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Performance measurement using overall equipment and resource effectiveness - A concrete block manufacturing case study

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Abstract

Companies are required to integrate a set of critical dimensions to measure and evaluate their performance to compete in globally competitive markets. Overall Equipment Effectiveness (OEE) and Overall Resource Effectiveness (ORE) are two quantitative metrics attempt to measure and improve the effectiveness of manufacturing operations. This study aims to use the concept of OEE and ORE to evaluate and monitor the performance of a concrete block manufacturing system at Dler Company in Iraq. The study was conducted in two years of operation during 2016 and 2017. Results from 2016 show that the level of effectiveness was lower than the world-class. An improvement in the average value of the OEE for 2017 was recorded, where the OEE value is increased in 2017 to 75% in comparison with its value in 2016 which was 67%. While the ORE value is increased in 2017 to 66% in comparison with its value in 2016 at 59%. It was also found that the reasons for this improvement are due to the enhancement that is made in the availability and quality.

Keywords: Overall Equipment Effectiveness; Overall Resource Effectiveness; Concrete Block Manufacturing; Total Productive Maintenance

1. Introduction

Numerous metrics are utilized by companies to evaluate their performance to keep their position stable in globally competitive markets [1]. Industries are unable to identify opportunities to improve their performance unless they collect and analyse the relevant data of their current performance [2]. However, selecting the right metrics by decision-makers of the company is necessary to give them the right information that is needed to continuously improve and refine their business. Schmenner and Vollmann [3] discussed the negative potentials of using wrong measures or using the right measures in the wrong way. In some cases, measurement systems that are used by companies are not sufficient enough to provide a big picture of their performance. Therefore, a comprehensive and effective measurement system is needed which is integrated with a set of critical dimensions for measuring and evaluating the manufacturing performance [4]. In this way, Total Productive Maintenance (TPM) is a systematic approach, developed by Nakajima [5] in 1988, focuses on maximizing the equipment effectiveness. Overall Equipment Effectiveness (OEE) is a quantitative metric, in

Nomenclature			
A	Availability	ORE	Overall Resource Effectiveness
A_f	Availability of Facility	P	Performance
A_m	Availability of Material	Q	Quality
A_{mp}	Availability of Manpower	R	Readiness
C	Changeover Efficiency	TPM	Total Productive Maintenance
OEE	Overall Equipment Effectiveness		

the context of TPM, attempts to measure and improve the effectiveness of manufacturing operations [6]. The OEE play an essential role in developing integration between different operations to indicate and eliminate the hidden costs that reduce the company's profitability [7] [8]. It measures the productivity of equipment in a factory in three important dimensions namely availability, performance rate and quality rate. It can also be used to analyse the efficiency of a single machine or an integrated machinery system [9]. The OEE is not just used to measure the performance of the manufacturing system, it can also be used as an indicator to compare the initial performance of the manufacturing system and the future performance which gives the top manager the information to evaluate the level of improvement That has been made by the company. Further, it can be used to compare between different production lines within the company and highlights any causes that reduce the manufacture performance [10]. According to Eswaramurthi and Mohanram [16], OEE has a problem which is no separate metric to discover the losses that raise from non-availability of manpower and material (components and sub-assemblies). These factors are considered important for measuring the effectiveness of a manufacturing system. In this way, Overall Resource Effectiveness (ORE) is developed as an alternative measure derived from OEE to provide decision-makers with more complete information about the effectiveness of manufacturing. This study aims to describe the OEE and ORE first, and then to use them to evaluate and improve the performance of a concrete block production system at Dler Company in Iraq.

