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Quantitative Assessment of Effectiveness and Utilization of Medical Equipment

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A B S T R A C T

The problem of operational efficiency assessment of medical equipment is becoming crucial, due to its increasing requirement in hospitals. It has been observed that a significant amount of medical equipment is out of service for several reasons such as lack of training, maintenance and health technology management. The unexpected failures, downtime associated with breakdown and make ready, loss of production and poor maintenance costs of medical equipment are the major drawback in any hospital. Quality of diagnostic and treatment care provided to patients largely depends on the reliability, availability and maintainability of sophisticated medical equipment. Aim of the present study is to determine quantitatively overall effectiveness and utilization of some medical equipment. Overall Equipment Effectiveness (OEE) and utilization coefficient is the metric measurement of Total Productive Maintenance (TPM) which specifies effective functioning of devices. The results of the effectiveness of the devices are found to be below the standard of 85%. The cause of low effectiveness value was due to poor performance and availability. Equipment utilization is also needed for the evaluation of medical equipment necessity, appropriateness and efficiency of the use in diagnosis and treating a patient. The proposed methodology may be able to increase the amount of working medical equipment by implementing preventive maintenance schedule. The methodology is also validated by failure probability and reliability of the machines.

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1. INTRODUCTION

The medical equipment is the vital part of health service activities. A medical device is equipment that helps doctors for diagnosing diseases for better health purposes. Biomedical equipments are very important tool that needs training of technicians or administrators and maintenance must be implemented at regular intervals of time. Generally, regular preventive measures are rarely followed leading to breakdown. Therefore, it becomes very important for hospitals to maintain the availability and reliability of biomedical equipment. It has been observed that when technicians are available to attempt repairs or maintenance, there are often a gap between their knowledge and level of technology (Perry & Malkin, 2011).

With increasing competition, hospitals are forced to enhance effectiveness and cost efficiency to sustain in market. A common problem in the modern hospitals is the efficient management of the maintenance of the medical equipment. If effective management of medical equipment maintenance is applied, overall effectiveness of the equipments can be increased. Overall Equipment Effectiveness (OEE) is a way to measure the efficiency of any costly equipment as it is the key performance indicator for implementation of Total Productive Maintenance (TPM) philosophy. The primary stages of assessing OEE are implemented by the measurement of availability loss, performance loss and quality loss (Kar & Pal, 2019).

Total effective equipment performance (TEEP) is a performance metric which takes account both effectiveness in terms of equipment losses and utilization in terms of schedule losses. The hospital management also concerned with the utilization of medical equipment, particularly with the reasons for utilization losses and how to enhance utilization. The utilization of any biomedical equipment is the ratio of equipment utilized days and equipment days available. The goal is the highest utilization of the costly equipment for healthcare improvement and best possible return of facilities.
Based on the existing problems on biomedical equipments a proposed methodology has been suggested by conducting an in-depth analysis of variation of availability, effectiveness and utilization so that proper maintenance schedule can be achieved.

2. LITERATURE REVIEW

Overall Equipment Effectiveness (OEE) is a method to measure the effectiveness of a machine condition (Purba, 2018). After reviewing various journals related to OEE, it was found that OEE is mostly utilised in the manufacturing industry (Atkino& Purba, 2021). A case study in the PVC Compound Industry was conducted to analyze the value of OEE including the Availability, Performance rate and Quality rate (Setiawan, Latif &Rimawan, 2021). In an experiment, two different techniques, a simple moving average and Holt's double exponential smoothing methods, are used to determine OEE and to predict the future performance of overall equipment effectiveness in R studio has been studied (Chintada & Venkata, 2020). A descriptive study (Marfinov&Pratama, 2020) on high downtime of continuous blanking machines is conducted and showed the analysis to minimize six big losses. A case study (Azizah & Rinaldi, 2022) of a packaging company has been done to improve overall equipment effectiveness performance.

2.1 Biomedical Equipments:

Some works in the domain of OEE and utilization of biomedical equipment had been done by various researchers. Firstly, a methodology had been proposed (Taghipour, 2011) to improve current maintenance strategies in the healthcare industry. In this work, the development of a model for the prioritization of medical equipment for maintenance decisions had been investigated. In a comprehensive study funded by World Health Organization (Perry & Malkin, 2011) it had been found that effectiveness of most of the medical equipments in the developing world is far below the standard and 96% of them are out of service. A detail study (Tadia & Kharate, 2020) of the maintenance of equipment at a tertiary care corporate hospital in India where a convenient sampling method was used to capture data from key participants. A methodological approach (Donin &Kneppo, 2013) had been presented for increasing the operational efficiency of medical equipment and it was found significant amount of medical equipment not in operable state. In an integrated approach (Houria, Masmoudi, Hanbali, Khatrouch& Masmoudi, 2016) the availability and reliability of high risk medical devices had been investigated. Assessment of Utilization Coefficient (UC) of dental equipment along with their maintenance schedule has been done (Gupta, Gupta, Sarode, Sarode & Patil, 2017) to increase operational efficiency. A research study (Corciovă, Andriţoi& Luca, 2020) presented a method to evaluate every aspect of the medical equipment maintenance process and provided a standardized approach supporting clinical engineering activities. The effectiveness of Dental Chair Unit had been analysed (Nerito, Sunardhi&Yustiawan, 2020) using the OEE method to find out the causes of deviation of standard OEE value. In Jakarta Government hospital, one of the machines named Linear accelerator Synergy Platform (LINAC) has been studied to improve overall equipment effectiveness (Sukma, Prabwo, Setiawan, Kurnia &Fahturizal, 2022).

