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Identifying Centrifugal Pump Effectiveness Through Utilizing OEE Measures as a Basis Towards Optimum Process Stability

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***Abstract:** The present global competitive within the petroleum industry obliges companies to improve production performance continually. In this paper, Overall Equipment Effectiveness (OEE) used as improvement driver tools that measure various types of production losses and indicate the area of process improvement. The study approach attempts to measure the effectiveness of the centrifugal oil pump during one year of operating based on the historical data acquired. Then used this gained data of the OEE metrics in order to predict the pump effectiveness over the three years. Monte Carlo simulation method used to prognosis the machine behavior patterns in the future and estimating the effectiveness of the pump system. Also, it supports management for clear understanding to draw their maintenance strategy in advance and identifies the opportunities to reduce wastages of time and resources. Further, the results show how individual OEE factors influence the overall productivity and efficiency of the oil pump. This identification will contribute not just to improve the maintenance plan but also will protect the equipment from early deterioration and achieve process stability. OEE is a globally recognized best practice measure to systematically improve processes for higher efficiencies and better productivity, ultimately leading to lower manufacturing costs and higher profitability.*

***Keywords:** Total Productive maintenance (TPM), Overall Equipment Effectiveness (OEE), Lean manufacturing, Key Performance Indicator (KPI), Productivity.*

I. INTRODUCTION

In today's competitive world, eliminating maintenance failure wastes is essential for the firm's survival. These wastes increase the maintenance cost and reduce the machine's performance [1]. [2] State that the competitiveness of the production firms depends on the productivity and availability of their facilities.

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Overall Equipment Effectiveness (OEE) is a standards tool established by Nakajima in 1960 that aims to measure machine productivity and identify the highest priority source of losses to increase the system's performance and work progress [3].

OEE is a best practice to monitor and evaluate machine productivity [4]. Based on Nakajima, OEE consist of three metrics elements applied to measure machine performance availability, efficiency, and quality rate. These three metrics concern the other six losses: breakdowns, setup and adjustments, small stops, slow running, startup losses, and production losses [5].

The primary role of the OEE is to reduce the impact of the six big losses, which are regarded as the main causes of the machine efficiency loss [6][7]. conducted a study on how OEE can be used in industrial fields, and they found that OEE works as a useful contributor to improving the overall system performance. Many organization benefits from implementing OEE, like Boeing, Whirlpool, and Eastern Chemical company (ASECO) [1]. This research paper aims to identify the current overall effectiveness of the centrifugal oil pump.

Twelve months of values were obtained for availability, performance efficiency, and quality rate. Then, an average of the given period was used to estimate the OEE within one year. After that, Monte Carlo simulation procedures were adopted to simulate the random numbers for the machine for the coming three years. The random simulation numbers for Availability, Performance and Quality over the thirty-six months meet the corresponding value based on the computed tables II, III, and IV.

The random numbers are based on the standard random table. The prediction of the Overall Equipment effectiveness earlier helps determine the machine's behavioural pattern in the next years, and that provides enough time to establish an investigation in advance, thus eliminating the causes of six big losses.

Accordingly, minimize the breakdowns of waste and improve productivity to achieve the threshold value of the OEE world-class target (85%). The industrial example was analyzed to show how the OEE concept is applied to enhance productivity in a plant and the different types of production effectiveness losses measured [8][9].

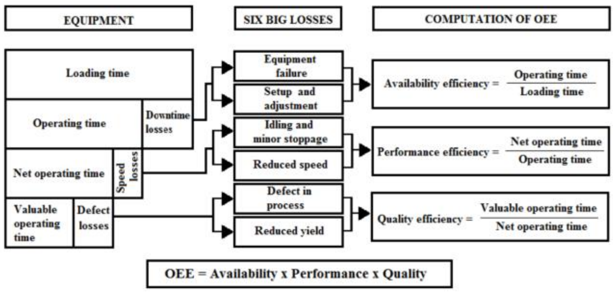

Fig. 1: Overall equipment Effectiveness model (*Source: based on Nakajima,1988: Singh, Shah, Gohil & Shah, 2013*).

