Mining Science, vol. 30, 2023, 157–169

www.miningscience.pwr.edu.pl

Mining Science

(Previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798)

ISSN 2300-9586 (print)
ISSN 2353-5423 (online)

Received March 22, 2023; Reviewed; Accepted September 28, 2023

PERFORMANCE EVALUATION TO MEASURE PRODUCTION EQUIPMENT EFFECTIVENESS IN BLOCK CUTTING MACHINE (GANG SAW)

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Abstract: The demand for natural stone is increasing with the construction development in Turkey. In natural stone quarries, frame saws and circular saw machines are preferred for block production. Frame saw machine is also known as gang saw and it is the most commonly used for slab production in stone cutting factories. Therefore, gang saw machine selection is the most significant factor in the number of slabs, size of slabs, production time, and cost. Also, cutting machine performance is important because it can increase productivity and quality while reducing costs. Overall Equipment Effectiveness (OEE) is a crucial technique for measurement of the performance, availability, and quality of the machine. Production Equipment Effectiveness (PEE) is a method of losses owing to downtime, reduced speed, and quality. However, there is no study in the literature on how to use effectiveness for stone cutting machines such as gang saw machines, circular saw machines, bridge plate cutting machines, bridge plate polishing machines, etc. In this study, 3 gang saw machines have been carried out by evaluating both OEE and PEE. It determines the time losses. The estimation of OEE and PEE of gang saw machines have been presented via 23 blocks for every machine. As a result, OEE values have been calculated as 80% and PEE values have been calculated as 90%. This situation shows that this factory uses the equipment effectively and slabs are quality for sale.

Keywords: *gang saw machines, performance measurement, OEE, PEE, natural stone*

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doi: 10.37190/msc233010

1. INTRODUCTION

Nowadays, quality slab production is significantly demanded by natural stone industries. Therefore, cutting slabs with the gang saw machine is one of the most significant production processes. The gang saw machine is generally used for slab production when the block is regular. In addition, performance evaluation increases quality, productivity, and efficiency. Total productive maintenance (TPM) is an approach to increase equipment availability and efficiency. Overall equipment effectiveness (OEE) is the associated metric of TPM. It rates the real capability of machinery in production by comparing it with the optimal capacity, ideal cycle time, and zero-defect quality (Hung et al. 2022). The most important outcome of OEE is observing errors in the system that decreases the effectiveness of the machine. For every factory, the aim is to produce slabs at a profit with an effective maintenance system. While this system helps maximize the availability of equipment, machine downtime is minimized due to unwanted stoppage that affects the overall performance of the equipment (Ahmad et al. 2018).

Many researchers have studied the performance evaluation in block cutting machines. Haghshenas et al. (2019) proposed two new models to predict the maximum electrical current. The aim of the Haghshenas' study was to carry out the role of the gang saw machines in the productivity and efficiency of stone-cutting factories. Bayram and Kulaksız (2021) investigated the role of segment wear with physical and mechanical properties and advanced rate in productivity in stone processing plants. Also, they proposed a prediction chart to be used to provide effective cutting conditions in diamond segmented frame saws. Sakaoğlu (2008) focused on the productivity and effectiveness of the jig saws used in a processing plant. The reasons for the low performance were investigated and measures were proposed to increase the machine performances. Ersoy et al. (2012) investigated the productivity between block and rubble cutting and they concluded that block cutting is more efficient than rubble cutting because of size and shape of samples. Bilim (2012) carried out sawing performances of travertine blocks during cutting with a circular diamond saw. Cutting speed and energy consumption were measured to determine performance measurement. According to the results, the optimum speed was determined for the travertine mines. However, despite the cutting performance of the block cutting machines is examined, there is no study on the effectiveness of block cutting machines in the OEE and PEE approaches.

The basic aim of the study is to analyze the OEE and the PEE of the gang saw machines in Turkey. In this paper, it is applied entropy weighting method to improve the OEE and the PEE. As far as known, there is not any literature about OEE and PEE studies on the gang saw machine. Firstly, OEE, PEE, and gang saw machines have been introduced, the second part is about the entropy method applied to gang saw machines and gives the performance of the machines in tables, and lastly results and conclusion have been given.

