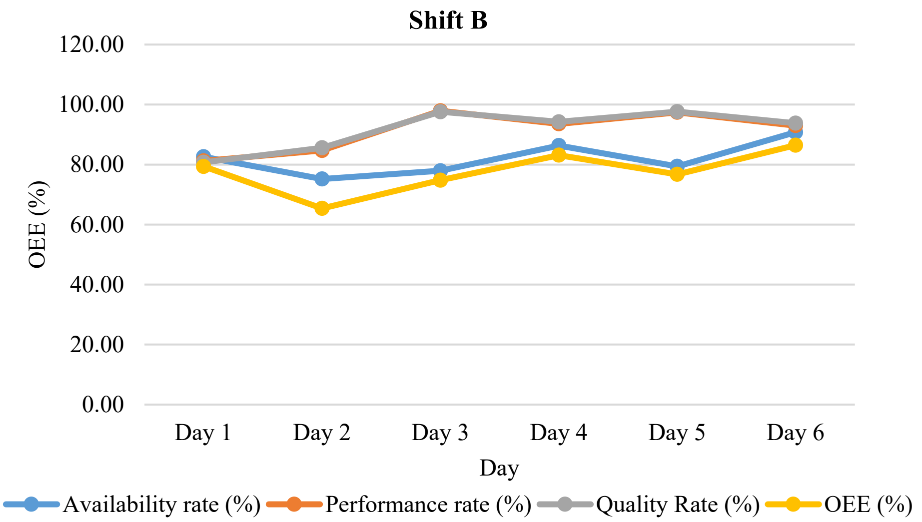

Figure 2. Graphical representation of OEE (%), availability rate (%), performance rate (%), quality rate (%)

The mean and standard deviation of OEE and the other three machine parameters was determined as shown in table 3. Among the three machine parameters quality rate has the highest mean and the availability rate has the lowest mean for the plant for six days. The mean availability rate is also nearest to OEE among the machine parameters. The performance rate has the highest standard deviation while the availability rate has the lowest standard deviation. For a more detailed analysis of the influence of the three machine parameters over OEE, a combined normal distribution curve of frequencies of OEE (%), availability rate (%), performance rate (%)and quality rate (%) was drawn and represented in Figure 3.

Table 3. Mean and standard deviation of OEE (%), availability rate (%), performance rate (%) and quality rate (%) of six days for both shifts.

	OEE (%)	Availability rate (%)	Performance rate(%)	Quality rate(%)
Mean	71.97	76.60	88.732	89.478
Standard deviation	5.25	4.76	8.801	7.647

From the graphical representation of Figure 3, the variance and mean of the performance rate and quality rate are relatively higher than the availability rate. The reason for the variance in performance rate and the quality rate is associated with high cycle time, rework and product quality problems. If these problems can be tackled, OEE will increase.

The normal frequency distribution of availability rate and OEE is relatively similar. So, even if the other two parameters remain unchanged, the increase in availability rate will result in increased OEE. The availability rate, of a production plant mainly fluctuates due tomanpower shortages, machine run problems, mold problems, downtime etc. By resolving these issues OEE of the plant can be improved.

