International Journal of Automotive Engineering, Vol. 8, No. 3, (2018), 2781-2791

Iran University of Science and Technology

International Journal of Automotive Engineering

Journal Homepage: ijae.iust.ac.ir

ISSN: 2008-9899

Improving the performance measurement using overall equipment effectiveness in an automotive industry

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ARTICLE INFO

Article history:
Received : 10-Dec-2017
Accepted: 24-Jul-2018
Published:

Keywords:
Assembly lines,
Manufacturing,
Overall equipment effectiveness,
Total productive maintenance

ABSTRACT

Considering the present business competitive scenario, the automotive industry is under pressure to achieve higher productivity. A high level of performance and quality standard could be achieved through improving the Overall Equipment Effectiveness (OEE) of the equipment in an automotive industry. Thus, the aim of this study is to investigate the performance measurement through OEE theory in an Iranian automotive industry. Data and basic information collected from the Computerized Maintenance Management System (CMMS) of the automotive assembly lines. In this case study, two different assembly lines such Peugeot and Sports Utility Vehicle (SUV) were studied. The results indicated that the indices such availability rate, performance and quality for Peugeot assembly line obtained an OEE value of 0.99, 0.70 and 0.38, respectively, and, these indices for SUV assembly line obtained as 0.99, 0.39 and 0.53, respectively. Statistical analysis results of net operating time parameter for two assembly lines revealed that there is significant difference in the confidence level of 5% (P-value < 0.05). In addition, the OEE index for Peugeot and SUV assembly lines gained 0.27 and 0.21 over a period of one year. Consequently, to improve the OEE in the automotive assembly lines, managing the time losses by systematic planning of manufacturing and the implementation of Total Productive Maintenance (TPM) are suggested.

[DOI: 10.22068/ijae.8.3.2781]

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1. Introduction

Many companies and organizations are competing in global marketplaces to achieve the highest profitability index and gaining market share [1-3]. On the other hand, in order to remain competitive in the markets, improving the production processes to achieve the highest quality of products is inevitable [4]. One of the major systemic attitudes to the dynamics of production processes is the use of physical assets management (PAM), while the utilization of optimal maintenance activities and increasing the effectiveness of equipment play significant role in improving physical assets [5-8]. Nowadays, there are many techniques to improve the effectiveness of equipment. One of the most important technique is the total productive maintenance (TPM), firstly presented in 1971 by the Japanese [9]. TPM is a strategy to improving the production processes which is designed to optimize the availability of the equipment, and make sure the efficient management of assets [10]. The aim of performing the TPM is to increasing the effectiveness of production equipment by reducing the six types of losses which includes the failure of equipment, set-up and adjustment times, idling and minor stoppages, reduced speed of equipment, defects in process, and constraints on manufacturing [11,12]. One of the best ways to measure the effectiveness of TPM is overall equipment effectiveness (OEE) which is the combination of the operation maintenance, equipment management, and available resources. OEE is the fundamental agent for measuring the promotion of TPM implementation program [13]. OEE is a key performance indicator (KPI) which has an important effect on increasing the productivity of systems [14]. Advances of OEE started in the 1990s and by early 2000 when it started becomes implement in several companies and then the topic become popular in academic research [15]. The OEE estimates to measuring performance index and help to manage the long-term effectiveness of equipment by restoring it to as good as new conditions thereby increasing its performability and reducing production losses [16, 17]. The concept of OEE metrics is widely used in production systems. Assessment of this attitude can be leading to effective production planning and improving the availability of equipment [18]. In general, OEE provides a systematic method to establishing production targets and incorporates practical management of tools and techniques in order to achieve the sustainable availability, high performance efficiency and quality rate [19]. According to the applied concepts in various industries, the expression of OEE has been modified by researchers differently. These differences has led to various concepts and terminology such as; overall factory effectiveness (OFE), overall plant effectiveness (OPE), overall throughput effectiveness (OTE), production equipment effectiveness (PEE), overall asset effectiveness (OAE), and total equipment effectiveness performance (TEEP) [20]. There are a considerable number of literatures have been published on the topic of OEE and its various applications in different industries:

Kigsirisina et al. [21] conducted a strategy of TPM for the role of OEE in water treatment plant (chlorinator machines) to reduce the problems of equipment breakdown, decrease water loss and enhance equipment effectiveness. The OEE was determined by availability, performance efficiency, and quality rate. They offered 17 steps for OEE evaluation. This research can be a good approach for other water treatment plant to get higher chlorinator effectiveness and lower water loss.