2. OVERALL EQUIPMENT EFFECTIVENESS (OEE)

Overall Equipment Effectiveness (OEE) is a performance measurement technique to evaluate the effectiveness of equipments. OEE was initially introduced as part of TPM (total productive maintenance) in the late 1980s and early 1990s (Norden and Ismail 2012). OEE has become a renowned tool, therefore very less application of OEE is found in mining, especially in marble mining (Waqas et al. 2015). It is a good indicator and compares the performance with capacity and practices. OEE analysis optimizes the process which need improvement (Mohammadi et al. 2015).

The goal of OEE is measured the management of the equipment. The advantage of OEE is that it identifies the reasons of losses in equipment. Advancement of the OEE will be raised to productivity, profitability, and quality of mining in the future.

Nakajima (1988) introduced the concept of OEE to measure the performance of machine/equipment in manufacturing industries which considers the various sources of production losses. OEE is calculated by obtaining the product of availability, performance efficiency, and quality (Afefy 2013; Mohammadi et al. 2017).

$$OEE = Availability \times Performance\ Effectiveness \times Quality\ Rate. \tag{1}$$

The loss in availability of equipment involved equipment failure due to technical reasons in case of minor stoppages of equipment during operation. The loss in equipment performance included the loss in speed of equipment during the operation due to operator's inefficiency or substandard material. The defect of the quality accounted the losses in the product (Muchiri and Pintelon 2008; Waqas et al. 2015).

It is determined by the relation given below (Elevli and Elevli 2010; Afefy 2013; Waqas et al. 2015):

$$Avaliability\ (A) = \frac{Operating\ time}{Loading\ time} \times 100, \tag{2}$$

$$Operating\ time = Loading\ time - Down\ time, \tag{3}$$

$$Performance\ Efficiency\ (P) = \frac{Operating\ time - Speed\ losses}{Operating\ time} \times 100, \tag{4}$$

$$Quality\ (Q) = \frac{Total\ \ production - Defect\ amount}{Total\ \ production} \times 100. \tag{5}$$

In mining, utilization is used instead of quality, however in stone cutting factory quality component can be used in OEE because slab production is considered in marble trade. Literature review in mining industry has specified components which impacts equipment availability, utilization and production performance. Mining literatures on performance improvement and optimization of equipment operations assert importance of these components as key parameters. These three parameters are useful for evaluating effectiveness of equipment (Lanke et al. 2016). Utilization of equipment can only be improved and controlled successfully if an appropriate performance measurement system is used. OEE is a known method as a measurement performance of production equipment in manufacturing industries and adapted for mining industry (Elevli and Elevli 2010). The OEE can be modified with introduction of weight for each factor in mining application.

Raouf (1994) stated that Production Equipment Effectiveness (PEE) is similar to OEE considering all parameters are not equally important. A reliable and quantitative analytical method is needed to calculate and assign weights (w_1, w_2, w_3). One of the applicable approaches is to use the multifactorial decision making techniques (Koçak 2012; Lanke et al. 2016). The weighting process are objective weighting and subjective weighting. Decision in subjective weighting covers expert's evaluations while decision in objective weighting takes into account quantitative features (Bakır and Atalık 2018). Raouf (1994) suggested Production Equipment Effectiveness (PEE) as a new method using different weights that are defined below.

$$PEE = Availability^{w_i} \times Efficiency^{w_2} \times Quality^{w_3}, \tag{6}$$

$$w_1 + w_2 + w_3 = 1, \tag{7}$$

$0 < w_i < 1$,

w_i: weight of the parameters.

This study has been carried out for the determination of OEE and PEE of gang saw machines in stone cutting factory. The focus of this study was to determine effectiveness of equipment with different weights such as equal weighting method and entropy weighting method and give suggestions for improvement of the machine.

3. GANG SAW MACHINES

Gang saw machines cut the natural stone blocks completely at once. Gang saw machines have a rectilinear motion for the rapid sawing of marble blocks (Dormishi et al. 2019). These machines are available with 60, 80 and 100 blades. In this case, the number of blade saws is adjusted according to the plate thickness, and then the blade-group is lowered to a close distance to the top of the block, according to the height of the marble. Gang saw machines cut the block along its length and divide it into large slabs with pre-set thicknesses, thanks to the numerous flat saws that vertically cut the natural stone block placed in the cutting chamber. Because of these features, gang saw machines have become the constant and important machines of natural stone cutting factories. They cut the natural stone block placed in the cutting chamber in different thicknesses (plate thickness 2 cm, height 1.8 m and length around 3 meters) and slicing the block into large slabs (ganges) (Yıldırım 2019; SFERA Catalog).