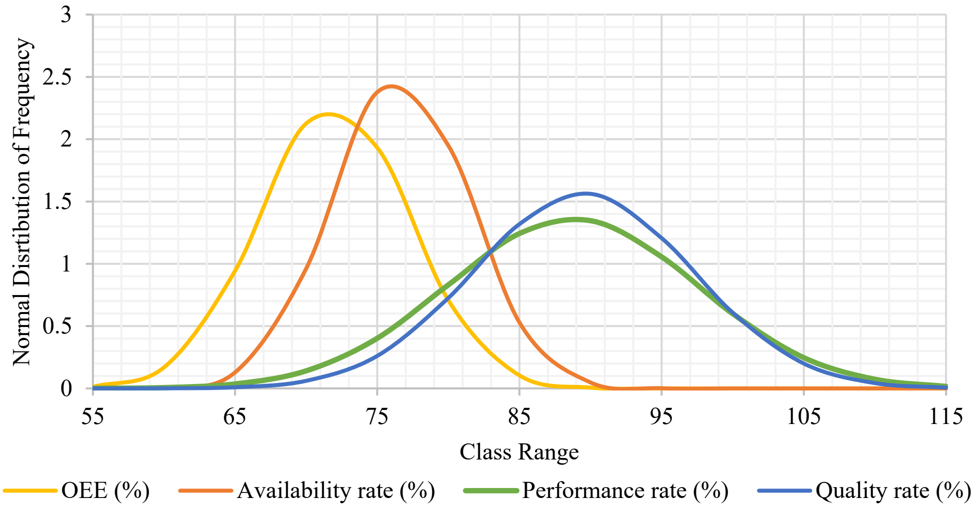

Figure 3. Graphical representation of normal frequency distribution of OEE (%), availability rate (%), performance rate (%), and quality rate (%) of six days for both shifts

5.2 Relationship between Downtime and OEE

This section aims to seek the relationship between OEE and downtime of two different shifts of the plant. So, previously calculated OEE and data of downtime directly collected will be used for linear regression. Later the correlation between OEE and downtime will be established.

Table 4 shows the downtime and calculated data of OEE for six days for shift A. From the table, it can be seen that when the downtime was 144.72 hours on day 1, OEE was 48.62% which was the minimum. For the minimum downtime of 71.42 hours on day 4, OEE was the maximum and it was 70.79%. So, there is a negative correlation between OEE and downtime for shift A. The negative value ofthe Pearson correlation coefficient also represents the strong negative correlation between OEE and downtime.

Table 4. OEE and downtime of six days for shift A

Day	OEE (%)	Downtime (Hour)
Day 1	48.62	144.72
Day 2	70.54	80.38
Day 3	66.07	100.07
Day 4	70.79	71.42
Day 5	68.63	83.17
Day 6	70.12	79.83
Pearson correlation coefficient		-0.985

From Figure 4, by applying linear regression, the negative correlation between OEE and downtime can be visualized clearly. It shows that OEE was higher when the downtime was lower. So, the percentage of OEE increased for shift A when the downtime decreased and vice versa.

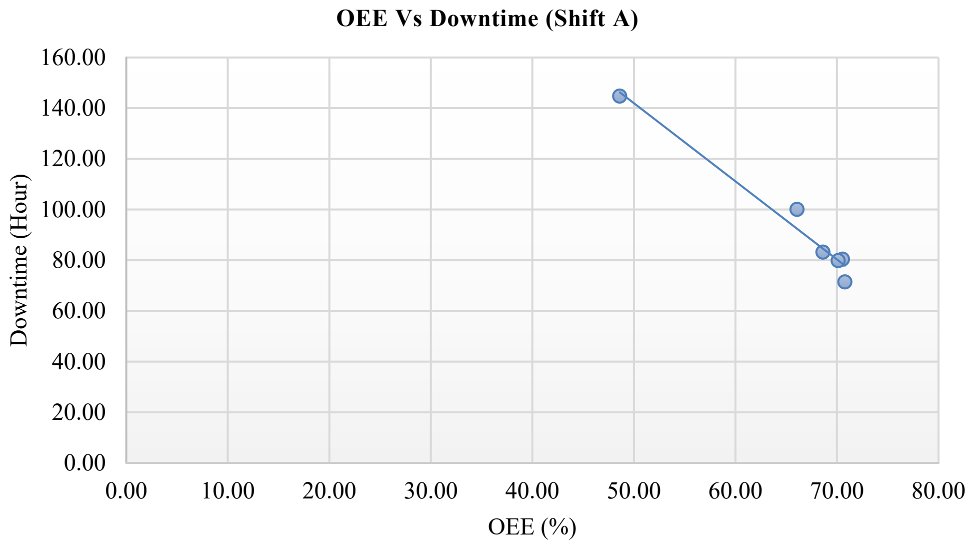

Figure 4. Linear regression between OEE and downtime for shift A

Table 5represents the downtime and calculated data of OEE for six days for shift B. It shows that for the minimum downtime of 27.083 hours on day 6, OEE was the maximum and it was 86.464%. Pearson correlation coefficient for shift B, also suggests a negative correlation between OEE and downtime, quite similar to shift A in Table 4.