II.OEE OBJECTIVES

- Overall Equipment Effectiveness data identifies a single machine or equipment related losses to improve total asset performance and reliability.
- OEE tool is designed to identify and categories the significant losses that lead to poor performance and establish the basis for setting improvement priorities and beginning root cause analysis.
- OEE percentage is used to track the improvement or decline in equipment effectiveness when it is scheduled to operate and compare it with the world-class target level.
- OEE percentage can point to hidden or untapped capacity in a machine and maximize the process productivity.
- Develop the strategy, policy, and early management activities to maximize equipment effectiveness utilization.
- Implementing the OEE philosophy can develop the collaboration between operation, maintenance, and engineering to work together and reduce or eliminate the big causes of poor performance since maintenance alone cannot improve OEE.

III. LITERATURE REVIEW

Overall Equipment Effectiveness (OEE) is derived from the focused improvement pillar of Total Productive Maintenance (TPM). It refers to a quantitative metric used to monitor and evaluate the machine's effectiveness in the process line. OEE Implementation in centrifugal pump in a petroleum company aims to know the current situation of the machine performance and how it will perform in the coming future. Also, it allowed management to take the necessary actions in advance to prevent machine deterioration and sustain productivity [10]. state that OEE is an efficient tool for analyzing machine performance and considering the six big losses. They noted that availability, performance, and quality metrics determine equipment losses. The aim is to maximize production equipment's output and reliability by identifying associate waste types. These wastes are losses in availability (equipment failure losses, setup and adjustment losses), losses in production output (reduced speed losses, idling and minor stoppage losses) and losses in quality (defects in process and reduced yield losses) [7] & [11]. [12] their study presents that the breakdown was reduced within six months period from 56 hours to 3 hours after applying TPM to a vertical boring machine, and the OEE of the machine improved from 45% to 79%. [13] they have worked in their research to utilize OEE metrics in the PVC pipe manufacturing industry to recognize the best opportunity to influence machine performance. The observed study results show the possibility of improving the OEE from 55.45% to 68.04%. [14] His study concentrated on determining the overall equipment effectiveness in the steel industry using collected data over fifteen days. After some improvements to the maintenance strategy, the study shows improvement of about 99% in quality factor, 76% in availability, and 72% in performance. [15] conducted a study to overcome machine deficiencies and improve its ability using the TPM methodology. The study starts by computing overall equipment effectiveness and six big losses. Also, it has attempted to increase the machine effectiveness and minimize the losses by determining the mean time between failures (MTBF) and mean time to repair (MTTR). Finally, it suggests implementing TPM to improve machine performance. The OEE results indicate an insufficient level due to low machine availability. [16] worked on research aiming to launch a framework of model-driven decision support system (MD-DSS) that helps improve the decision-making in the manufacturing industry process. The OEE data was gained and simulated to prognosis the improvement output.

Study results indicate that the MD-DSS can be adopted in firms with internet networks to support the improvement of plan activities' decision making. According to [17], the OEE is a general approach used to determine the efficiency of the production equipment under the frame of lean management with the introduction of total productive maintenance. TPM uses quantitative metrics to measure the performance of the productive system called OEE. OEE methodology combines metrics from whole equipment manufacturing instructions into a measuring system that assists manufacturing and operation teams raise equipment performance, thus minimizing maintenance costs [18]. [19] carry out a study to improve overall equipment effectiveness (OEE) in a company manufacturing steering housing equipment to address and determine challenges faced in implementing TPM. The main issue in the company is lack of stock and changeover time which impact availability, thereby leading to a significant decline in OEE results. The current machine OEE level is found to be around 54.09%. Implementing lean concepts like TPM and Single Minute Exchange of Dies (SMED) would improve OEE by 6.06%. [20] Carry out simulation tests in their study to evaluate the applicability of OEE as an indicator in discrete manufacturing companies using energy OEE assessment in supporting management decisions. The study results pave the way for optimal data utilization of energy monitoring and sensor technology in the future. [21] conducted research that applied a multivariate control chart to OEE performance, combining three metrics: availability rate, performance rate, and quality rate. The methodology followed concentrated on cost and time. The results show that applying this technique will allow all staff to attain project