2. Literature Review

Different measurement tools are used by top managers to analyse, discover losses and check the performance of their manufacturing system. OEE was proposed by Nakajima (1988) [5] as an approach to evaluate the improvement that is achieved through TPM philosophy. One of the reasons that make OEE increasingly used as a measure of performance in manufacturing environments is its ability to integrate three important factors of performance (i.e. availability, performance and quality) within a single measure. Applications of OEE for improving production process can be found in many fields including metal profiles [4], steel company [11], wire mesh manufacturing [2], salt company [12], injection moulding process industry [13], and yoghurt production line [14]. Eswaramurthi and Mohanram [16] proposed a new method to calculate the effectiveness of manufacturing process that differs from OEE and includes new factors known as Readiness, availability of facility, changeover efficiency, availability of material, and availability of manpower. They name the new index as ORE since the new methodology addressed the losses that are associated with the resources (i.e. material and manpower). Abdullah and Dawood [8] employed OEE and ORE to evaluate the effectiveness of the manufacturing process of AL-Kufa Cement plant in Iraq. The outcome of the study shows that the finish grinding process has the lowest factors in terms of performance, quality rate, availability of material, readiness, and availability of facility which lead to decrease OEE and ORE performance indicators at 65.02 % and 15.45% respectively. In the same way, Sahib and Dawood [15] investigated the effective elements of OEE and ORE of the continuous production system at Baghdad Company for Soft Drinks for two consecutive years. The results showed that OEE value has been reduced from (11%) at 2014 to (9%) in 2015, while ORE value has been reduced from (8%) in 2014 to (7%) in 2015. The study recommended to employ TPM in the production line and to conduct systematic maintenance activities and increase productivity.

3. Theoretical Background

3.1 Overall Equipment Effectiveness (OEE)

OEE is a three dimensions measurement tool (availability, performance, and quality) developed under the context of TPM in 1988 to evaluate the equipment performance. In other word, OEE measures the degree by which the equipment is achieving what it is expected to achieve [9]. The objective of OEE is to determine losses that reduce equipment performance. These losses can be classified into six big losses as given below [5]:

- Downtime losses
  - Breakdown losses are considered as time losses and quality losses.
  - Set-up and adjustments losses which happen when the production is switched from one item to another.
- Speed losses
  - Idling and minor stoppage which happened when the production process is interrupted by a temporary malfunction or the machine is being idle.
  - Reduced speed losses that resulted from the difference between the stated equipment speed and actual operation speed.
- Quality losses
  - Quality defects due to malfunction production equipment.
  - Start-up losses that occur during the early stages of production.

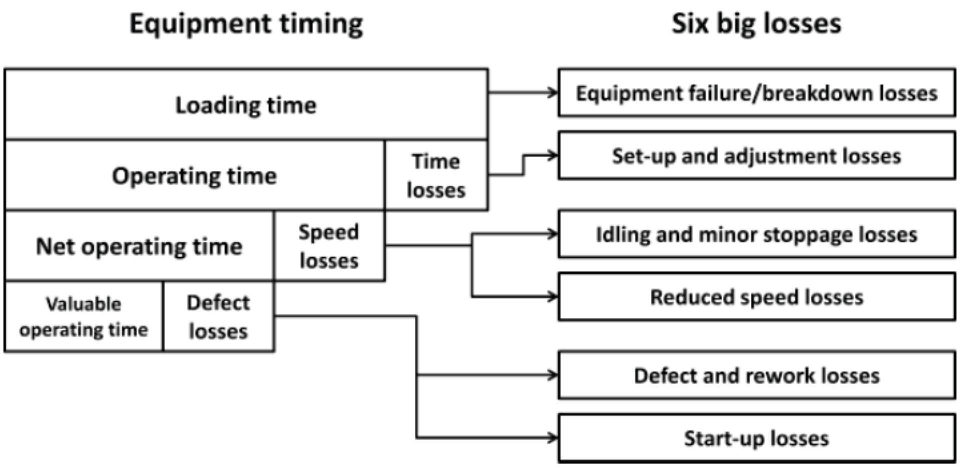

Fig. 1 Relationship between equipment timing and the six big losses [2]

Fig. 1 illustrates the relationship between equipment timing and the six big losses. OEE can be measured based on the following equation [1]:

$$OEE = A \times P \times Q \tag{1}$$

where A, P and Q denote to the availability, performance and quality respectively. The next section provides the formula and brief description of each element in the OEE equation.