Azizi [22] proposed the integration between the statistical process control (SPC), OEE, and autonomous maintenance (AM) to achieve the continuous improvement in the production capability. The OEE is offered as the indicator to measure the equipment efficiency. The results indicated the implementation of AM has successfully reduced %8.49 of the defect rates of the glazing line from 14.61% to 6.12%. Machine breakdown time has been decreased from 2502 minutes to 1161 minutes whereas the OEE has been improved 6.49% from 22.12% to 28.61%.

Andersson and Bellgran [23] declared a theory to enhancing sustained production improvement capability by combining OEE and productivity indicators. They concluded that a combination of these indices can lead to improve the production process, systematically. Thus two new productivity measures for driving improvements at the shop floor level were suggested.

Kumar et al. [24] assessed the production planning and process improvement in an impeller manufacturing using scheduling and OEE techniques. OEE as a quick changeover technique helps in reduction of setup time of the standardized product. They resulted that there are increasing in performance to %4.4 and reduction in set-up times in particular impellers to %47.

Palanisamy and Ananth-Vino [25] investigated the implementing OEE in a Plastic Injection Molding industry. A pilot scale study is undertaken in the product manufacturing industry and OEE concepts are implemented in the job floor. The three parameters such as availability, performance, and quality of the process were estimated 0.59, 0.79 and 0.95, respectively. Moreover, OEE index for this study was obtained 0.44. To conclude, The OEE concepts were implemented in a periodic manner, and continuous improvement in the shop floor was monitored which proved some positive output.

Tsarouhas [26] evaluated the OEE in the beverage industry. The most important results of this research were actual performance efficiency of the line was 85.72%, which abstained enough from the target (95%) of the production line. The actual quality rate (96.21%) approximates the target (99%) for the limoncello line. The overall OEE performance of the line was low (73.69%), considering the world class target of 85%. The main causes such as; speed losses, excessive breakdowns and high levels of defective products were reported.

Karim and Rahman [27] implemented a performance analysis of OEE and improvement potential at a selected apparel industry. OEE was applied for measuring the performance of the sewing section. Evaluating the OEE measurement for every sewing line helps to minimize equipment breakdown, downtime due to setup, defects and minor stoppage for a particular sewing line.

Puvanasvaran et al. [28] improved the OEE metric of the autoclave process through the implementation of time studies in an Aerospace industry. Their results showed that there is a 4.64% of increment for the availability ratio. Bon and Ping [29] suggested a TPM strategy based on OEE index in the automotive industry. Their findings showed that comparison between before and after the implementation of TPM was carried out to see what difference TPM can bring to an organization. Elements that constitute the OEE equation have been analyzed and identified the factors that affected OEE result. After identifying, improvement has been made on the factors so that OEE result would be improved ultimately. As well as other studies on implementing the performance measurement indicators such OEE metrics have been conducted in various industries [30-33].

For sustainability of manufacturing operations in automotive industry and to achieve the highest production international standards from qualitative and quantitative points of view, improving assets' performance is essential. Therefore, estimating the key performance indicators (KPI) and comparing them to world-class standards can provide very important information about the status of physical assets such as machinery and equipment in the production lines. Consequently, this research work aimed to provide a framework for improving the performance measurement through the overall equipment effectiveness (OEE) in two assembly lines Iranian automotive industry.

The remainder of this paper is organized as follows. Section 2 describes the material and methods including location and data collection in Section 2.1 and OEE measurement methodology in Section 2.2. Section 3 discusses the results and discussion. Section 4 summarizes this paper with concluding remarks.