Principle of the gang saw process is stated as move the reciprocating movement from the start point to the endpoint of a cutting stroke. The mutual cutting movement is generated by the rotation of a crank connected with a rod, which transfers the rotation to the horizontal movement of a frame. The feed motors drive the frame to move down for the blades cutting into the stone block continuously. The major factors affecting the frame sawing process are the dimensions of the blade; segment and stone; the value of blade pre-tension; the cutting performance of diamond and diamond segment; the properties of the stone and the cutting parameters limited by the power of frame sawing machine (Fig. 1). The cutting forces of the blade and the segments not only decide the energy consumption but also affect the deformation of the steel blade and the wear of the segments and diamonds. The stability of cutting will decide not only the surface quality of slabs, but also the numbers of the slabs split from a block (Wang ve Clausen 2003). In this paper, SIMEC, SFERA model with 800/100 blades gang saw machine is carried out as shown Fig. 2. Also, the technical features are represented in Table 1.

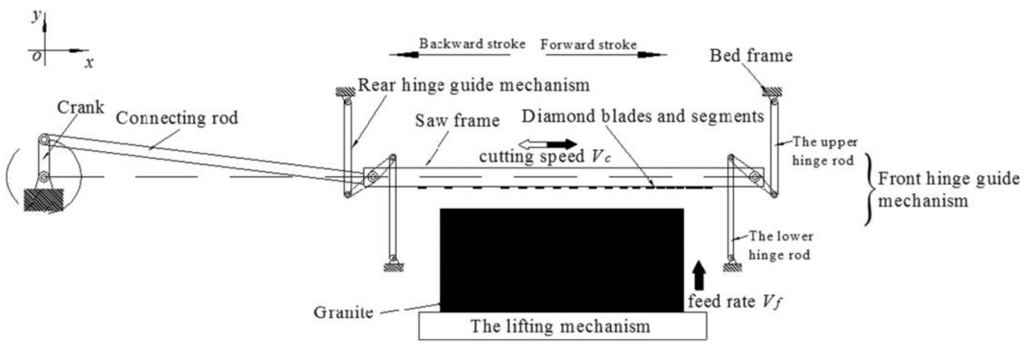

Fig. 1. Sawing System of the Gang Saw Machine
(Zhanga et al. 2018)

Fig. 2. Gang saw machine (SFERA Catalog)

Table 1. Technical data (SFERA catalog)

SFERA 800/100			
Maximum block width [mm]	2500	Block-carrying trolley motor power [kW]	1.8
Maximum block length [mm]	3500	Rapid raising/lowering motor power [HP]	9
Maximum block height [mm]	2050	Main motor power [kW]	160
Recommended blade dimensions [mm]	180 × 4650	Slow lowering motor power [kW]	1.8
Maximum number of blades [nº]	100	Rapid raising and rapid lowering speed [mm/min]	236
Strokes per minute [nº]	85	Machine width [mm]	5500
Blade stroke [mm]	800	Machine length [mm]	13 450
Total water requirement [Lt/min]	1000	Machine height [mm]	5100
		Whole machine weight [kg]	55 000

4. ASSESSMENT OF OVERALL EFFECTIVENESS OF GANG SAW MACHINE

23 blocks for every gang saw machine are taken for study. From the data and using the equation, OEE indicator and the components are calculated. In this paper, performance of three same gang saw machines cut 69 beige marble blocks are evaluated in block cutting factory in Burdur, Turkey. In accordance with the cutting plan, dimensional slabs of 23 blocks with 3 cm and 46 blocks with 2 cm thick were cut. Meanwhile, the time spent for each block and the amount of product obtained were noted. The results which are obtained from the factory are given in tables (Tables 2–4) as separately. Each block has been noted in thickness, width, length, height, number of slabs cut, number of quality slabs, and number of broken slabs. Added, amount of cut, quality, needs slabs in m^2, and work time, planned time, and unplanned time have been noted.