3.1.1 Availability

The availability is a measure of total stoppages such as breakdowns, unplanned downtime, process set-up and changeovers. It can be calculated from the following equations [10]:

$$Availability\ (A) = \frac{Actual\ Operation\ Time}{Planned\ Operating\ Time} \times 100\% \tag{2}$$

$$Planned\ Operating\ Time\ = Total\ Operating\ Time\ - Planned\ Downtime \tag{3}$$

$$Actual\ Operation\ Time\ = Planned\ Operating\ Time\ - Breakdown\ Time \tag{4}$$

Where total operating time is the designed shift time which is determined by the company. Planned Downtime includes prepared work like cleaning, an inspection of the machine, initial part inspection, lubrication, tightening.

3.1.2 Performance

Performance is the second element in the OEE equating. This index is a ratio between the actual production rates and the theoretical production rates. It can be calculated from the following equations [10]:

$$Performance\ (P) = \frac{Actual\ products}{Theoretical\ \ products} \times 100\% \tag{5}$$

$$Theoretical\ \ products = \frac{Actual\ Operation\ Time}{Cycletime\ per\ product} \tag{6}$$

3.1.3 Quality

Quality is the last element in the OEE equation. It measures the percentage of good output units. It can be calculated from the following equations [10]:

$$Quality\ (Q) = \frac{Good\ products}{Actual\ products} \times 100\% \tag{7}$$

$$Good\ products = Actual\ products - Defects \tag{8}$$

3.2 Overall Resource Effectiveness (ORE)

ORE is another tool which measures the overall effective time of the manufacturing system resources. ORE can be used as a supportive tool to decision-makers for additional analysis and enhancement of performance resources. ORE is calculated as follows:

$$ORE = R \times A_f \times C \times A_m \times A_{mp} \times P \times Q \tag{9}$$

where $R, A_f, C,\ A_m, A_{mp}, P$ and Q denote to the readiness, availability of facility, changeover efficiency, availability of material, availability of manpower, performance and quality respectively. The next section provides the formula and brief description of each element in the ORE equation.

3.2.1 Readiness

The readiness measure is concerned with the total time that the system is not ready for the operation due to the planned downtime.

$$Readiness\ (R)\ = \frac{Planned\ Production\ Time}{Total\ Operating\ Time} \tag{10}$$

where total operating time is the designed shift time by the company. Planned Operating Time can be calculated from Eq. (3).

3.2.2 Availability of Facility

The availability of facility measure is concerned with the total time that the system is not operating because of the downtime of facilities such as non-availability of tools, jigs and fixtures, and non-availability of gauges and instruments.

$$Availability\ of\ Facility\ (A_f) = \frac{Loading\ Time}{Planned\ Operating\ Time} \tag{11}$$

$$Loading\ Time\ = Planned\ Operating\ Time\ \ - Facility\ Downtime \tag{12}$$

3.2.3 Changeover Efficiency

The changeover efficiency measure is concerned with the total time that the system is not operating due to the setup and adjustments.

$$Changeover\ Efficiency\ (C) = \frac{Operating\ Time}{Loading\ Time} \tag{13}$$

3.2.4 Availability of Material

In some cases, the manufacturing process stops due to the shortage in the raw materials, components, subassemblies. Thus, the availability of material measure is concerned with the total time that the system is not operating because of these shortages.

$$Availability\ of\ Material\ (Am)\ = \frac{Running\ Time}{Operating\ Time} \tag{14}$$

$$Running\ Time\ = Operating\ Time\ \ - Material\ shortages \tag{15}$$

3.2.5 Availability of Manpower

In some cases, the manufacturing process stops due to the absence of the manpower for some reason such as leave, discussion with supervisor and medical-related issues.