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time and budget at the beginning of the project. The idea is that OEE has three correlated indicators and is to be monitored altogether to avoid the OEE trend performance rate.

IV. METHODOLOGY

The empirical findings presented in this research were based on OEE factors (availability, performance, and quality rate) data collected from a centrifugal oil pump for twelve months in the petroleum industry. First, the gained data were initially computed for each month individually to determine the OEE value to observe the machine performance over one year, as shown in table I. The OEE results directly presented monthly machine utilization and operational efficiency. Then simulated, the values for availability, performance, and quality rate (see tables II, III, and IV) to determine the random number interval for three OEE factors derived from the calculation of probability and cumulative probability. The random interval number ranges from 0 to 99. Each month's value range is based on the factor value calculated and their frequency (ex: 83% of availability has intervals between 0-22 whereas 95% of availability has interval number between 91-99). The random interval numbers were compiled in an excel sheet for each OEE factor. Further, the Monte Carlo simulation process was used to generate unduplicated random numbers ranging from 0 to 99 to predict the pump performance for the next three years. Thereafter select the corresponding factor value from tables II, III, and IV that meets the created random number based on where the interval number falls. The OEE value prognosis for the coming thirty-six months will forecast the pump performance and contribute to identifying the major losses. Moreover, the root cause analysis can be implemented in advance to investigate the pump deficiencies and set the maintenance activities plans to prevent low pump effectiveness and deterioration in the future. In order to better understand the machine performance and trend, it is important to elaborate on the OEE results and perform calculations precisely. Availability was calculated by considering the planned machine production time, not the total machine operating time. Figure 1 represents the distribution of different factors of overall equipment effectiveness, major six losses and production times from which the calculations are made. The total machine operating time is the scheduled time for production without disturbances (breakdown) whatsoever. After the calculations and analysis have been done, the next step is to draw the conclusion by following world-class standards and provide the suggestion that will drive the incremental improvement of the oil centrifugal pump. The calculation result considers the threshold value of OEE as 85%, according to the world-class target.

V. RESULTS AND DISCUSSION

The results and discussion chapter present the gathered OEE factors (availability, performance, and quality) data for about twelve months which were used to calculate the OEE value as illustrated in table I.

Table I: Centrifugal Oil Pump OEE Values for ONE year.

Month	Availability (%)	Performance Efficiency (%)	Quality Rate (%)	OEE = A x P x Q (%)
1	90	89	89	71
2	91	82	93	69
3	95	92	99	86
4	83	89	98	72
5	91	85	93	72
6	87	89	99	77
7	83	85	93	66
8	91	90	98	80
9	90	82	93	69
10	83	93	99	76
11	92	95	100	87
12	87	92	89	71

5.1 Availability compares planned production time and actual running time, as demonstrated in equation 1. From the above calculation results in table I, the availability values of the oil pump from the first month to twelve-month had experienced fluctuating movement. One of the factors that impact the low availability is the frequent disturbances (breakdowns) that lead to unscheduled activities that can hamper the production process and consequently cause downtime.

$$A = \frac{actual\ running\ time}{Planned\ machine\ production\ tim} x100 \qquad \text{Equ-1}$$

5.2 Performance efficiency is the measurement that will describe the speed of the machine in producing the actual amount against the designed machine capacity. Performance rate calculation is done based on equation 2. The performance results demonstrated that the second and nine months have the lowest values among other months because the actual production amount is very far from the designed amount target.