2. Method

2.1. Location and data collection

The Iranian automotive industry known as Iran-Khodro is the most active automotive industry in Iran. Iran-Khodro produces its products at different locations in Iran. This company is comprised of two units. To achieve the company’s vision, an administrative division including strategic management for short-term and long-term planning is prepared. The most important corporate objectives of the company includes customer satisfaction, improvement of

[DOI: 10.22068/ijae.8.3.2781]

product quality, reducing the production cost and increasing the revenue. Education and research unit, focuses on education and training new employees, as well as, research activities to improve production operations are discussed. Operating units, includes the auto body shop, paint shop, assembly shop and, environment and safety unit. Data and basic information is obtained from the database on the assembly automobile production lines (CMMS software) which includes the production of Peugeot and SUV lines. Fig.1 shows the schematic diagram of the assembly process. The automobile body painted in paint shop can be transported through automatic fork lift machine. A rail system such as skeeds (loading equipment), sends to the forklift and then it will be transferred by hangers to the beginning of the assembly line. Generally, automotive assembly process is consists of three main lines such as the sub-assembly lines (include assembling of motors and front and rear axles), final lines and improvement lines.

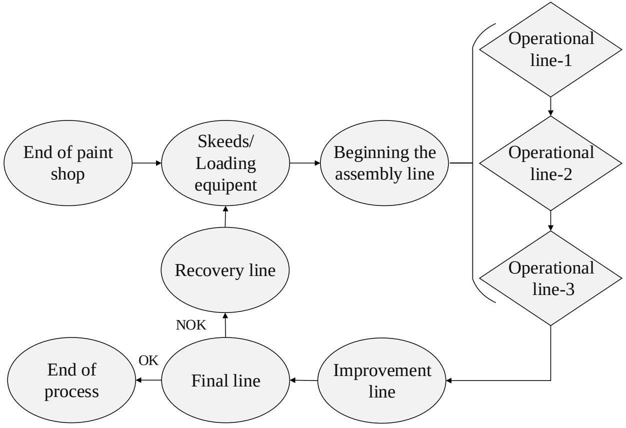

Figure 1. Schematic of automobile assembly line

2.2. OEE measurement methodology

OEE provides an effective way of measuring and analyzing the efficiency of equipment in an integrated manufacturing system. In this research to measure the availability, performance and quality rates, and also OEE metric, as shown in Fig. 2 is used on assembly lines. It organized in three sectors; equipment timing (such as effective and losses times), six major losses (such as; equipment failure, set-up and adjustment times, idling and minor stoppages, reduced speed of equipment, defects in process, and constraints on manufacturing (reduced yield)) and applying them for calculating the expected indices (perspectives). Eventually, the calculation of OEE is performed by obtaining the availability of the equipment, the performance efficiency, and the rate of quality products.

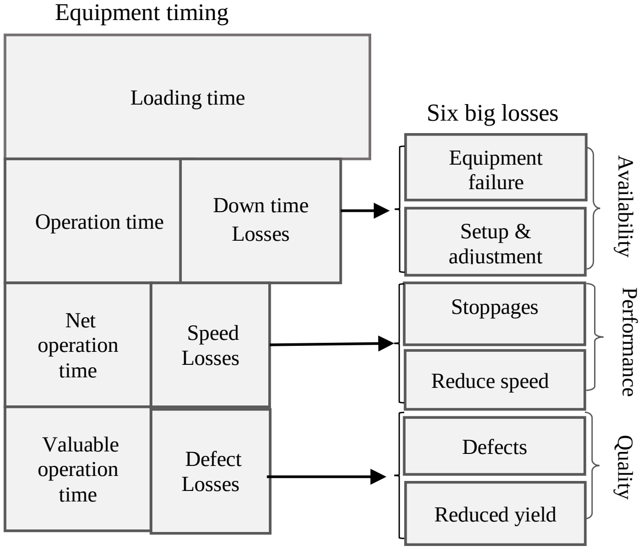

Figure 2: OEE concept and the six big production losses [34]

Basic parameters and operation times for estimating the OEE index in Iranian automotive industry presented in Table 1.These parameters are loading time, operating time, perfect amount produced, net operating time, total time waiting, and mean down time. Data and information monthly extracted for a year production.