$$Availability\ of\ Manpower\ (Amp)\ = \frac{Actual\ Running\ Time}{Running\ Time} \tag{16}$$

$$Actual\ Running\ Time\ = Running\ Time\ - Manpower\ absent\ time \tag{17}$$

3.2.6 Performance

Performance is calculated as OEE in Eq. 5

3.2.7 Quality

The Performance is calculated as OEE in Eq. 7

4. Evaluation equipment in Dler Company

The production of a concrete block at Dler Company in Iraq has been taken as a case study for this research. The study was conducted in two years of operation during 2016 and 2017 to evaluate and improve the production system efficiency using OEE and ORE. Concrete block (sometimes called cement brick) are bricks widely used in construction. Dler Company uses highly automated manufacturing machines as shown in Fig. 2 that can produce up to 1,000 concrete block per hour. The company produces various types of concrete block as shown in Fig. 3 which could be used in different types of constructions. The concrete block selected for this study has a size of 20 cm by 20 cm by 40 cm with two cubic hollows. Fig. 4 shows the mould of the selected concrete block and Fig. 5 shows the production process. The manufacture process at Dler Company of concrete hollow blocks contains the following five steps:

1. **1.** Proportioning: this step is concerned with the selection of suitable amounts of raw materials required to produce blocks with desired quality.
2. **2.** Mixing: The objective of this step is to mix aggregates, cement and water so that the cement-water paste completely covers the surface of the aggregates. The mixer is rotated for about 1 ½ minutes.
3. **3.** Forming (moulding): in this step, an automatic machine is used for making blocks. The machine consists of an automatic vibrating unit, a lever operated up and down metallic mould box and a stripper head contained in a frame work.
4. **4.** Curing: in this step, bocksare removed from the mould and hardened to permit handling without damage. Then, blocks are cured in a curing yard for at least 21 days.
5. **5.** Drying: After curing is over, the blocks should be allowed to dry out gradually in the shade for 7 to 15 days before they are used in the construction work.

Fig. 2. Concrete block machine

Fig. 3. Variety types of concrete block at Dler Company

(a) (b)

Fig. 4 (a) Mould of the selected concrete block,(b) Shape of the selected concrete block

Fig. 5 Production process

Table 1. Data measurement for 2016 and 2017

Year	***Month***	***Total Operating Time*** (***hr***.)	***Planned Downtime*** (***hr***.)	***Breakdown Time*** (***hr***.)		***Actual Operation Time*** (***hr***.)	***Actual products*** ($\mathbf{10^3}$)	***Defects***
				UPM*	S+A**			
2016	Jan	480	50	55	5	370	350	9
	Feb	460	50	90	10	310	290	10
	Mar	480	50	66	9	355	340	15
	Apr	480	40	73	10	360	340	12
	May	480	50	55	5	370	340	20
	Jun	480	50	63	5	360	305	30
	July	480	60	48	2	370	240	40
	Aug	480	50	65	10	360	320	25
	Sep	480	50	77	3	350	310	20
	Oct	300	50	52	8	190	150	15
	Nov	480	50	70	10	360	340	40
	Dec	480	80	77	13	310	280	30

2017	Jan	480	50	45	5	380	360	9
	Feb	460	45	43	7	365	330	18
	Mar	480	50	38	2	390	350	7
	Apr	480	60	50	10	360	340	9
	May	480	50	48	12	370	345	10
	Jun	480	50	60	10	360	330	12
	July	480	50	40	5	385	300	20
	Aug	480	50	41	4	385	340	10
	Sep	480	50	33	7	390	350	20
	Oct	300	50	15	5	230	200	2
	Nov	480	50	20	10	400	300	18
	Dec	480	70	36	4	370	310	10

* UPM: unplanned maintenance

** S+A: setup and adjustments

Before implementing the evaluation process, a training session has been given to workers at Dler Company to educate them about the theoretical aspect of OEE and ORE so they know what things need to be measured and how it should be measured. For example, how to calculate the breakdown time, production rate and defects. After that, the data was collected monthly to perform the OEE and ORE calculations. The software Excel was used to do the calculations and plot graphs.