Table 5. OEE and downtime of six days for shift B

Day	OEE (%)	Downtime (Hour)
Day 1	79.371	117
Day 2	65.380	56.5
Day 3	74.786	60.917
Day 4	83.124	37.75
Day 5	76.729	56.833
Day 6	86.464	27.083
Pearson correlation coefficient		-0.236

Figure 5 is a visual illustration of negatively correlated OEE and downtime for shift B.It means that when OEE was higher, the downtime was lower.So, the negative correlation between OEE and downtime is supported by statistical data for both shifts. Therefore, by decreasing downtime, OEE and profitability of the plant can be improved significantly.

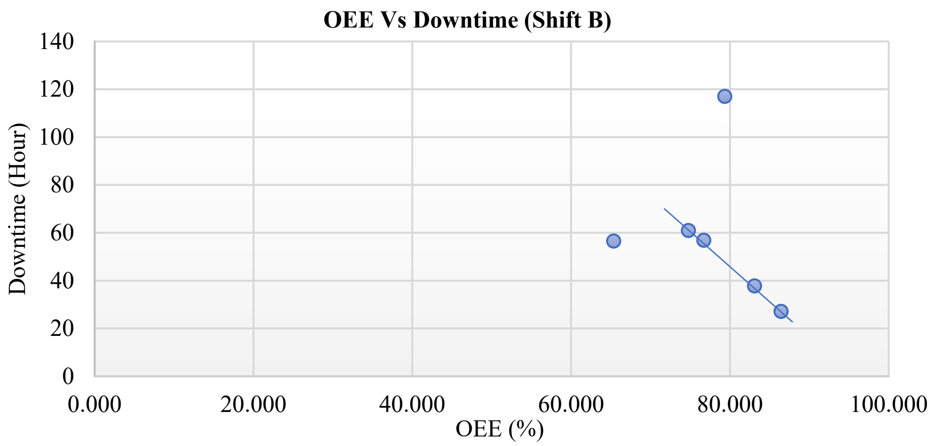

Figure 5. Linear regression between OEE and downtime for shift B

5.3 Cause Analysis of Downtime

The present status of downtime on this production floor is high. Ishikawa diagram has been used for this root cause analysis. For high downtimes, the major categories of the causes have been identified by inspection. Then, the main causes and sub-causes of the downtime were identified. The major causes can be classified as Manpower problems, Machine problems, Process problems, Raw material problems and Product problems.

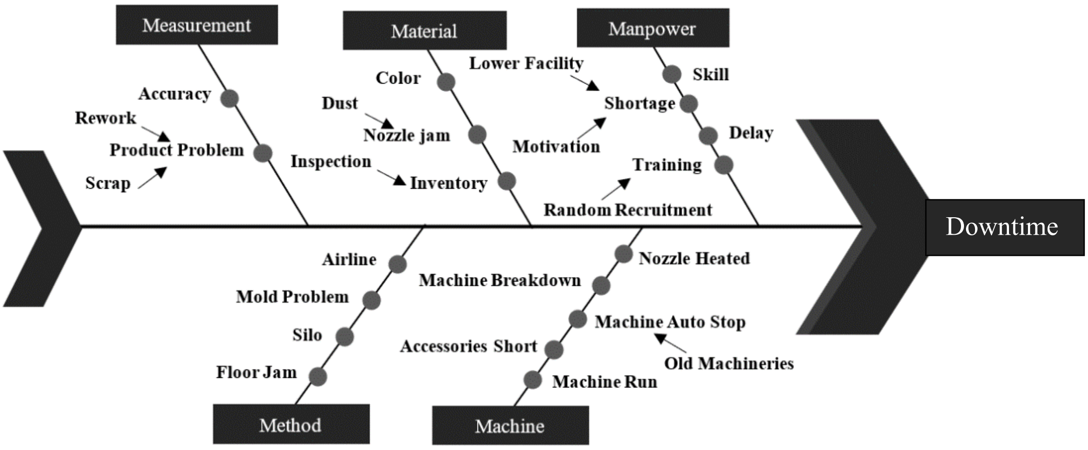

Figure 6. Cause-Effect diagram for downtimes

From the Cause-Effect diagram, the critical causes for the higher downtime have been revealed such as nozzle jams due to dust, mold change problem, manpower shortage, lack of proper training, accessories shortage and floor jam. By eliminating the above-mentioned causes by taking proper measures, the downtime of the production floor can be reduced.