Table1. Main parameters for estimating the OEE

Item	Description
Loading time	Total time - Planned downtime
Operating time	Loading time - Unplanned downtime
Perfect amount produced	Total amount produced - Defect amount
Net operating time	Cycle time × Total amount produced
Total time waiting	Unplanned downtime - Total repair time
Mean down time (MDT)	Unplanned downtime ÷ Number of failures

To obtain the availability, performance and quality, the equations 1 to 3 presented, respectively. Eventually, by using these parameters, OEE_1 (with planned downtime) and OEE_2 (unplanned downtime) metrics were estimated for Peugeot and SUV assembly lines (Equations of 4 and 5).

[DOI: 10.22068/ijae.8.3.2781]

$$\text{Availability(A)} = \frac{\text{Loding time} - \text{Unplanned downtime}}{\text{Loading time}} \quad (1)$$

$$\text{Performance(P)} = \frac{\text{Cycle time} \times \text{Total amount produced}}{\text{Operating time}} \quad (2)$$

$$\text{Quality(P)} = \frac{\text{Total amount produced} - \text{Defected amount}}{\text{Total amount produced}} \quad (3)$$

$$\text{OEE}_1 = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (4)$$

$$\text{OEE}_2 = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (5)$$

The values of OEE parameters in this research also compared with performance measurement of standard automotive industry for the world-class industry (Table 2) [35].

Table 2. World class OEE in automotive industry (Singh et al., 2013)

Performance measurement factor	World class (%)
Availability (A)	90
Performance (P)	95
Quality (Q)	99
OEE	85

One of the aims of this research is to investigate the measurement of maintenance performance (MPM) for Iranian automotive industry. The MPM concept approves the preventive maintenance (PM) system, which is used for strategic planning and its application for organization and companies. The MPM can be effectively utilized for the improvement and process appraisement [36]. In this research, some of the measures for maintenance performances including mean waiting time (MWT), mean time between failures (MTBF), mean time to repair (MTTR), mean time to failures (MTTF) calculated (Equations 6, 7, 8 and 9). Software used in this study include Minitab 17, Excel 2015 and CMMS (internal version) software.

$$\text{MWT} = \frac{\text{Total time waiting}}{\text{Number of failures}} \quad (6)$$

$$\text{MTBF} = \frac{\text{Loading time}}{\text{Number of failures}} \quad (7)$$

$$\text{MTTR} = \frac{\text{Total repair time}}{\text{Number of failures}} \quad (8)$$

$$\text{MTTF} = \text{MTBF} - \text{MTTR} \quad (9)$$

3. Results and discussion

3.1. Requirement data and Pareto chart

In order to improve the equipment performance, such as; OEE metrics, equipment with the most failures on the assembly line for Peugeot and SUVs were evaluated. The results for failure modes of critical equipment, root cause analysis, and the total number of downtimes for assembly lines are presented in Table 3. These data can be used to determine trends, root causes, and implementing improvements internally within the company and external with equipment suppliers.

Table 3. The weightage result for different failure mode of assembly lines

Row	Failure mode	Root cause	Rep.	Downtime	Weightage
1	Failure of limit leave sensor	Getting stuck of the salt screw to Belt guide	1	30	30
2	Lift engine failure (1)	Not recorded	1	4	4
3	Failure of the lift chain	Operator fault	1	4	4
4	Lift engine failure (2)	Not entering hangar into lift	1	4	4
5	Cutting the caterpillar shaft	Depreciation	1	17	17
6	Fluctuation C4	Not recorded	1	8	8
7	Emergency fault Lift (2)	No, reset of pilz lift	1	51	51
8	Wire connection at the terminal	Depreciation	1	13	13
9	Dali Jack failure	Breaking the base Jack	2	46	92
10	Crane engine failure (SUV2)	Electrical fault	2	95	190
11	Crane engine failure (SUV3)	Wire connection	1	4	4
12	Crane engine failure (SUV4)	Not recorded	1	13	13
13	Crane engine failure (SUV5)	Mechanical Fault	1	8	8
14	Crane engine failure (SUV6)	Not recorded	1	10	10
16	Axle crane failure	Lack of a spare part by traders	1	10	10
17	Non-injection brake fluid equipment	Parking sensor failure	1	4	4
18	Brake gearbox failure	Lack of a spare part by traders	1	6	6
19	SUV Sezer lift failure (1)	Electrical fault	2	120	240
20	Release of hanger in chain line	Under review	1	3	3