5. Results and Discussion

All the required information to calculate OEE and ORE of the concrete block production line at Dlar Company for 2016 and 2017 are collected and summarised in Tables 1 and 2. It can be seen from Table (1) that the first column is the total operating time which is fixed at 480 hr. /month and it is calculated as follows (2 shift/day × 8 hr. /shift × 30 day/month= 480 hr. /month) except February 2016 and 2017 was 460 hr. /month and October 2016 and 2017 was 300 hr. /month. The second column is the planned downtime and it is calculated from cleaning, official production breaks and meeting time. The third column is the breakdown time. It was divided into unplanned maintenance time (i.e. mechanical breakdown and electrical breakdown) and setup and adjustment time. Moreover, Table (2) presents the data of material shortages and absent of manpower

Table 2. Data measurement for material shortages and absence of manpower for 2016 and 2017

Month	2016		2017	
	Material Shortages $(hr.)$	Absence of Manpower $(hr.)$	Material Shortages $(hr.)$	Absence of Manpower $(hr.)$
Jan	1	1	2	2.5
Feb	4	2	1	2
Mar	2.5	0.5	3.0	1
Apr	5	2	2.5	0.5
May	3	1.5	1	1
Jun	2.5	0.5	0.5	1
July	1	1	2	2
Aug	2	2	4	1
Sep	4	1.5	3	2
Oct	2	1	1	0.5
Nov	2	1	2	0.8
Dec	5	2	4	1

Table 3 presents the calculation value of the availability, performance, quality, and the overall OEE for 2016 and 2017 associated with the changes in monthly basis according to equations 1 to 8. Fig. 5 plots the OEE for 2016 and 2017. Further, Table 4 compare the availability, performance, quality, and the overall OEE for 2016 and 2017 with world-class value.

Table 3. OEE values and its parameters values in a monthly basis for 2016 and 2017

Month	Availability			Performance			Quality			OEE		
	2016	2017	Change	2016	2017	Change	2016	2017	Change	2017	2017	Change
Jan	86	88	+2	95	95	0	97	98	+1	79	82	+3
Feb	76	88	+12	94	90	-4	97	95	-2	68	75	+7
Mar	83	91	+8	96	90	-6	96	98	+2	76	80	+4
Apr	82	86	+4	94	94	0	96	97	+1	75	79	+4
May	86	86	0	92	93	+1	94	97	0	74	78	+4
Jun	84	84	0	85	92	+1	90	96	+6	64	74	+10
July	88	90	+1	65	78	+13	83	93	+10	48	65	+17
Aug	84	90	+6	89	88	-1	92	97	+5	69	77	+8
Sep	81	91	+10	89	90	+1	94	94	0	67	77	+10
Oct	76	92	+16	79	87	+8	90	99	+9	54	79	+25
Nov	84	93	+9	94	75	-19	88	94	+6	70	66	-4
Dec	78	90	+12	90	84	-6	89	97	+8	63	73	+10
Avg.	82	89	+7	88	88	0	92	96	+4	67	75	+7