$$P = \frac{Actual\ produced\ amount}{Designed\ amount\ capacity} x100 \qquad \text{Equ-2}$$

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5.3 Quality rate measures the percentage of the produced production amount that meets the specification standard of all production. The calculated results of the quality rate show that the value of some months is quite low, whereas it increased in certain months. The quality rate of fluctuation is influenced by loss production and rise in production concerning the proposed amount target.

$$Q = \frac{Proposed\ amount - loss\ amount}{Proposed\ amount} x\ 100 \quad \text{Equ-3}$$

5.4 After obtaining all OEE factors (availability, performance, and quality) to determine the pump effectiveness (OEE) for each month individually, as presented in table I. According to the OEE calculation results, the third and eleven months have the highest values, 86% and 87%, respectively, which correspond to the world-class target set by the Japan Institute of Plant Maintenance (JIPM). The lowest OEE percentage recorded was 66% in month seven, and 69% was observed for the second and nine months.

Based on the one-year data collected from the centrifugal pump in c I thus, start to compute the probability and cumulative probability to obtain the random number interval for availability, performance, and quality rate as explained in tables II, III, and IV.

Table II: Availability random interval number.

Availability (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
83	3	0.23	0.23	0-22
87	2	0.16	0.40	23-39
90	2	0.17	0.57	40-56
91	3	0.26	0.83	57-82
92	1	0.08	0.91	83-90
95	1	0.09	1.00	91-99

Table III: Performance efficiency random interval number.

Performance (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
82	2	0.15	0.15	0-14
85	2	0.16	0.31	15-30
89	3	0.25	0.56	31-55
90	1	0.09	0.65	56-64
92	2	0.17	0.82	66-81
93	1	0.09	0.91	82-90
95	1	0.09	1.00	91-99

Table IV: Quality rate random interval number.

Quality Rate (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
89	2	0.16	0.16	0-15
93	4	0.32	0.48	16-47
98	2	0.17	0.65	48-64
99	3	0.26	0.91	65-90
100	1	0.09	1.00	91-99

VI. FUTURE PREDICTION OF OIL PUMP EFFECTIVENESS

The prognosis of the machine performance provides critical information/data that helps management understand the machine behavior pattern for the coming periods and accordingly can take the decision in advance to protect the machine from deterioration at the right time. Furthermore, it sustains productivity, stabilizes the process, and minimizes the failure frequency, subsequently reducing maintenance and operating costs. The Monte Carlo simulation procedures are adopted to simulate the random number for the next three years. The random numbers are generated between 0 to 99 for each OEE factor (availability, performance, and quality) Based on tables II, III, and IV. Every simulated random number will take the corresponding factor value according to the interval. OEE values were computed for each month and used to consider the world-class threshold target of 85%.

Table V: Predict the Availability, Performance, and Quality over the 36 months based on the random number to determine the future OEE value.

Month	Random Numbers	Availability (%)	Random Numbers	Performance (%)	Random Numbers	Quality (%)	OEE (%)
1	74	91	83	93	22	93	79
2	91	95	85	93	93	100	88
3	49	90	86	93	78	99	83
4	1	83	18	85	10	89	63

5	94	95	71	92	72	99	86
6	2	83	4	82	65	99	67
7	62	91	17	85	56	98	76
8	46	90	32	89	7	89	71
9	3	83	75	92	62	98	75
10	4	83	92	95	31	93	73
11	31	87	20	85	14	89	66
12	84	92	27	85	63	98	77
13	40	90	1	82	42	93	69
14	58	91	52	89	81	99	80
15	79	91	91	95	40	93	80
16	69	91	45	89	49	98	79
17	75	91	81	92	33	93	78
18	7	83	46	89	53	98	72
19	26	87	25	85	94	100	74
20	59	91	78	92	84	99	83
21	5	83	10	82	64	98	67
22	53	90	33	89	50	98	78
23	47	90	9	82	4	89	66
24	41	90	11	82	75	99	73
25	80	91	39	89	85	99	80
26	35	87	87	93	68	99	80
27	11	83	30	85	2	89	63
28	24	87	43	89	26	93	72
29	43	90	24	85	73	99	76
30	12	83	34	89	77	99	73
31	19	83	69	92	30	93	71
32	77	91	51	89	57	98	79
33	98	95	57	90	15	89	76
34	9	83	42	89	66	99	73
35	8	83	21	85	87	99	70
36	71	91	13	82	11	89	66