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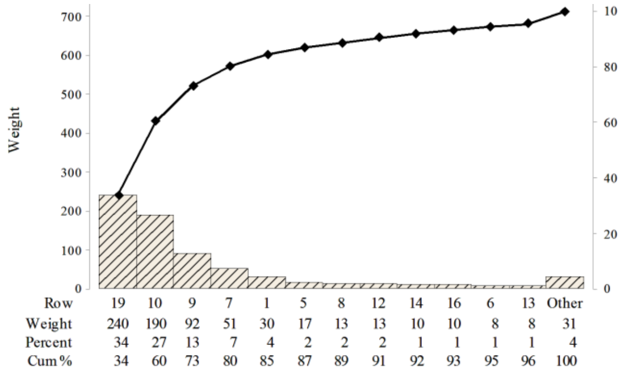
The results of the scenarios, root cause and the weightage of each failures in order to show the equipment with most downtime is used in the form of Pareto Chart (Fig. 3). The greatest value of failure weight is related to rows 19 (SUV Sezer lift), 10 (SUV Crane engine) and 9 (Dali Jack) with a share of 36, 30 and 18 percent, respectively



Row	19	10	9	7	1	5	8	12	14	16	6	13	Other
Weight	240	190	92	51	30	17	13	13	10	10	8	8	31
Percent	34	27	13	7	4	2	2	2	1	1	1	1	4
Cum %	34	60	73	80	85	87	89	91	92	93	95	96	100

Figure. 3. Pareto chart for ranking the failures in assembly lines

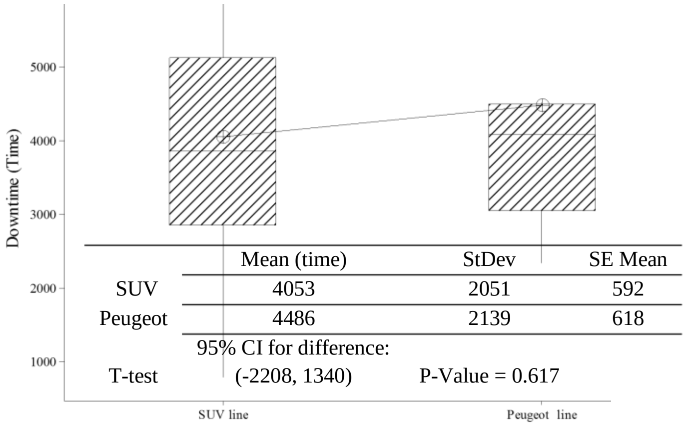
The information related to the Peugeot and SUV assembly lines for estimating the performance metrics is shown in Table 4. As mentioned, the total annual available time for Peugeot and SUV assembly lines estimated as 390,520 and 158,000 minutes, respectively. The annual operating time which can be obtained from the difference between the total available time and the loading time, for these assembly lines are 53,837 and 48,632 minutes, respectively. Moreover, the net operating time for these assembly lines estimated as 234,954 and 4,488 minutes, respectively. In other words, the net operating time for both of the assembly lines devoted 30 and 60 percent of the available time to themselves. Also, the planned and unplanned downtimes for both of the assembly lines are shown in this Table.