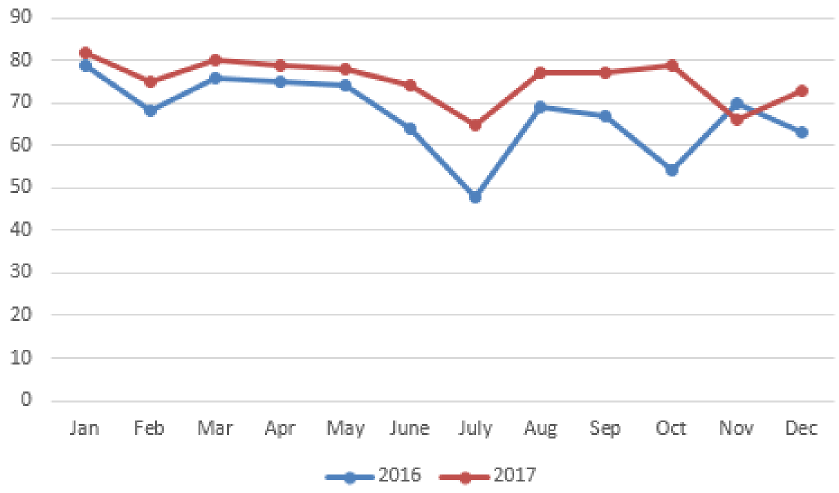

Fig. 6. OEE values in monthly basis during 2016 and 2017

Table 4 Comparison between OEE world class and the OEE in the production line for 2016 and 2017

OEE Factors	2016	2017	World Class
Availability	82%	89%	90%
Performance rate	88%	88%	95%
Quality rate	92%	96%	99%
OEE overall	67%	75%	85%

Table 5. ORE values and its parameters values in a monthly basis for 2016

Month	R	A_f	C	Am	Amp	P	Q	ORE
Jan	0.90	0.87	0.99	1.00	1.00	0.95	0.97	0.71
Feb	0.89	0.78	0.97	0.99	0.99	0.94	0.97	0.60
Mar	0.90	0.85	0.98	0.99	1.00	0.96	0.96	0.67
Apr	0.92	0.83	0.97	0.99	0.99	0.95	0.96	0.67
May	0.90	0.87	0.99	0.99	1.00	0.92	0.94	0.66
Jun	0.90	0.85	0.99	0.99	1.00	0.84	0.90	0.57
July	0.88	0.89	0.99	1.00	1.00	0.65	0.83	0.41
Aug	0.90	0.85	0.97	0.99	0.99	0.90	0.92	0.61
Sep	0.90	0.82	0.99	0.99	1.00	0.89	0.94	0.59
Oct	0.83	0.79	0.96	0.99	0.99	0.79	0.90	0.44
Nov	0.90	0.84	0.97	0.99	1.00	0.97	0.88	0.62
Dec	0.83	0.81	0.96	0.98	0.99	0.90	0.89	0.51
Avg.	0.89	0.84	0.98	0.99	1.00	0.89	0.92	0.59

OEE is considered an indicator that measures and improves the performance of a company. OEE can help to diagnose the main causes that lower the performance of a company based on the values of availability, performance rate and quality rate. Comparing the values of OEE for 2016 with the world-class value as given in Table (4) provides decision makers in Dler Company a motivation to implement TPM and improve the equipment effectiveness. As a result, the concrete block manufacturing shows an increase in the value of the OEE for the year 2017 in comparison with the year 2016, where the value of the OEE was 67% in 2016 and it became 75% in 2017. It was also found that the reasons for this improvement are due to the enhancement that are made in the availability and quality. For example, it can be seen from Table 3 that the availability has been increased significantly in Feb, Sep, Oct and Dec. In the same way, the OEE has been increased significantly in June, July, Sep, Oct and Dec.