In the present investigation, a novel methodology has been developed on the basis of weekly variation of effectiveness and utilization of medical equipment for implementation of TPM philosophy in the hospital to avoid unexpected failures and downtime of these machines.

2.2 Study Objective

Total productive maintenance (TPM) initiatives in hospital helps in streamlining health care management and other business functions accumulating sustained profits. The strategic outcome of TPM implementations is the reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of funds annually. OEE is one of the best practices to monitor and improve the efficiency of medical equipment and is a function of machine availability, performance efficiency and the rate of quality.

TPM initiatives are focused upon addressing major losses and wastes associated with the radiological equipment by affecting continuous and systematic diagnosis system, thereby resulting significant improvements in healthcare facilities. TPM employs OEE as a quantitative metric for measuring the performance of a productive system. The overall goal of TPM is to raise the overall equipment effectiveness. OEE is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality product (Nakajima, 1988) .OEE provides a way to measure the effectiveness of processing operations from a single piece of equipment to the entire radiology sections in a group. It becomes the key decision support tool for continuous improvement programmes. Availability losses result from breakdowns and change-over, i.e. the situation in which the device is not running when it should be. Performance deteriorations arise from speed losses and small stops or idling or empty positions. Moreover, the device may be running, but it is not producing the quality it should.

2.3 OEE Measurement

The overall effectiveness of facilities is its best possible return and calculated as percentage of each group of six big losses. The six big losses are due to breakdown, set up and adjustment, minor stop, low operating speed, poor product quality, yield and start up or restart (Kar & Pal, 2019) (Marfinov&Pratama, 2020).The above identified losses can be evaluated in terms of OEE by the following Equation (1).

$$\text{OEE} = \text{A x P x Q} \tag{1}$$

Where, 'A' is the Availability, 'P' is the Performance and 'Q' is the Quality.

Availability takes into account of breakdown losses and is given by

$$\text{Availability (A)} = \frac{Operating\ Time}{Planned\ Production\ Time} \text{x } 100\% \tag{2}$$

Performance takes into account of Speed Loss, and is given by

$$\text{Performance (PE)} = \frac{Ideal\ Cycle\ Time}{\frac{Operating\ Time}{Total\ Pieces}} \text{x } 100\% \tag{3}$$

Ideal Cycle Time is the amount of time it takes to complete a specific task from start to finish. It is sometimes called Design Cycle Time or Theoretical Cycle Time. Since Run Rate is the reciprocal of Cycle Time, Performance can also be expressed by:

$$\text{Performance (PE)} = \frac{\frac{Total\ Pieces}{Operating\ Time}}{Ideal\ Run\ Rate} \tag{4}$$

Quality takes into account Quality Loss, and is given by

$$\text{Quality (Q)} = \frac{Good\ Pieces}{Total\ Pieces} \tag{5}$$

The quantitative assessment of OEE is central to the formulation and execution of a TPM improvement strategy. TPM has the standards of 90 per cent availability, 95 per cent performance efficiency and 99 per cent rate of quality (Marfinov&Pratama, 2020) (Nakajima,1988). An overall 85 per cent benchmark OEE is considered as world-class performance. OEE measure provides a strong impetus for introducing a pilot and subsequently companywide TPM program.

2.4 Utilization Coefficient

Insufficient preventive maintenance of equipment will result in low standards of diagnosis and treatment and increases the cost of maintenance of equipment. Utilization index is one of the significant parameters to monitor the functional status of the equipment or it is parameter to assess the productivity of equipment. An optimum utilization may result in optimal patient handling and rapid turnover, limited possible cost, quality patient care and patient satisfaction. The present study is carried out with objectives to assess utilization coefficient (UC) of radiology department equipment along with their maintenance schedule to enhance operational efficiency. Use coefficient or Utilization coefficient is applied to determine the utilization of equipment, i.e., whether the equipment is moderately utilized or underutilized. Use coefficient of equipment is measured by the given formula (Gupta, Gupta, Sarode, Sarode & Patil, 2017).

$$\text{Utilization coefficient} = \frac{N}{M} \times 100 \quad (6)$$

where, N is the Average number of hours the equipment is used per day and M is the Maximum number of hours the equipment can be used per day.

2.5 Detail of Medical Equipment

The present study is conducted in a radiology department of a government hospital situated in Kolkata, India. The radiology department plays essential role on treatment of patients as well as on research and diagnosis of diseases. This department comprises of various biomedical instruments such as Magnetic Resonance Imaging, Ultrasonography, X-Ray Manual, Electrocardiogram and CT-Scan, the details of which is described in Table 1. All these devices have been taken into consideration for the study and are used for emergency diagnosis of diseases.

Table 1. Different equipment of the diagnostic centre.