In Entropy Weighting Method m indicators and n samples are set in the evaluation. The first step is standardization of measured values. The standardized value is denoted as p_i, entropy value is defined E_i and the weight is denoted as w_i and this method is determined below (Zhu et al. 2020):

$$p_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}, \tag{8}$$

$$E_i = \frac{\sum_{j=1}^{n} p_{ij} \ln p_{ij}}{\ln n}, \tag{9}$$

$$w_i = \frac{1 - E_i}{\sum_{i=1}^{m} (1 - E_i)}. \tag{10}$$

In general, the determination of weights is up to the author. There is no route about how/why is chosen the weighting method. In this study, the main idea is each parameter is not the same. Thus in calculating the weight for each parameter is decided to use the quantitative properties because there are no objective opinions to find parameters. For calculating the Availability (A), Quality (Q), and Performance Efficiency (PE) have given equal weights (0.33). The other weighting method is entropy. When calculating the entropy-weighting method (Eqs. (8)–(10)), Availability: 0.21, Quality: 0.56, and Performance Efficiency: 0.23 have been calculated.

Depending on the data received, capacity, efficiency, overall equipment effectiveness and production equipment effectiveness values were calculated and the results were examined.

5. RESULTS AND DISCUSSION

Overall equipment effectiveness is proposed by Nakajima (1988) and Raouf (1994) proposed the PEE with weight. In this study, OEE and PEE helped to identify the contribution of different weights to equipment performance. This part summarizes the results of our analysis based on the OEE and PEE. The aim of this study is to measure the effectiveness of equipment. Equipment with a high score in OEE and PEE is the most effective equipment and this analysis contributes most to system performance. The OEE and PEE contribute to equipment for overall system availability, quality, and performance efficiency. Analysis of the comparison of the OEE and the PEE will lead to evaluate the bottleneck for the system.

Table 2. Number 1 gang saw machine

Block number	Thickness [cm]	Width [cm]	Length [cm]	Height [cm]	Slabs needs to be cut (number)	Quality slabs (number)	Broken slabs (number)	Total slabs [m^2]	Cut slabs [m^2]	Quality cut [m^2]	Needs to be cut [m^2]	Work time of the cutting block [min]	Planned break [min]	Unplanned break [min]
1	3	120	285	145	35	33	2	35	144.64	136.37	145.85	520	60	165
2	3	160	200	300	47	44	2	46	276.00	264.00	282.35	1210	60	165
3	3	150	200	180	44	41	1	42	151.20	147.60	158.82	1310	60	165
4	3	140	275	180	41	38	2	40	198.00	188.10	203.82	1150	60	165
5	3	170	280	170	50	49	2	51	242.76	233.24	238.00	1110	60	165
6	3	150	300	185	44	43	2	45	249.75	238.65	244.85	1315	60	165
7	3	180	300	190	53	48	2	50	285.00	273.60	301.76	1425	60	165
8	3	125	265	115	37	35	2	37	112.76	106.66	112.04	70	60	165
9	3	140	260	150	41	39	2	41	159.90	152.10	160.59	310	60	165
10	3	165	210	180	49	46	2	48	181.44	173.88	183.44	1155	60	165
11	3	110	270	190	32	30	2	32	164.16	153.90	165.97	300	60	165
12	3	140	250	150	41	40	2	42	157.50	150.00	154.41	1240	60	165
13	3	180	300	190	53	50	2	52	296.40	285.00	301.76	100	60	165
14	3	150	255	145	44	42	1	43	158.99	155.30	163.13	25	60	165
15	3	195	220	160	57	55	2	57	200.64	193.60	201.88	1290	60	165
16	3	115	260	170	34	31	2	33	145.86	137.02	149.50	750	60	165
17	3	155	275	150	46	44	1	45	185.63	181.50	188.05	250	60	165
18	3	160	280	125	47	46	2	48	168.00	161.00	164.71	1185	60	165
19	3	175	250	180	51	49	2	51	229.50	220.50	231.62	1065	60	165
20	3	170	285	130	50	49	1	50	185.25	181.55	185.25	130	60	165
21	3	165	280	155	49	46	2	48	208.32	199.64	210.62	85	60	165
22	3	170	295	160	50	47	2	49	231.28	221.84	236.00	1365	60	165
23	3	145	275	130	43	40	2	42	150.15	143.00	152.46	135	60	165
Total									**4483.12**	**4298.05**	**4536.90**	**17 495**	**1380**	**3795**