Table 4. The annual and average time parameters for the manufacturing units in Iranian automotive industry

Assembly lines		**Peugeot**	**SUV**
Total time (min)	Annual	390520	158000
	Average*	32543.33	13166.66
Loading time (min)	Annual	336683	109368
	Average	28056.92	9114
Operating time (min)	Annual	336206	109368
	Average	28017.16	9114
Planned downtime (min)	Annual	53837	48632
	Average	4486.41	4052.66
Unplanned downtime (min)	Annual	477	-
	Average	39.75	-
Net operating time (min)	Annual	234954	44880
	Average	19579.5	3739.8

* Average per month

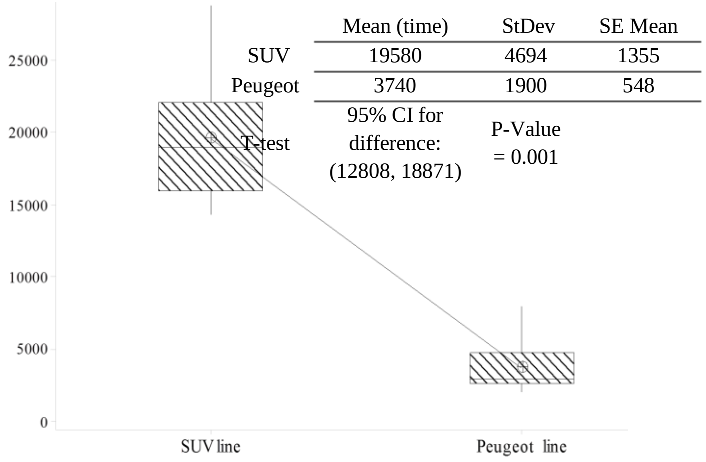
Statistical analysis results of planned downtime parameter for Peugeot and SUV assembly lines is shown in Fig.4. Two-sample T test for SUV line versus Peugeot lines revealed that there was no significant difference in the confidence level of 5% (P-value=0.617).



	Mean (time)	StDev	SE Mean
SUV	4053	2051	592
Peugeot	4486	2139	618
T-test	95% CI for difference: (-2208, 1340)	P-Value = 0.617	

Figure.4.Two-sample T test for SUV line versus Peugeot lines (planned downtime)

In addition, statistical analysis results of net operating time parameter for Peugeot and SUV assembly lines is shown in Fig.5. Two-sample T test for SUV line versus Peugeot lines revealed that there was significant difference in the confidence level of 5% (P-value=0.001).



	Mean (time)	StDev	SE Mean
SUV	19580	4694	1355
Peugeot	3740	1900	548
T-test	95% CI for difference: (12808, 18871)	P-Value = 0.001	

Figure 5.Two-sample T test for SUV line versus Peugeot lines (Net operating time)

Evaluation of maintenance performance for Iranian automotive industry is undertaken by some of the measures which include the estimated values of mean time between failures (MTBF), mean time to repair (MTTR), and mean time to failure (MTTF), see Fig.6. The annual values of these indices obtained as 82326.65, 84.20 and 82218.75 minutes, respectively. Also, the average values of each index gained as 6860.55, 7.02 and 6851.56 minutes per month, respectively. According to the MTBF results, in May and March with a 27% (22764 minutes) and 14% (16680.5 minutes) shares the highest value of total failure times allocated. Based on MTTR results, in March and January with 17% and 15% shares, the highest of total repair activities were taken, respectively. Also, the mean down time (MDT) and mean waiting time (MWT) factors obtained 8.99 and 1.98 minutes, respectively.