In order to analyze the distribution of the OEE values, the total set of 36 samples was simulated to plot the chart (figure 2) that shows the OEE percentage rating over three years. From simulated results, it can be observed that the OEE average is 74.5 %, and the OEE percentage rating lies between 88 % and 63%.

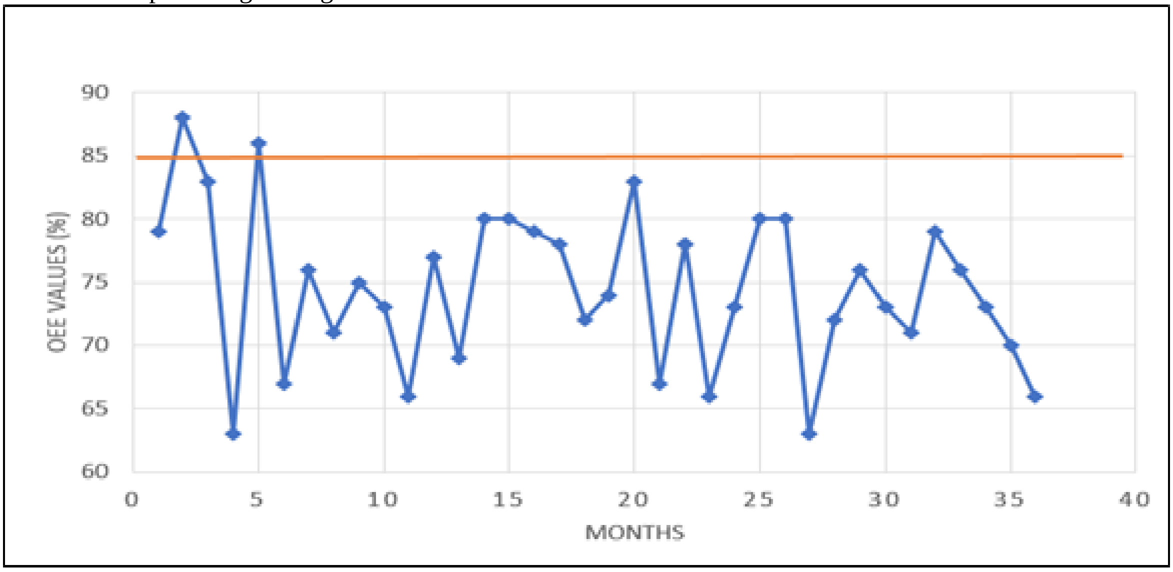

Fig. 2: illustrates the oil pump effectiveness (OEE) status for the coming 36 months.

Since the OEE value accepted is 85% according to the world-class standard. The machine effectiveness reliability is estimated by considering the ratio of observations above the threshold value (2) to the total number of observations (36). Figure 2 demonstrates this procedure.

$$Reliability = \frac{\text{Number of observations above the threshold value}}{\text{Total number of observations}}$$