6. Proposed Improvements

The causes and sub-causes are identified which have a direct impact on the downtime of the production floor by using cause effect diagram. It is also shown in Figures4 and 5 that the overall effectiveness and the downtime are negatively correlated. So, if it is possible to reduce the causes of downtime, then the effectiveness will be increased.

For reducing the downtimes of the production floor, this study proposes to implement total productive maintenance (TPM) based on expert's opinions. Applying the Pillars of TPM in the downtime causes area, the current condition can be improved. In every category, mentioned in the previous section, different pillars of TPM have been suggested for application.

Table 6. Solution Approaches for Machine Problems

Implementation of Planned Maintenance	• Before starting the work, checking the machines' parameters that reduce breakdown. • Replacing the parts of older machines with newer ones. • Properly maintaining the machines at the time of working.
Implementation of Autonomous Maintenance	• After proper training, transferring the responsibilities of a machine to the worker that he operates.
Implementation of Training	• Training should be arranged on regular basis for giving proper directions. • Training is compulsory when modern machines are brought to the floor.
Implementation of Safety, Health &Environment	• Ensuring the safety measures while operation is running. • If any accident may occur at the time of working, immediate curing facilities have to be ensured.
Implementation of Quality Management	• Checking the machine condition to prevent random defective products and taking actions for betterment in the quality ofproducts.

Table 6 illustrates the initiatives for reducing the machine problems such as arranging proper training of the operators, checking machine parameters, ensuring safety measures and preventive maintenance.

Table 7. Solution Approaches for Manpower Problems

Implementation of Planned Maintenance	• Directing the workers towards the proper maintenance of the machines and the process.
Implementation of Autonomous Maintenance	• Giving independence of working to the workers while operating the machines to increase workers' motivation.
Implementation of Training	• Arranging some training programs on regular basis for making the operators skilled enough to run the machines.
Implementation of Safety, Health & Environment	• Enhancing recreational facilities for creating an environment of flexible working. • Providing safety assurance in working environment. • Giving some health care facilities to the employees.

For eradicating manpower problems, Table 07 suggestsa proper recruitment process, arrangement of the necessary training sessions for skill development, giving freedom to the operator and enhancing recreational facilities need to be ensured.

Table 8. Solution Approaches for Process Problems

Implementation of Planned Maintenance	• Maintaining the process of inputflow properly. • Filtering the input material before flowing through the nozzle. • Scheduling the material and product flow process for reducing floor jams.
Implementation of Focused Improvement	• Applying the PDCA cycle for smoothing the way of material supply and product delivery for quality maintenance, proper flow, nozzle jam and silo effect reduction.
Implementation of Training	• Training programs are essential for the workers for acquiring knowledge about mold, material and machine handling.

From Table 8, filtering the input materials can reduce the nozzle jam problem. Ensuring raw material quality, training programs for a better understanding of the process steps, application of the PDCA cycle for quality maintenance and silo effect reduction are some of the measures for the improvement of the process problems.

Table 9. Solution Approaches for Raw Material Problems

Implementation of Planned Maintenance	• Proper inspection is required for handling material inventory. • The lead time approach can be used to solve inventory problems.
Implementation of 5S	• Removing unnecessary items like breakage units, dust, and oil from the working area. • Presenting the required material at the right place at right time.
Implementation of Quality Management	• The quality of the raw material should be inspected whether they are dust free and of definite color.
Implementation of Focused Improvement	• Improving the way of material flow to the working by proper area scheduling of the supply lines.

From Table 9, Raw material problems at the plant can be resolved by handling the material inventory through proper inspection, ensuring the proper and required environment and improvement of the flow of the materials.

Table 10. Solution Approaches for Product Problems

Implementation of Quality Management	• Checking the overall conditions of the process parameters and equipment for lowering the defectives and reworked items.
Implementation of Planned Maintenance	• Inspecting each part of a final product before mating is very important for reducing errors. • Proper dimensions should be fixed up in the process parameters before starting production.
Implementation of Focused Improvement	• Measuring the product's efficient and accurate dimension for reducing production time and cost by using KAIZEN.