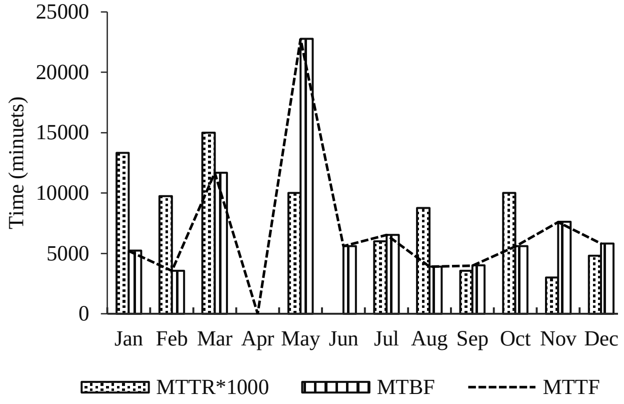


Figure 6. Estimation of MTTR, MTBF, and MTTF for Peugeot assembly line

Estimation of availability, performance and quality rates for Peugeot assembly line are shown in Fig. 7. The averages of these indices are 99%, 70.76% and 38%, respectively. The main reason for high availability rate is the optimal use of the available loading time as compared with unplanned downtime. The maximum of performance rate during a year for Peugeot line allocated in January, July and August with the share of %95, %88 and 87%, respectively. It also indicates, regarding the available operating time the company has utilized the most capacity of manufacturing. Also, the highest quality rate obtained in August and July with 60.8% and 53.30 % shares, respectively. This index calculated the lowest quantity in compared with the other indices. As a result, the main suggestions to improve the quality factor in production lines, supplying the durable raw material and development of quality control by using updated software mentioned.

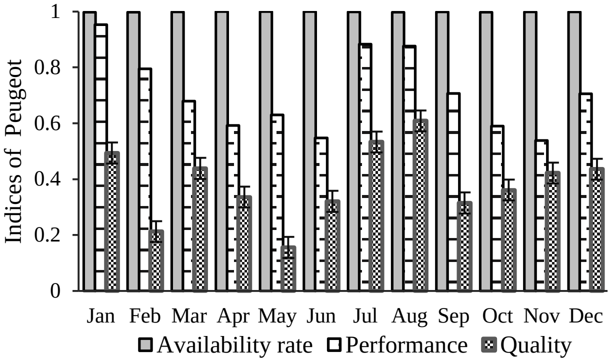


Figure 7. The availability, performance and quality indexes for Peugeot assembly line

On the other hand, the quantity of these indices for SUV assembly line calculated 99%, 39.90% and 53%, respectively (Fig. 8). The maximum performance during a year for SUV line are given in May and February with 69.87% and 53.23 % shares, respectively. As well, the highest quality rate concluded in January and February with the share of 77.94% and 69.88%, respectively. This index had the lowest quantity in compared with other indices. Therefore, to improve the indicators for SUV line the results of the Peugeot assembly line can be used.

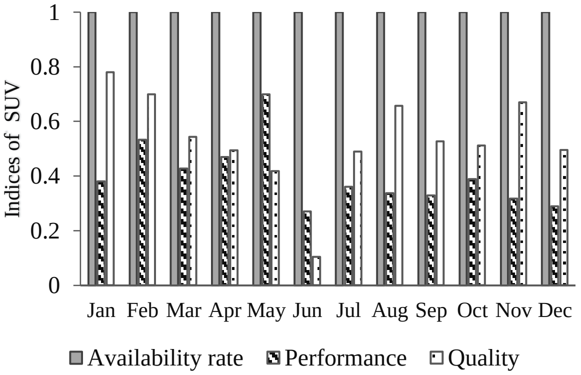


Figure 8. Amounts of availability rate, performance and quality indexes for SUV assembly line

Figure9 indicates the OEE_1 (planned downtime) and OEE_2 (unplanned downtime) indices based on availability, performance and quality rates for

Peugeot assembly line. These indices estimated as 27.26% and 24.09%, respectively. The highest quantity of the OEE_1 is in August and July with a 53.17% and 47% shares, respectively. In addition, the maximum OEE_2 was obtained in August and July with 46.58% and 43.83 % share.