Serial No.	Name of machine	Name of the company	Year of manufacture	Output
1	Magnetic Resonance Imaging (MRI)	Midnapore Diagnostic Pvt. Ltd., India	2014	It produces diagnostic images.
2	Ultrasonography (USG)	SynerMED Technologies LLP, India	2004	It produces high frequency sound waves to scan the internal organs of the body.
3	X-Ray Manual	M.E.X'RAY (I)PVT. LTD, India.	2001	Images of tissues and bones are produced.
4	Electrocardiogram (ECG)	Clarity Medical Pvt. Ltd, India.	2019	It shows three wave signals.
5	Computerized Tomography (CT) Scan	Liasio Medical Services, India.	2006	Tomographic images are produced.

3. RESEARCH METHOD

Usually biomedical equipment work for 24 hours based upon the requirement of test for patients. Our primary study involves tabulation of all factors leading to the calculation of the Overall Equipment Efficiency and Utilization coefficient of the system and its direct influence in determining the efficiency of the existing system. The key assumption is that the results of the empirical study will provide insight into the impact of TPM on the performance of the selected medical equipment, thereby improving the Overall Equipment Efficiency. It is assumed that the hospital management desires to adopt

the total productive maintenance philosophy as part of their future strategic objectives.
The empirical study consists of observations and calculations of highly visible measures of performance such as: Overall Equipment Efficiency (OEE), Utilization coefficient (UC), variation of OEE and UC over a period of nine consecutive weeks. In the present investigation the strategy for maintenance of medical equipment is known as the key performance indicator in terms of mainly OEE. The flowchart given in Fig. 1 represents the proposed framework of the methodology.

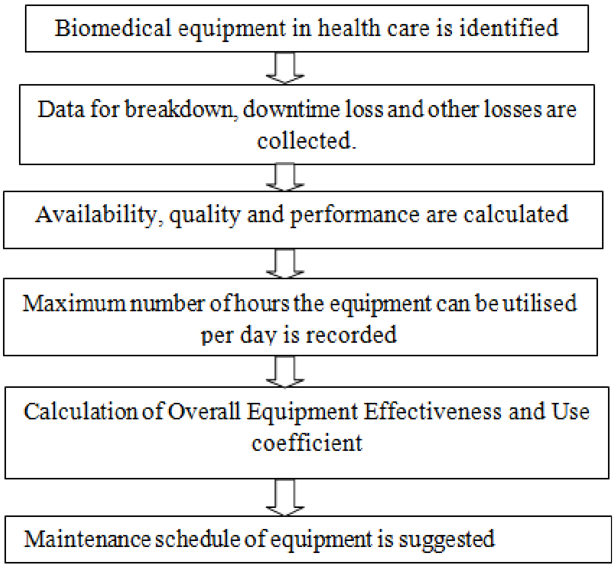

Fig. 1. Framework of the proposed methodology

4. RESULT AND DISCUSSION

4.1 RESULT

The result of specific data has been selected in order to find the values of Overall Equipment Efficiency and UC. On the basis of collected data, OEE of five equipment for consecutive nine weeks have been determined. The results are graphically plotted to find the variation of OEE for a period of nine weeks. Availability, performance efficiency and Quality rates have been evaluated to calculate OEE of the five machines. Tables 2 to 6 show the availability, performance rate, quality rate and overall equipment effectiveness of MRI, USG, X-Ray Manual, ECG and CT Scan and Figures 2 to 6 show the corresponding graphical representation of availability(%), performance (%), quality (%) and OEE(%) of the above machines against number of weeks. Also variation of average OEE (%) of five numbers of equipment in the radiology unit with consecutive nine weeks is shown in Figure 7 for understanding the comparison of performances as well as the effectiveness of each machine.The average OEE of all the equipments is shown in Figure 8. This in turn may help to provide a valuable insight- an accurate picture of which equipment in the hospital is running effectively.

Table 2. OEE of Magnetic Resonance Imaging (MRI) machine for nine weeks

Production Parameters ↓ / Weeks →	1	2	3	4	5	6	7	8	9
Total time (in hrs)	170	168	168	168	168	158	152	142	96
Machine Downtime (in hrs)	26	12	24	20	16	45	47	20	22
Total units production	256	253	248	269	267	182	203	252	144

Total units rejected	0	0	0	0	0	0	0	0	0
Total good units produced	256	253	248	269	267	182	203	252	144
Total planned production time	170	168	168	168	168	158	152	142	96
Total operating time(in hrs)	144	156	144	148	152	113	105	122	74
Machine availability (%)	84.70	92.85	85.71	88.09	90.47	71.51	69.07	85.91	77.08
Performance (%)	88.5	81.08	86.11	90.87	87.82	80.53	96.66	84.01	97.29
Quality (%)	100	100	100	100	100	100	100	100	100
OEE (%)	**73.9**	**74.5**	**73.1**	**79.2**	**78.3**	**56.8**	**66.2**	**71.4**	**74.6**