From Table 10, ensuring product specifications accurately, proper inspection and checking the process parameters are important to reduce errors.

8. Discussion

Initially, to evaluate the current state of the effectiveness of the production system, the OEE of the machines on a manufacturing floor was assessed. It was evident from the analysis of the OEE result that there is a substantial negative association between OEE and downtime. Downtime, therefore, has an impact on the rates of availability, performance, and quality. Moreover, in the selected manufacturing plant, a lower availability rate is a considerable reason for decreasing the OEE of the system. So, downtime is the key reason for reducing the machine parameters and consequently, OEE. Additionally, it was revealed that issues with inventory, mold, and reworks result in lengthy machine downtimes, which is a sign of complete machine ineffectiveness. Root cause analysis was used to determine the critical causes of downtime. Some solution options utilizing TPM were given to enhance the OEE from the current situation. Though there was no numerical data available on the improvement of OEE after the application of TPM, theoretically TPM will improve the current OEE by reducing unwanted downtime.

9. Conclusion

This study has considered OEE as a tool for assessing the effectiveness of the equipment during the production process. Primarily, the study illustrated how machine parameters affect OEE. Then, the negative impact of downtime on OEE statistically was unveiled. The critical causes of the higher downtime were also disclosed in this work. TPM has been considered a remedy for decreasing unwanted downtime. During the entire study, OEE was used as an excellent starting point for identifying operational areas that may be addressed for change and a quantitative approach to track development when paired with the information from other machine parameters. So, OEE can be measured periodically to do a comparison study, track advancements, and determine the best course of action for moving forward.

References

Ahuja, I.S. and Khamba, J.,Strategies and success factors for overcoming challenges in TPM implementation in Indian manufacturing industry. *Journal of Quality in Maintenance Engineering,* vol. 14,no. 2, pp. 123 – 147, 2008.

Aspinwall, E. and Elgharib, M.,TPM implementation in large and medium size organisations. *Journal of Manufacturing Technology Management*, vol. 24,no. 5, pp. 688-710, 2013.

Dal, B., Tugwell, P. and Greatbanks R., Overall equipment effectiveness as a measure of operational improvement- A practical analysis. International Journal of Operations & Production Management, vol. 20,no. 12, pp.1488-1502, 2000.

Fakhri, N., Supenti, L., and Prabawo, G., Overall equipment effectiveness (OEE) analysis to improve the effectiveness of vannamei (Litopenaeus vannamei) shrimp freezing machine performance at PT. XY, Situbondo-East Java. *IOP Conference Series: Earth and Environmental Science*, 2000.

Garza-Reyes, J. A., Eldridge, S., Barber, K. D., and Soriano-Meier, H., Overall equipment effectiveness (OEE) and process capability (PC) measures: A relationship analysis, International Journal of Quality and Reliability Management, vol.2,no. 1, pp. 48–62, 2010.

Goyal, R., Jindal, S., A Systematic Approach towards Implementation of TPM in an Automobile Industry,*International Journal of Emerging Research in Management &Technology*, vol. 4,no. 10, pp. 35-52, 2015.

Gupta, P., Vardhan,S., Optimizing OEE, productivity and production cost for improving sales volume in an automobile industry through TPM: ACase Study,*International Journal of Production Research,* vol. 54,no. 10, pp. 2976-2988, 2016.

Jonsson, P., and Lesshammar, M., Evaluation and improvement of manufacturing performance measurement systems - The role of OEE,*International Journal of Operations and Production Management*, vol. 19 no. 1, pp. 55–78, 1999.

Kumar, S. V., Mani, V. G. S., and Devraj, N., Production Planning and Process Improvement in an Impeller Manufacturing Using Scheduling and OEE Techniques,*Procedia Materials Science*, vol. 5, pp. 1710–1715, 2014.

Modgil, S., Sharma S., Total productive maintenance, total quality management and operational performance: An empirical study of Indian pharmaceutical industry, Journal of Quality in Maintenance Engineering, vol. 22,no. 4, pp.353-377, 2016.

Muchiri, P., and Pintelon, L., Performance measurement using overall equipment effectiveness (OEE): Literature Review and Practical Application Discussion, vol.46, no. 13, pp. 3517–3535, 2008.