Table 6. ORE values and its parameters values in a monthly basis for 2017

Month	R	A_f	C	Am	Amp	P	Q	ORE
Jan	0.90	0.90	0.99	0.99	0.99	0.95	0.98	0.72
Feb	0.90	0.90	0.98	1.00	0.99	0.90	0.95	0.67
Mar	0.90	0.91	0.99	0.99	1.00	0.90	0.98	0.71
Apr	0.88	0.88	0.97	0.99	1.00	0.94	0.97	0.68
May	0.90	0.89	0.97	1.00	1.00	0.93	0.97	0.69
Jun	0.90	0.86	0.97	1.00	1.00	0.92	0.96	0.66
July	0.90	0.91	0.99	0.99	0.99	0.78	0.93	0.58
Aug	0.90	0.90	0.99	0.99	1.00	0.88	0.97	0.68
Sep	0.90	0.92	0.98	0.99	0.99	0.90	0.94	0.68
Oct	0.83	0.94	0.98	1.00	1.00	0.87	0.99	0.66
Nov	0.90	0.95	0.98	1.00	1.00	0.75	0.94	0.58
Dec	0.85	0.91	0.99	0.99	1.00	0.84	0.97	0.62
Avg.	0.89	0.91	0.98	0.99	1.00	0.88	0.96	0.66

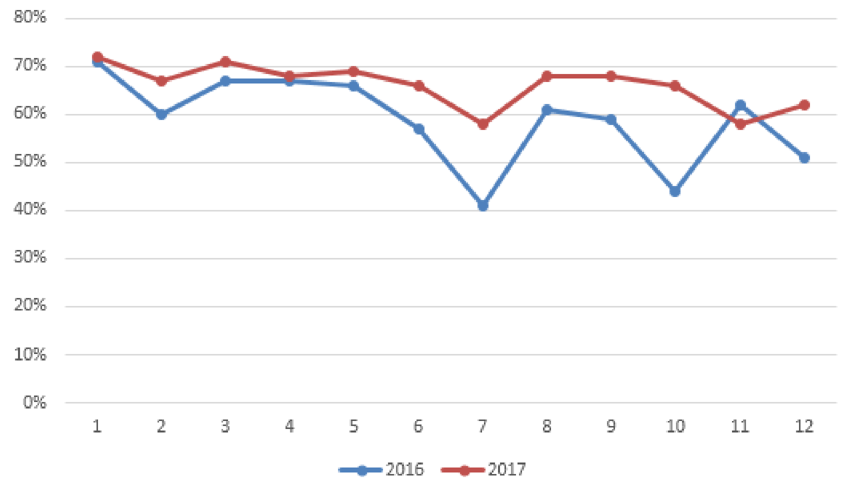

Fig. 7. ORE values in monthly basis during 2016 and 2017

In terms of ORE, Tables 5 and 6 present the value of the readiness, availability of facility, changeover efficiency, availability of material, availability of manpower, performance and quality and the overall ORE for 2016 and 2017 in a monthly basis according to Eqs. 9 to 17. Fig. 7 plots the ORE for 2016 and 2017. Comparing the value of ORE in Table 5 with its value in Table 6, it can be found that the concrete block manufacturing shows an increase in the value of the ORE for the year 2017 in comparison with the year 2016, where the value of the ORE was 59% in 2016 and it became 66% in 2017. It was also found that the reasons for this improvement are due to the enhancement that is made in the availability of facility and quality. It also can be seen that the availability of material and availability of manpower are very high and can be almost negligible.

6. Conclusions

Industrial companies are unable to improve their overall production performance unless they have precise information regarding their current production performance. Therefore, industrial companies are required to select appropriate measurement systems that provide a correct guide to improve the position of the company in the global market. Hence, the OEE and ORE are selected for this research as a measurement system to evaluate and improve the manufacturing performance of a company in Iraq and further to indicate potentials opportunity for improvement for the future. The two indices have been implemented for two consecutive years during 2016 and 2017. The main objective of these indices is to find out the major cause of production losse in the company and to suggest an appropriate strategy for decision makers by which these problems can be reduced. The study showed that the OEE and ORE for the production line were low in 2016 at 66% and 59% respectively. The top manager realized the root causes that reduce the company's efficiency form the result obtained from 2016. A systematic maintenance program has been performed to eliminate the causes. Eventually, the OEE was improved to 75% in 2017 and the ORE was improved to 66% in 2017.

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