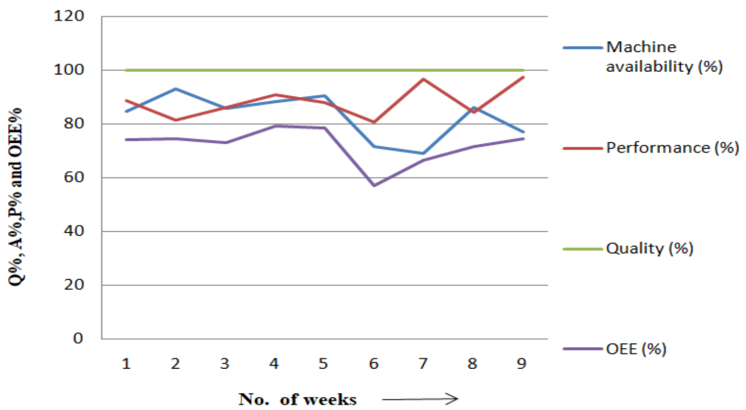

Fig. 2. Weekly variation of availability, performance, quality and OEE for MRI

Table 3. OEE of Ultrasonography (USG) machine for nine weeks

Production Parameters ↓ / Weeks →	1	2	3	4	5	6	7	8	9
Total time (in hrs)	128	120	168	120	72	144	96	96	72
Machine Downtime (in hrs)	96	83	125	82	57	113	68	83	49
Total units production	44	56	60	56	22	46	40	20	32
Total units rejected	0	0	0	0	0	0	0	0	0
Total good units produced	44	56	60	56	22	46	40	22	32
Total planned production time	128	120	168	120	72	144	96	96	72
Total operating time(in hrs)	32	37	43	38	15	31	28	13	23
Machine availability (%)	25	30.83	25.59	31.66	20.83	21.52	29.16	13.54	31.94
Performance (%)	68.75	75.67	69.76	73.68	73.33	74.19	71.42	76.92	69.56
Quality (%)	100	100	100	100	100	100	100	100	100
OEE (%)	**17**	**22.5**	**17.25**	**22.63**	**14.6**	**15.54**	**20.59**	**9.88**	**21.39**

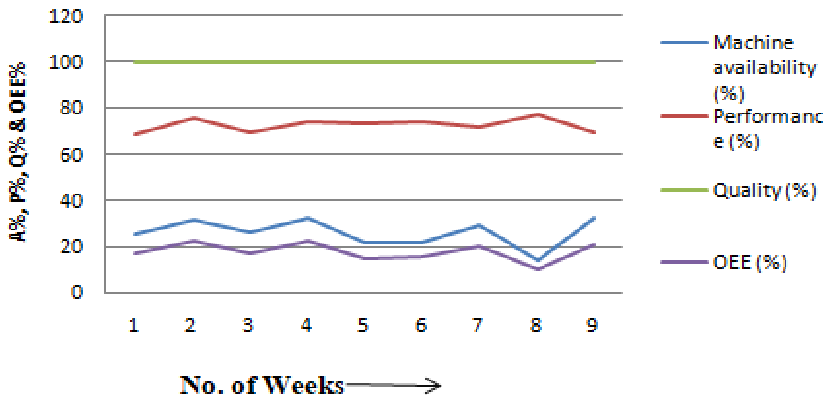

Fig. 3. Weekly variation of availability, performance, quality and OEE for USG

Table 4. OEE of X-Ray Manual machine for nine weeks

Production Parameters ↓ / Weeks →	1	2	3	4	5	6	7	8	9
Total time (in hrs)	120	144	120	144	121	144	120	120	96
Machine Downtime (in hrs)	79	113	82	93	105	116	90	94	78
Total units production	25	17	20	45	8	15	17	14	7
Total units rejected	0	0	0	0	0	0	0	0	0
Total good units produced	25	17	20	45	8	15	17	14	7
Total planned production time	120	144	120	144	121	144	120	120	96
Total operating time(in hrs)	41	31	38	51	16	28	30	26	18
Machine availability (%)	34.16	21.52	31.66	35.41	13.22	19.44	25	21.66	18.75
Performance (%)	30.48	27.41	26.31	44.11	25	26.75	28.33	26.92	19.44
Quality (%)	100	100	100	100	100	100	100	100	100
OEE (%)	**10.2**	**5.67**	**8.06**	**15.4**	**3.25**	**4.94**	**7**	**5.46**	**3.42**

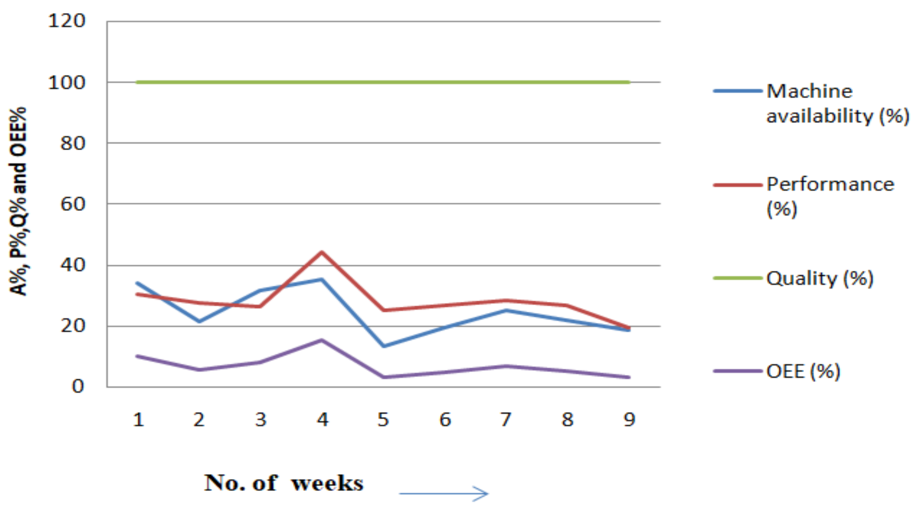

Fig. 4. Weekly variation of availability, performance, quality and OEE for X-Ray Manual

