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Analysis of Production System Effectiveness Elements

Abstract- *The global competition turbulent manufacturing environment, declining profit margin, customer demand for the high-quality product had a major impact on the manufacturer. The purpose of this research is to investigate the effective elements of the continuous production system at Baghdad Company for Soft Drinks as a case study consecutive for two years. Production system has been investigated by employing Overall Equipment Effectiveness (OEE) and Overall Resources Effectiveness (ORE). As a result, OEE shows low average values of (11%) at 2014 to (9%) in 2015, while ORE values show an average of (8%) in 2014 and (7%) in 2015 respectively.*

Keywords- *Overall Equipment Effectiveness, Overall Resource Effectiveness, Total Productive Maintenance, Availability, Performance, Quality rate, Operating time, Pareto chart.*

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1. Introduction

Today's manufacturing organizations worldwide are facing many challenges to achieve successful operation in a competitive environment using different tools to improve effectiveness [1]. There are a wide number of tools that used in the evaluation of equipment effectiveness and the selection of these tools is depending on the available requirements of implementation as Overall Equipment Effectiveness (OEE) and Overall Resource Effectiveness (ORE) [2,3]. Overall Equipment Effectiveness (OEE) quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run [3]. The definition and use of Overall Equipment Effectiveness over the years has been widely debated. The OEE metric offers a starting point for developing quantitative variables relating maintenance measurement to corporate strategy [4-6]. A comparison between the expected and current OEE measures can provide the much-needed impetus for the manufacturing organizations to improve the maintenance policy and effect continuous improvements in the manufacturing systems. OEE offers a measurement tool to evaluate equipment corrective action methods and ensure permanent productivity improvement [1, 3]. Applying OEE in manufacturing environment became clear that it is not only equipment's that contribute to operational losses, but other resources and systems may cause losses. OEE could be measured according to the following equations [3, 6]:

$$Availability = \frac{Required\ Availability - Downtime}{Required\ availability} \times 100\% \quad (1)$$

Required availability equals to Time of production to operate the equipment minus planned downtime like breaks, meetings. (2)

$$\text{Performance rate} = \frac{\text{output / design cycle time}}{\text{operating time}} \times 100\% \quad (3)$$

$$Oper.Time = [Planned\ Dwontime + Total\ working\ time] \quad (4)$$

$$\text{Quality rate} = \frac{\text{production input - quality defects}}{\text{production input}} \quad (5)$$

$$OEE = Availability \times \text{Perf. Rate} \times \text{Quality Rate} \quad (6)$$

Overall Resource Effectiveness (ORE) is another tool defined as "the measure of overall effective time of the manufacturing system resources". It is used to classify the present situation of the manufacturing system and for benchmarking the manufacturing effectiveness with the world-class standard. ORE will be supportive to the decision makers for additional analysis and frequently enhancing of performance resources. ORE reports the losses related to the resources (man, machine, material, method) separately. The inclusion of these new metrics enables additional exhaustive

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and stratified classification of the resource losses and evaluate production system effectiveness. ORE could be measured according to following equations [7, 8]:

$$\text{Readinees} = \frac{\text{Planned Production time}}{\text{Total time}} \quad (7)$$

$$Planned\ Prod.Time = Total\ Time - Planned\ Downtime \quad (8)$$

$$\text{Af} = \frac{\text{Loading time}}{\text{Planned Production time}} \quad (9)$$

$$Loading\ Time = Planned\ Production\ Time - Facilities\ Downtime \quad (10)$$

$$\text{C} = \frac{\text{Operating time}}{\text{Loading time}} \quad (11)$$

$$Operating\ Time = Loading\ Time - Set-up\ and\ Adjastments \quad (12)$$

$$\text{Am} = \frac{\text{Running time}}{\text{Operating time}} \quad (13)$$

$$Running\ Time = Operation\ Time - Material\ Shortage \quad (14)$$

$$\text{Amp} = \frac{\text{Actual Running time}}{\text{Running time}} \quad (15)$$

$$Actual\ Running\ Time = Running\ Time - Manpower\ Absence\ time \quad (16)$$

$$ORE = R \times \text{Af} \times \text{Am} \times \text{Amp} \times \text{P} \times \text{Q} \times \text{C} \quad (17)$$