R = 2/36 = 0.055

Hence, the reliability is inferior (5.5) because most predicted OEE values for the next three years are below the class-world target (85%). Moreover, the OEE factors (availability, performance, and quality rate) that most influenced the overall OEE were identified (figure 3). From the analysis of the simulation results, it is observed that availability and performance efficiency have the highest impact on the OEE, and both are quite the same, followed by the quality rate, which has the most negligible impact. The availability average of the centrifugal oil pump from the simulated empirical data is 83.3 %, with a minimum of 83 per cent and a maximum of 95 per cent. This suggests that the oil pump does not use to its full planned capacity. The availability of the remaining time after subtracting the unplanned breakdowns and setup time losses of the pump represents approximate 16.7 %. The second OEE factor is performance efficiency. The computed performance data show that obtained an average of 83.2 per cent. It can see that performance efficiency varies between 82 per cent and 95 per cent. The performance peak was recorded in the month of the tenth and fifteenth, respectively, whereas the lower performance occurred around six times over three years. The utilization loses primarily ripple effects (minor stoppage & reduced speed) in the production, and these two losses were about 16.8 %. This indicates that pump losses have a substantial impact on OEE. The last factor used to calculate OEE is the quality rate. From simulated data in table 5, the quality rate is generally high, with an average of 95.7 per cent, a minimum of 89 per cent, and a maximum of 100 per cent. The simulation of the OEE components averages is shown in figure 3.

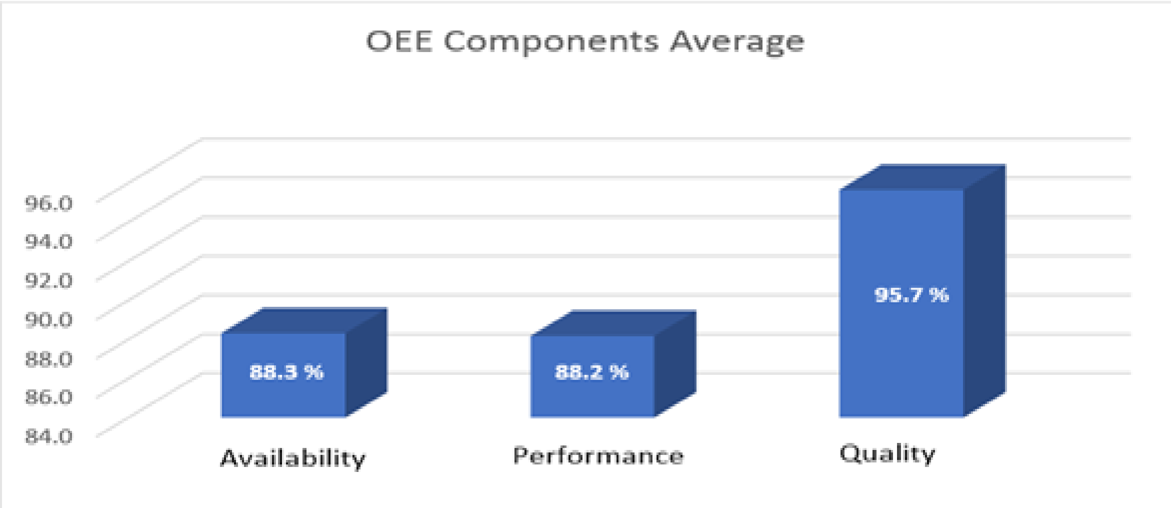

Fig. 3: Show the average of the OEE components over 36 months.

From simulated data results, it was observed that more effort needs to be put into the availability and performance and optimize the pump to achieve a world-class OEE target level. Considering the current low value of OEE components will result in low pump effectiveness, which requires embracing root cause analysis to overcome these failures causes which pave the way to the world-class level. [22] has defined the world-class OEE as a standard used to compare the OEE of the machine or plant. The comparison of the world-class OEE factors and the actual centrifugal oil pump effectiveness are given in table VI.

Table VI: Comparison between world class OEE and the machine future effectiveness.