Prabowo, H. A., Agung,P. H., Bobby,S.Y., and Farida, F.,The Evaluation Of Eight Pillars Total Productive Maintenance (Tpm) Implementation And Their Imact On Overall Equipment Effectiveness (OEE) And

Waste, 2018.
Sharma, R.K., Kumar, D., Kumar, P., Manufacturing Excellence through TPM Implementation: APractical Analysis,*Industrial Management & Data Systems,* vol. 106,no. 2, pp. 256-280, 2006.
Singh, K., Ahuja, I.S., Effectiveness of TPM Implementation with and without Integration with TQM in Indian Manufacturing Industries, *Journal of Quality in Maintenance Engineering*, vol. 20,no. 4, pp. 415-435, 2014.
Singh, R. K., Gupta, A., Kumar, A., Khan, T. A.,Ranking of Barriers for Effective Maintenance by using TOPSIS Approach, *Journal of Quality in Maintenance Engineering*, vol. 22,no. 1, pp.18-34, 2016.
Vivekprabhu, M., Karthick, R., & Senthil Kumar, G. (2014). Optimization of Overall Equipment Effectiveness in A Manufacturing System. *International Journal of Innovative Research in Science, Engineering and Technology*, vol.3, 2014.
Wakajira, M. W., Singh, A.J., Total Productive Maintenance: A Case Study in Manufacturing Industry, *Global Journal of researches in engineering Industrial* engineering,vol. 12,no. 1, pp. 126-14, 2012.
Wikipedia, Available: https://en.wikipedia.org/wiki/Ishikawa_diagram , Accessed on: October 22, 2022.
Yazdi, P. G., Azizi, A., & Hashemipour, M. An empirical investigation of the relationship between overall equipment efficiency (OEE) and manufacturing sustainability in industry 4.0 with time study approach. *Sustainability (Switzerland)*, vol. 10, no. 9, 2018.

Biographies

Md. Ariful Haque is currently working as a lecturer in the department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET), Bangladesh. He started his early academic career at the National Institute of Textile Engineering and Research under the department of IPE. Currently, he is pursuing his M.Sc. in Industrial and Production Engineering from the Department of IPE of Bangladesh University of Engineering & Technology (BUET), Bangladesh. He obtained his B.Sc. in Industrial & Production Engineering from RUET. His research area covers Operations Research, Production Management, Supply Chain Disruption, and Solid Waste Management.

A M Almas Shahriyar Azad is a student of Rajshahi University of Engineering & Technology (RUET), currently pursuing his undergraduate on Industrial & Production Engineering (IPE). Previously, he completed his HSC from Notre Dame College, Dhaka. He enjoys solving problems, and in the 2020 competition "Face the Case" hosted by IEEE, CUET, he came in second place. Additionally, he received the International Supply Chain Education Alliance's(ISCEA) 'Certified Supply Chain Analyst ™' certification in 2021 with scholarship. Designing affordable mechatronic devices and optimizing the energy supply chain are two of his research interests.

Moumita Ghosh is currently pursuing her MBM in Bank Management at Bangladesh Institute of Bank Management. She obtained her B.Sc. in Industrial & Production Engineering from Rajshahi University of Engineering & Technology (RUET), Bangladesh. Her research area covers operations management, quality control management, supply chain management etc.

Zarin Tasnim Oishi is an undergraduate student of the Department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET). Her HSC was completed from Rajshahi College, Rajshahi in 2017. She won the first runner-up position in the 'National STEM Competition 2021' organized by 'Bangladesh Stem Foundation'.She also received 'Certified Supply Chain Analyst ™'certification from the International Supply Chain Education Alliance (ISCEA) in 2021 with scholarship. Her research interest is different types of the supply chain.

Md. Mohibul Islam is an Assistant Professor of the Department of Industrial & Production Engineering at Rajshahi University of Engineering & Technology, Bangladesh. Currently, he has been pursuing his Ph.D. research at Nagoya Institute of Technology, which has been financed by the Japanese government (MEXT Scholarship) since 2019. His research theme focuses on the development of mathematical models and algorithms to solve industrial problems, related to the fields of supply chain and logistics management. He completed his M.Sc. and B.Sc. in Industrial & Production Engineering from RUET, Bangladesh.