Table 5. OEE of Electrocardiogram (ECG) machine for nine weeks

Production Parameters ↓ / Weeks →	1	2	3	4	5	6	7	8	9
Total time (in hrs)	144	144	168	94	164	173	166	165	54
Machine Downtime (in hrs)	6	6	29	1	11	26	7	10	8
Total units production	220	221	240	110	238	222	225	224	65
Total units rejected	0	0	0	0	0	0	0	0	0
Total good units produced	220	221	240	110	238	222	225	224	65
Total planned production time	144	144	168	94	164	173	166	165	54
Total operating time(in hrs)	138	138	139	93	153	147	159	155	46
Machine availability (%)	95.83	95.83	82.73	98.93	93.29	84.97	95.78	93.93	85.18
Performance (%)	79.71	80.07	86.33	59.13	77.77	75.51	70.74	72.25	70.65
Quality (%)	100	100	100	100	100	100	100	100	100
OEE (%)	**75.05**	**76**	**70.52**	**57.82**	**71.61**	**63**	**66.5**	**66.96**	**59.5**

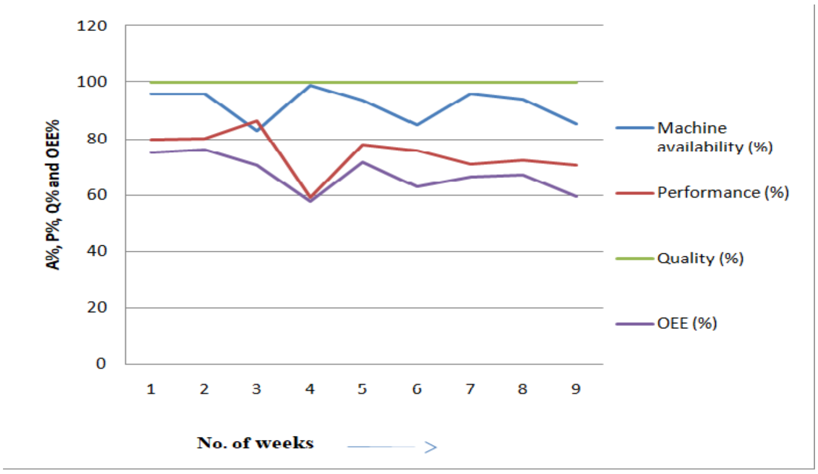

Fig. 5. Weekly variation of availability, performance, quality and OEE for ECG

Table 6. OEE of Computerized Tomography (CT – Scan) machine for nine weeks

Production Parameters ↓ / Weeks →	1	2	3	4	5	6	7	8	9
Total time (in hrs)	168	120	168	144	72	168	168	120	48
Machine Downtime (in hrs)	11	40	10	3	5	5	4	30	0
Total units production	219	120	252	197	93	244	229	135	67
Total units rejected	0	0	0	0	0	0	0	0	0
Total good units produced	219	120	252	197	93	244	229	135	67
Total planned production time	168	120	168	144	72	168	168	120	48
Total operating time(in hrs)	157	80	158	141	67	163	164	90	48
Machine availability (%)	93.45	66.66	94.04	97.91	93.05	97.02	97.61	75	100
Performance (%)	69.74	75	79.74	69.85	69.40	74.84	69.8	75	69.79
Quality (%)	100	100	100	100	100	100	100	100	100
OEE (%)	**64.17**	**49.5**	**74.26**	**66.93**	**64.17**	**71.78**	**66.93**	**56.25**	**69**

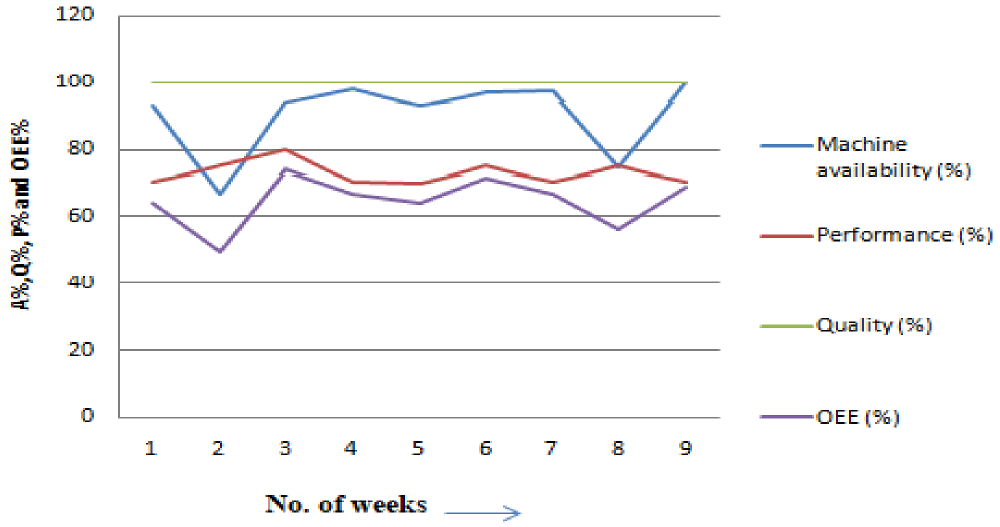

Fig. 6. Weekly variation of availability, performance, quality and OEE for CT- Scan