Table 3. Number 2 gang saw machine

Block number	Thickness [cm]	Width [cm]	Length [cm	Height [cm]	Slabs needs to be cut (number)	Quality slabs (number)	Broken slabs (number)	Total slabs [m^2]	Cut slabs [m^2]	Quality cut [m^2]	Needs to be cut [m^2]	Work time of the cutting block [min]	Planned break [min]	Unplanned break [min]
1	2	195	245	165	81	78	2	80	323.40	315.32	328.45	270	60	150
2	2	185	190	180	77	72	2	74	253.08	246.24	263.63	1280	60	150
3	2	140	300	190	58	53	2	55	313.50	302.10	332.50	965	60	150
4	2	130	275	150	54	52	2	54	222.75	214.50	223.44	140	60	150
5	2	95	300	200	40	37	2	39	234.00	222.00	237.50	80	60	150
6	2	95	300	200	40	37	2	39	234.00	222.00	237.50	80	60	150
7	2	170	205	195	71	68	1	69	275.83	271.83	283.16	250	60	150
8	2	155	190	165	65	63	2	65	203.78	197.51	202.47	1215	60	150
9	2	140	210	140	58	54	3	57	167.58	158.76	171.50	1250	60	150
10	2	105	235	160	44	43	2	45	169.20	161.68	164.50	1170	60	150
11	2	165	270	180	69	66	2	68	330.48	320.76	334.13	1265	60	150
12	2	110	230	175	46	43	2	45	181.13	173.08	184.48	1250	60	150
13	2	110	275	190	46	44	2	46	240.35	229.90	239.48	40	60	150
14	2	180	280	145	75	72	3	75	304.50	292.32	304.50	270	60	150
15	2	150	275	175	63	58	2	60	288.75	279.13	300.78	65	60	150
16	2	185	280	145	77	73	1	74	300.44	296.38	312.96	755	60	150
17	2	125	215	150	52	49	2	51	164.48	158.03	167.97	1355	60	150
18	2	155	280	140	65	61	2	63	246.96	239.12	253.17	1080	60	150
19	2	100	280	165	42	38	2	40	184.80	175.56	192.50	185	60	150
20	2	165	280	155	69	40	2	42	182.28	173.60	298.38	1380	60	150
21	2	145	245	130	60	59	2	61	194.29	187.92	192.43	360	60	150
22	2	125	275	155	52	51	2	53	225.91	217.39	222.01	1120	60	150
23	2	70	250	200	29	27	2	29	145.00	135.00	145.83	1320	60	150
Total									**5386.47**	**5190.10**	**5593.24**	**17 145**	**1380**	**3450**

Table 4. Number 3 gang saw machine

Block number	Thickness [cm]	Width [cm]	Length [cm]	Height [cm]	Slabs needs to be cut (number)	Quality slabs (number)	Broken slabs (number)	Total Slabs [m^2]	Cut Slabs [m^2]	Quality cut [m^2]	Needs to be cut [m^2]	Work time of the cutting block [min]	Planned break [min]	Unplanned break [min]
1	3	155	175	250	46	44	2	46	201.25	192.50	199.45	500	60	160
2	3	180	295	165	53	50	2	52	253.11	243.38	257.69	1220	60	160
3	3	145	295	190	43	42	2	44	246.62	235.41	239.04	1310	60	160
4	3	195	275	190	57	54	2	56	292.60	282.15	299.67	1335	60	160
5	3	135	240	160	40	39	2	41	157.44	149.76	152.47	370	60	160
6	3	140	230	115	41	39	2	41	108.45	103.16	108.91	1170	60	160
7	3	100	245	185	29	27	2	29	131.44	122.38	133.31	1310	60	160
8	3	105	225	190	31	29	2	31	132.53	123.98	132.02	1310	60	160
9	3	180	250	180	53	51	2	53	238.50	229.50	238.24	1290	60	160
10	3	195	215	190	57	54	2	56	228.76	220.59	234.29	1395	60	160
11	3	175	210	145	51	50	2	52	158.34	152.25	156.73	360	60	160
12	3	120	225	200	35	33	2	35	157.50	148.50	158.82	655	60	160
13	3	160	210	165	47	45	2	47	162.86	155.93	163.06	1420	60	160
14	3	95	200	165	28	30	2	32	105.60	99.00	92.21	120	60	160
15	3	105	180	155	31	25	2	27	75.33	69.75	86.16	120	60	160
16	3	175	300	190	51	50	2	52	296.40	285.00	293.38	405	60	160
17	3	190	290	160	56	54	2	56	259.84	250.56	259.29	1410	60	160
18	3	180	270	190	53	50	2	52	266.76	256.50	271.59	120	60	160
19	3	175	290	190	51	48	2	50	275.50	264.48	283.60	1330	60	160
20	3	180	265	160	53	50	2	52	220.48	212.00	224.47	1260	60	160
21	3	165	280	180	49	47	2	49	246.96	236.88	244.59	485	60	160
22	3	165	275	150	49	46	2	48	198.00	189.75	200.18	230	60	160
23	3	200	235	185	59	55	2	57	247.81	239.11	255.74	1180	60	160
Total									**4662.07**	**4462.50**	**4684.90**	**20 305**	**1380**	**3680**