OEE Factors	World Class (%)	Oil centrifugal pump effectiveness (%).
Availability	90	88.3
Performance	95	88.2
Quality	99.9	95.7
OEE	85	74.5

VII.RECOMMENDATIONS

- ❖ Empower operators and maintenance personnel to understand and quickly respond to production problems.
- ❖ Conduct intensive monitoring and machine maintenance activity in real-time.
- ❖ To repair suction/discharge valves for smooth running and ensure operating within the set time limit.
- ❖ Check pipeline integrity periodically and make sure it is in good condition and can handle the pump pressure.
- ❖ Make sure the maintenance activities (adjustment/alignment/calibration) are carried out according to the approved machine settings and schedule.
- ❖ Apply maintenance procedures efficiently to avoid short circuits and prevent damage to the machine items.

VIII. CONCLUSION

This paper has analyzed the obtained data for the centrifugal oil pump in the petroleum industry for twelve months and found the Overall Equipment Effectiveness (OEE) to be 74.7 per cent. This result is far from the world-class target (85%) and means that the current production resource utilization is low, leading to insufficient productivity and resource efficiency. After that, this study predicts the pump effectiveness in the coming thirty-six months and tracks the machine's progress in the future based on the current status. Forecasted OEE components showed that availability and performance efficiency are the main contributors in terms of losses. The average availability is 88.3 %, and the performance average is 88.2 %. Direct unplanned downtime is generally critical because it impacts the OEE highly, including speed loss and quality loss. The predicted average OEE over three years is 74.5 %, which is unsatisfactory. The adopted approach helps determine the OEE's reliability over the predicted period. This prediction supports the maintenance and management of the activities necessary to achieve a high level of effectiveness and identifies the opportunities to improve the availability and performance. The main events that are reasonable for losses in oil centrifugal pump are as follows:

- Frequent failures (breakdowns).
- Pipeline rupture / leakage.
- Suction & Discharge valves delay in operating (open / close).
- Power deep/ short current.
- Improper maintenance (adjustment / alignment / calibration).
- Operator efficient (experience).

The analysis concludes that OEE is a valuable measure that provides information on the lost time and losses in production sources. Furthermore, it helps to optimize the performance of the existing machine capacity and reduce the process variability. Implementing OEE provides management clearer reports and insight understanding into process efficiency and where improvements can be made. Also, it gives the ability to take immediate action to reduce the downtime and confidence to set long-term strategic decisions to improve productivity based on historical data.

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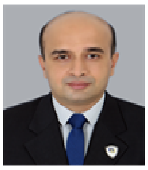
AUTHORS PROFILE

Soud Al-Toubi, is a PhD student at Glasgow Caledonian University. The most exciting field is maintenance management and operation based on artificial intelligence. I have experience operating maintenance for more than thirteen years in the petroleum and gas industry. I have gained a lot of experience through my work journey, especially in maintenance aspects, and I learned a lot from the maintenance challenges I faced during my occupation.

Professor Sudhir C. V., currently hold Head of Mechanical & Industrial Engineering Department at the National University of science and technology/ Oman. His research is interesting in renewable energy and its application in industry fields. His main responsibility is teaching, research, and academic administration in his current position. Also, to contribute, manage, and develop programs that the department offers and ensure it achieves the highest possible standards of excellence in all its activities.

Professor Babakalli Alkali, is the Head of Department for Mechanical Engineering at Glasgow Caledonian University. His research interests are in Industrial Maintenance Modelling and its Application in Business and Industry; Energy Assets Management and Statistical Process Control; Reliability Analysis and Applied Probability Modelling in Transport Systems; and Stochastic Processes, Optimization, Risks and Availability Assessment. He has project led several KTPs within the School of Computing, Engineering and Built Environment including the First Scotrail partnership.



Professor David Harrison, manages a wide range of collaborative projects with colleagues and students plus a diverse group of manufacturing companies at Glasgow Caledonian University. His research interests are primarily concerned with improving overall manufacturing competitiveness in companies via Optimized Design, CADCAM and advances towards CIM. Most of his research has been in association with industrial partners. He has an active interest in the Total Technology program at UMIST. Through his involvement with European projects, he has built up strong links with fellow academics in several European countries and during the past four years five applications for funding have been made.