Actual number of hours for which biomedical equipment is utilised, maximum number of hours for which equipment can be used, along with corresponding UC calculated for each equipment, are mentioned from Tables 7 to 11. The average UC of five equipment are shown in Fig. 9 in the form of bar chart. From this chart it is observed that, Ultrasonography (USG) has maximum average use coefficient of 31.02, whereas X-Ray Manual and CT Scan has UC of 30.3 and 23.33 respectively. The Electrocardiogram (ECG) has average UC of 21.34 and 19.11 is the UC of Magnetic Resonance Imaging (MRI) which is underutilized and has the least UC among the all. Also weekly variations of utilization coefficients of MRI, USG, X-Ray Manual, ECG and CT Scan are shown in Figure 10 for understanding of utilization of the machines for consecutive nine weeks. This may help to increase the utilization of the equipment by taking some appropriate strategies.

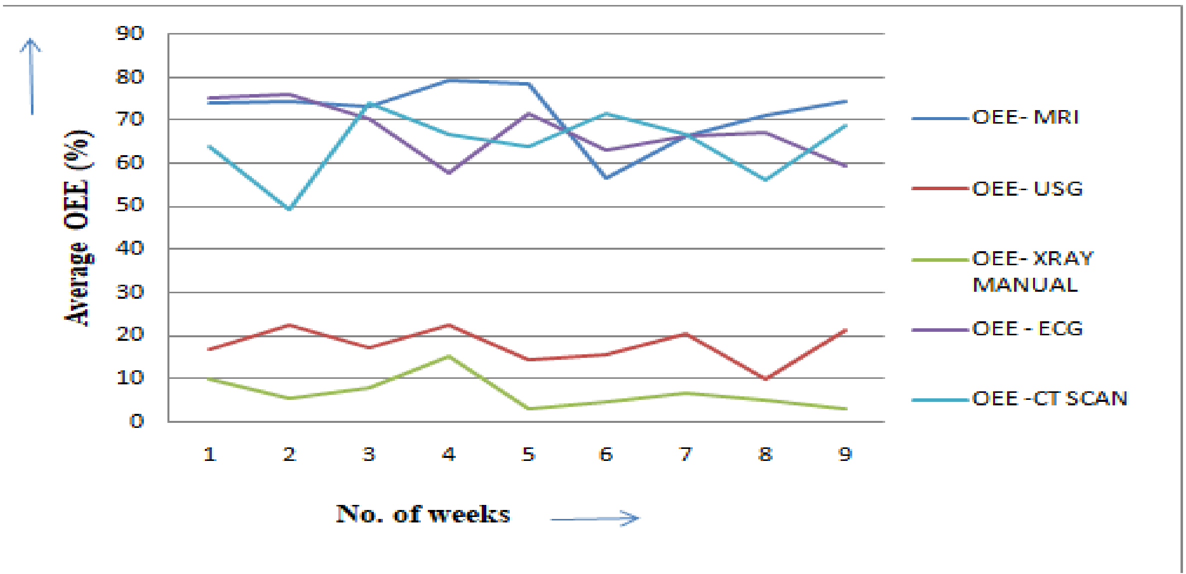

Fig. 7. Variation of average OEE for biomedical equipment

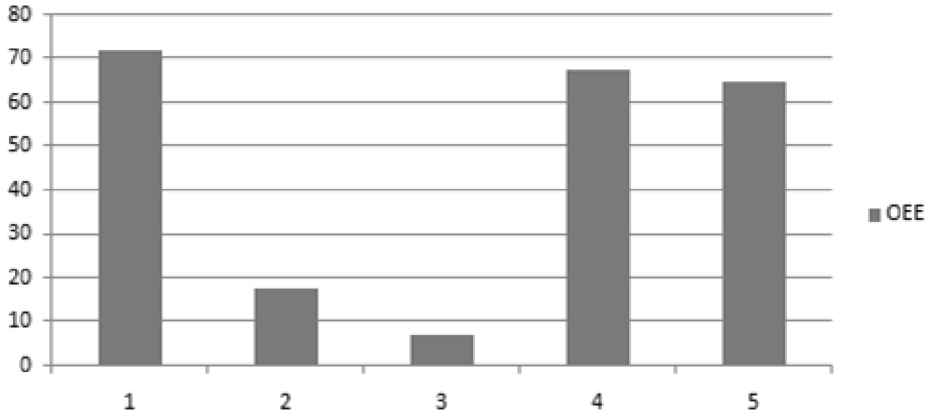

Fig. 8. Average OEE of five biomedical machines
(1- MRI, 2- USG, 3- X Ray Manual, 4-ECG, 5- CT Scan)

Table 7. Utilization coefficient of Magnetic Resonance Imaging (MRI)

UC of equipment ↓ Week →	1	2	3	4	5	6	7	8	9
Actual number of hours used	24	18	24	24	23	24	24	24	24
Maximum number of hours used	144	156	144	148	152	113	105	122	74
Utilization coefficient (UC)	**16.6**	**11.5**	**16.6**	**16.2**	**15.1**	**21.2**	**22.8**	**19.6**	**32.4**

Table 8. Utilization coefficient of Ultrasonography (USG)