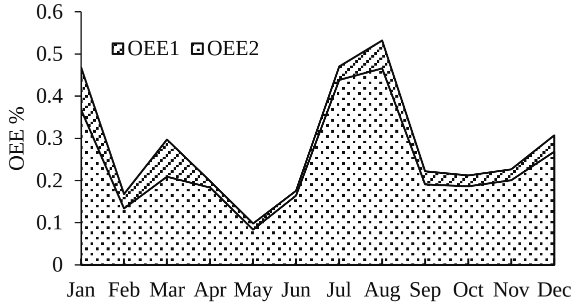


Figure 9. OEE_1 and OEE_2 metrics for Peugeot assembly line

On the other hand, the OEE_1 (planned downtime) and OEE_2 (unplanned downtime) metrics for SUV assembly line were obtained 21.47% and 14.77%, respectively (Figure 10). The OEE_1 in February and OEE_2 in May with 37% and 27.29% share obtained the highest of total performance measurement, respectively. The results shown the effectiveness of OEE_1 index by considering the planned downtime parameter obtained 1.5 times more than OEE_2. Thus, by taking an exact estimation of this parameter, realistic results of OEE as a key performance measurement are achievable.

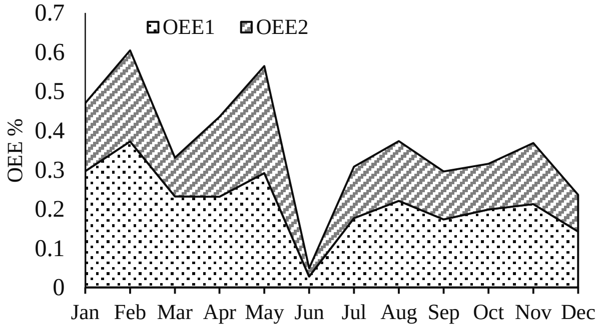


Figure 10. OEE_1 and OEE_2 metrics for SUV assembly line

Comparison of actual quantity for two assembly lines (SUV and Peugeot) in an Iranian automotive industry with the target value of the perspective on world-class was conducted (Table 5). In this research, according to performance measurement standard in automotive industry, only the availability index has been improved. The main reason for its increment is minor total stoppage time and time to failures.

The OEE index for the both lines including the Peugeot and SUV are lower than the OEE world-class. The most important causes of lowest OEE is little performance index due to the lack of optimal operation time to manufacturing. Also, another reason is the low quality index due to defective production in assembly process.

Table 5. Actual and target values for performance measurement factors

Performance measurement	Actual value (%)		Target value (%)
	Peugeot	SUV	World class
Availability (A)	98	99	90
Performance (P)	70	39	95
Quality (Q)	38	53	99
OEE	26	20	85

Strategy implementation is an important issue for any industry. This cannot be achieved without involving and convincing top managers. After the decision making, the production target can be converted into OEE figure and both production and maintenance staffs need to pursue it. In order to achieve the highest reliability of equipment in manufacturing process, many organizations are seeking to use the Total Productive Maintenance (TPM) approach as a capable and supportive tool in improving the effectiveness of equipment through the optimal combination between human labor and machinery [37-39]. By implementing TPM strategy in Iranian automotive industry, the quality of production would be increased to the international level, and the manufacturing waste such as downtime losses, and material waste can be eliminated. The make a TPM team of automotive specialists for improving manufacturing operations is indispensable. In order to achieve more practical TPM results, efforts such as development and application of CMMS software and its integration with the other production planning software are suggested.

4. Conclusion

OEE is a key performance indicator (KPI) to measure the performance of equipment in production lines of manufacturing industries. In this research, OEE methodology was adopted for measuring performance of two production lines of Iranian automotive industry. The main important parameters for estimating the performance indicators including loading time, operating time, total amount produced and unplanned downtime obtained from the CMMS database of the automotive assembly lines. The results of this study revealed that availability can be improved by 8 and 9 percent for Peugeot and SUV lines, respectively. Whereas, the performance and quality were obtained lower than the desired values. The results of this research made it possible to improve the manufacturing productivity. In order to improve the indicators such as OEE in Iranian automotive industry, managing production losses time, appropriate and systemic planning of manufacturing and the implementation of total productive maintenance (TPM) strategy are recommended.

Acknowledgement

This research was funded by Ferdowsi University of Mashhad, Iran (Project No. 43956) and Iranian Automotive Industry (Iran Khodro Khorasan Co.). Their contributions for funding and support are warmly acknowledged.

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