To analyze the data with Tables 2–4, objective weighting method is carried out. Entropy weighting method needs no expert's opinions. In Table 5 the summary of OEE and PEE values are given. PEE values are the average of the PEE with equal weighting method and entropy weighting method.

Table 5. The summary of OEE and PEE of gang saw machines

1 number gang saw machine				
Availability	Quality	Performance	OEE	PEE
83,.26%	95.87%	98.81%	78.88%	92.60%
2 number gang saw machine				
Availability	Quality	Performance	OEE	PEE
84.30%	96.35%	96.30%	78.22%	91.95%
3 number gang saw machine				
Availability	Quality	Performance	OEE	PEE
85.49%	95.72%	99.51%	81.43%	93.74%

The efficiency of gang saw machines was also recorded to evaluate the productivity. The graph in Fig. 2 illustrates the OEE and PEE per cutting block for 69 different marble blocks. The dimensions of each block were measured and then, cutting time was kept for each block. The number of slabs were determined after cutting. According to results, the performance of gang saw machines are very close to each other. Figure 3 shows that the percentage of OEE's. It is also found from Fig. 3 that most effective of the gang saw machine is number 3, followed by 1 and 2, respectively.

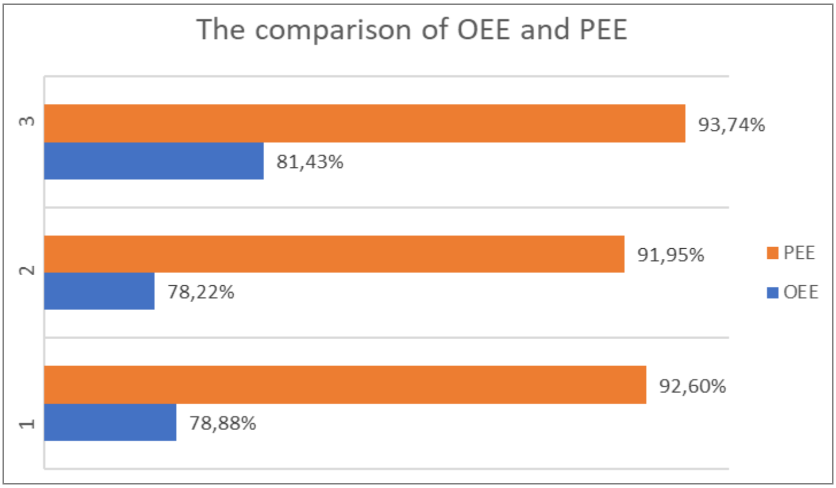

Fig. 3. The comparison of OEE and PEE

As a result of the study, the most effective of the gang saw machine is the number 3 with cutting 3 cm thickness slabs. Number 2 gang saw machine is cutting 2 cm thickness slabs and is the least effective equipment. We also carried out equipment production efficiency. In general, all machines are effective and cutting times vary depending on block dimensions. Lastly, future studies about OEE and PEE will contribute to the further understanding of productivity, efficiency, and effectiveness in block-cutting factories.

6. CONCLUSION

The goal of this study was to investigate the OEE and PEE by identifying the losses. Breakdown, failure, setup, stoppage, reduced speed and defects in the production were identified. PEE is the expanded method of OEE by calculating the component with weights. Here, entropy weighting method was used for determining the weights. This study shows that cutting marble blocks by gang saw machines is effective way to product in smooth slabs. The bottleneck of the system is availability and needs improvement with decreasing unplanned break. In terms of quality, there is a little broken slabs such as 6%. Lastly, the performance of the machines are quite well off. When PEE is applied, the system overall effectiveness increases owing to weights and this situation increases the quality and trade.

ACKNOWLEDGEMENT

The author is grateful and wishes to express thanks to the staff members of the Basarırlar Marble Factory, Burdur, Turkey for supporting this work by providing the data at gang saw machines.

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