UC of equipment ↓ Week →	1	2	3	4	5	6	7	8	9
Actual number of hours used	8	9	8	9	9	8	9	4	9
Maximum number of hours used	32	37	43	38	15	31	28	13	23
Utilization coefficient (UC)	**25**	**24.3**	**18.6**	**23.6**	**60**	**25.8**	**32.1**	**30.7**	**39.1**

Table 9. Utilization coefficient of X-Ray Manual

UC of equipment ↓ Week →	1	2	3	4	5	6	7	8	9
Actual number of hours used	12	7	12	20	5	8	8	8	6
Maximum number of hours used	41	31	38	51	16	28	30	26	18
Utilization coefficient (UC)	**29.2**	**22.5**	**31.5**	**39.2**	**31.2**	**28.5**	**26.6**	**30.7**	**33.3**

Table 10. Utilization coefficient of Electrocardiogram (ECG)

UC of equipment ↓ Week →	1	2	3	4	5	6	7	8	9
Actual number of hours used	24	24	24	24	24	24	24	24	24
Maximum number of hours used	138	138	139	93	153	147	159	155	46
Utilization coefficient (UC)	**17.3**	**17.3**	**17.2**	**25.8**	**15.6**	**16.3**	**15.09**	**15.4**	**52.1**

Table 11. Utilization coefficient of Computerized Tomography (CT Scan)

UC of equipment ↓ / Week →	1	2	3	4	5	6	7	8	9
Actual number of hours used	24	18	24	24	23	24	24	24	24
Maximum number of hours used	157	80	158	141	67	163	164	90	48
Utilization coefficient (UC)	**15.2**	**22.5**	**15.1**	**17.02**	**34.3**	**14.7**	**14.6**	**26.6**	**50**

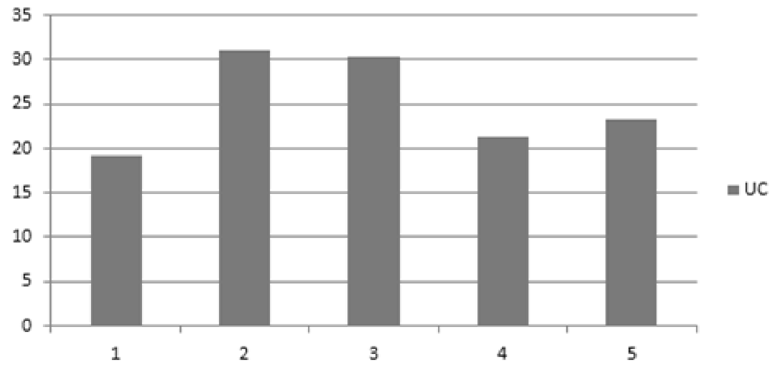

Fig. 9. Average Utilization coefficient (UC) of machines :
1 – MRI, 2- USG, 3- X-Ray Manual, 4- ECG, 5- CT Scan

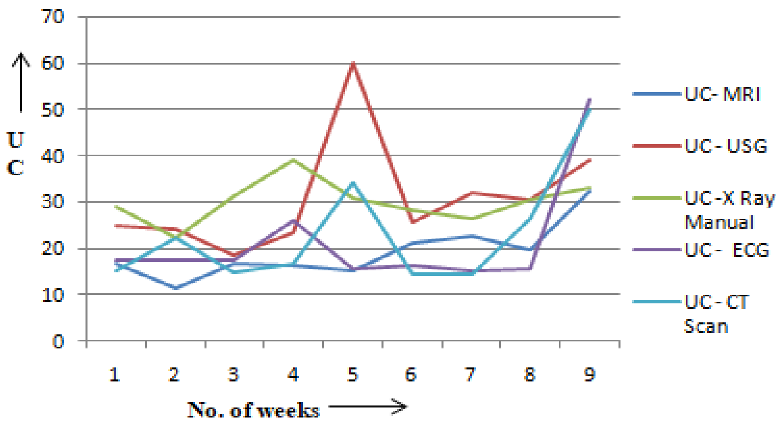

Fig. 10. Weekly variation of Utilization coefficient (UC) of five biomedical machines

Failure probability and reliability of the selected equipments has been also analysed with the consideration of operating hours, breakdown hours and number of failures. For these, data have been collected for the selected equipments from the hospital for consecutive 63 days. Failure probability for the selected equipment has been estimated by the following Equations (7), (8) and (9).

$$R_{x,f(x)} = \frac{p}{q} \quad (7)$$

$$p = \sum[xf(x)] - \frac{[\sum x \, X \sum f(x)]}{N} \quad (8)$$

$$q = \sqrt{\left[\sum(x^2) - \frac{(\sum x)^2}{N}\right]\left[\sum f(x^2) - \frac{\{\sum f(x)^2\}}{N}\right]} \quad (9)$$

where,

$R_{x,f(x)}$ = Correlation coefficient

x= breakdown hour (in hours)

f(x) = Cumulative % failure (calculated from number of failures per day and sum of number of failures for 63 days).

N = Sum of operating hours for 63 days (in hours).

Reliability function for the equipments has been calculated by using Equation (10).

$$R(t) = 1 - F(t) = 1 - \int_0^t f(t)dt \quad (10)$$

The cumulative density function for reliability is denoted as F(t) which is also related to failure probability and in combination with the fact that the area under the probability density function is always equal to 1 (Kar & Pal, 2019). Probability density function of time to failure is denoted by f(t), 't' is the operating time. Table 12 represents the corresponding results of the failure and reliability analysis of the selected equipments.

Table 12. Failure Probability and Reliability of Biomedical Equipments

Name of the equipments	Failure Probability	Reliability (in %)
Magnetic Resonance Imaging (MRI)	0.4342	56.58
Ultrasonography (USG)	0.7523	24.77
X- Ray Manual	0.8027	19.73
Electrocardiogram (ECG)	0.5224	47.76
Computerized Tomography Scan (CT- Scan)	0.5358	46.42

4.2 DISCUSSION

The average OEEs of the five machines in the form of a bar chart is shown in Figure 8 to analyse the comparative efficiency of the machines in the radiology unit. The average OEE of MRI is 72%, USG is 17.93%, X-Ray Manual is 7.04%, ECG is 67.44% and CT Scan is 64.77%. OEE of these equipment is found to be less than the world class standard of 85%. In X-Ray Manual where OEE is minimum, the major downtime reasons are due to tube leakage, IC Circuit breakdown and transformer breakdown. These processes form a major part of the system and cannot be eliminated. The usage of the X-Ray machine is found to be comparatively high due to non-availability of any other types (particularly digital X-Ray) of bone scanning machines. Moreover, X-Ray machine is used for outdoor patients and emergency services. Since this machine forms the initial part of the bone fracture treatment process, it requires adequate time for patient preparation thus leading downtime. Since its effectiveness is very low, it requires a schedule maintenance planning. The strategy for schedule maintenance planning should be adapted by estimating the maintenance duration and further re-estimating with re-evaluation of the downtime in terms of availability. This approach of increasing availability and maintainability may help to improve the overall effectiveness of X-Ray machine. In Ultrasonography (USG), the major downtime reason is due to the hardware failures, software corruption and defects in ultrasound probes. Make ready and cleaning processes also increases the downtime sufficiently. In CT scan, the main reason for the downtime is due to malfunction of the machine, tube failure and circuit fault. For the equipment MRI, OEE value suggests a comparatively high efficiency but below the world class standard value. The major downtime of the machine is due to image artifacts, intense vibration and poor cooling.

From OEE results it is seen that the quality (%) for all the machines is as per with the standard value. So it can be postulated that OEE of these machines can be increased by improving availability and performance ratio. If output of the medical equipment improves then the productivity can be improved as well as the total productivity. Productivity can be related to OEE, as OEE improves means output increases, so does productivity.

It is also observed from Figure 9 that all the equipment in the radiology unit of the hospital are having the utilization coefficient below 50%. It indicates that the equipment can be regarded as bad investment. If the utilization coefficient is found to be greater than 50%, the equipment can be regarded as good investment.

To ensure optimum utilization of the equipment, networking with other hospitals and also a marketing strategy can be developed where services can be provided to the society to gain maximum benefits of the capital invested.

The weekly variations of OEE of five equipment as shown from Figures 2 to 6 indicate that the quality rate for all the machines is 100% that means the equipment are producing good pieces. Whereas the availability and performance ratio for all the machines are found to be far below the standards of 90% availability and 95% performance ratio. It can be assumed that the equipment under investigations need more strategically maintenance planning to reduce losses like breakdown, downtime, speed, start-up etc. Figure 7 shows the comparison of effectiveness of all the five machines. This in turn may help to prioritize the equipment for better performance.

Variation of utilization coefficient of all the equipment as shown in Figure 10 indicates a notable fluctuation with weeks. This shows that the equipment merely crosses 50% of the utilization coefficient. So, appropriate strategies should be taken for optimum utilization of the equipment to make this as good investment.

For validation of the analysis of effectiveness and utilization of the selected equipments, failure probability and percentage reliability of the machines has been determined. It is observed that for lowest effectiveness of X-Ray machine has the highest failure probability whereas MRI has the highest effectiveness with lowest failure probability. Finally, it can be said that MRI is more reliable while X-Ray Manual is comparatively less reliable. Moreover, data collection for longer duration of time would give more accurate results.

5. CONCLUSION

OEE is a powerful tool to identify previously hidden treatment losses and inefficiencies. Tracking OEE scores and using them to drive improvements in treatment processes is a vital step towards world-class lean treatment for hospitals. OEE systems provide the rich functionality necessary to expose exactly what percentage of production time is truly productive and to dig deeper to reveal the causes of lost productivity. Even increasing the OEE score by 1% can lead to dramatic savings and turn-around lost production time into a positive contribution to profit. Value of OEE is observed to be maximum in Magnetic Resonance Imaging (MRI) machine which is not frequently used. Ultrasonography (USG) is the most frequently used machine owing to its high usage, downtime is more hence OEE is less. The variation of the OEE also gives the hospital where they are and where is the weakness point and how to improve.

The various problems occurring in the hospital can be resolved or prevented from causing unwanted troubles leading to decrease the overall efficiency of the system. The sequencing of jobs plays an important role in saving time. The sequencing of jobs depends not only on the operator but also on the condition of patients. Thus the planned number of hours is not saved by the hospital which therefore leads to drop the overall efficiency of the machine. Hence sequencing of jobs needs to be improved for better results.

The proposed methodology influences not only maintenance management but also knowledge management because it is quantitative method to estimate equipment effectiveness and utilization validated by failure probability and reliability. Finally, this quantitative assessment support top hospital management in complying with the requirements of quality management standard.

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