2. Literature Survey

Researchers used different tools to analyze, discover losses and check the performance of the different manufacturing system. To evaluated the existing equipment performance in Steel Company at Jordan that works using continuous production system. The data collected during fifteen working days for two shifts. Results showed that the company achieved (55%) of OEE. Set of techniques like SMED, production planning and computer maintenance management system are suggested to improve their maintenance and improve the productivity [6]. Nilmani and Sridhar used Overall Equipment Effectiveness (OEE) tool to increase its from (46%) to (61%) after 2 years of Total Productive Maintenance (TPM) implementation aiming to improved towards world class OEE value of (85% -90%) throughout increasing availability, performance and quality rates [9]. Eswaramurthi evaluated Overall Resource Effectiveness (ORE) including readiness, availability of material changeover efficiency and availability of manpower in a manufacturing line at India during four months. As a result, after three months for the evaluation they declared that (53%) of ORE is achieved [10]. Afefy focused on studying TPM in Salt Company (Emisal) in Egypt, using OEE as tool for TPM to evaluate the existing production efficiency during one year, they outlined that the company achieved about (93%) in quality rate, (87%) in availability and (87.5%) in performance efficiency [11]. Sahib investigated TPM implementation to reveal the big losses at the continuous production system for two years [12]. In the next paragraph, literatures are reviewed to reveal the current studies that employ different tools/metrics at different production system, this is followed by data collection from Baghdad Company for soft drinks for two consecutive years are; 2014 and 2015, as a case study, these data are analyzed to reveal the factor effecting this production system effectiveness. The generated results are reviewed and discussed so as conclusions from this research could be deduced.

3. Results and Discussion

There are eight production lines in the company; each production line has its own specifications. There are four production lines in Al-Forat factory (number five produces plastic bottles and the other production lines produce cans and glass bottles). Production line number five was established in 2009, designed with max. production of 768000 bottle/day, it is fully automated in all its processes and served throughout planned maintenance every 5000 operating hour by "KEONES" [German Company] throughout contract until 2021 year. This production line is the newest, largest in size and the highest in productivity [13]. The production line operates at two speeds (4000 bottle/hr. and 2333 bottle/hr.) depending on the bottle size and the market need. The fully automated production line consists of the following sequence of processes that are shown in Table 1 and the process flow diagram for this production line is shown in Figure 1 [13]. Analysis of Production System Effectiveness Elements is very important for any organization in order to reveal the weaknesses and areas of losses so that to improve productivity. In this research, production system effectiveness elements at Baghdad company for soft drinks in Line No. Five (Al-Forat factory) are analyzed by using two evaluation tools (OEE and ORE) for two years as a case study. OEE has a several factors to measure different kinds of losses in production, while ORE is used to measure some areas of losses that are not covered by OEE to enable decision makers initiating improvements actions according to the related losses.

Table 1: Detailed production processes of line five, Al-Forat factory [12]

Process	Description of the Process / Stage
1- Hot blowing.	Ampules are heated by furnace and then extruded using hot pressure air to form the standard required size of bottles (750ml, 2.25L and 1.75L etc.)
2- Mixing.	Water is heated to 85C° and circulates with separator sieves and mixed with crystal sugar and flavor.
3- Filling.	Bottles are washed first and filled, then covered by bottle's cap.
Inspection Stage No. one	X-ray inspection for the filling level.
4- Hot air fan blower	Eliminating any wet from outside the bottle to stick the labels well.
5- Labeling.	Bottles are labeled automatically using stickers.
Inspection Stage No. two	Checking the alignment of the stickers X-ray.
6- Automatic all-round packer.	Bottles are arranged and each 6 bottles (set) are covered by Nylon bag and passed to a hot air station that will shrink the nylon to form a unique package set.
Inspection Stage No. three	Packages are inspected using X-ray.
7- Fully automatic grouping station.	At this stage, each 18 set package are arranged and moved to the other stage.
8- Single-column palletizing robot.	A robot will separate previous 18 packages from the next 18 package that will come over it.
9- Final packaging.	This is the final step that surrounds a package of 4 rows, each row consists of 18 packages by Nylon and shrike it. After that, it is moved by forklift to the temporary storage area.

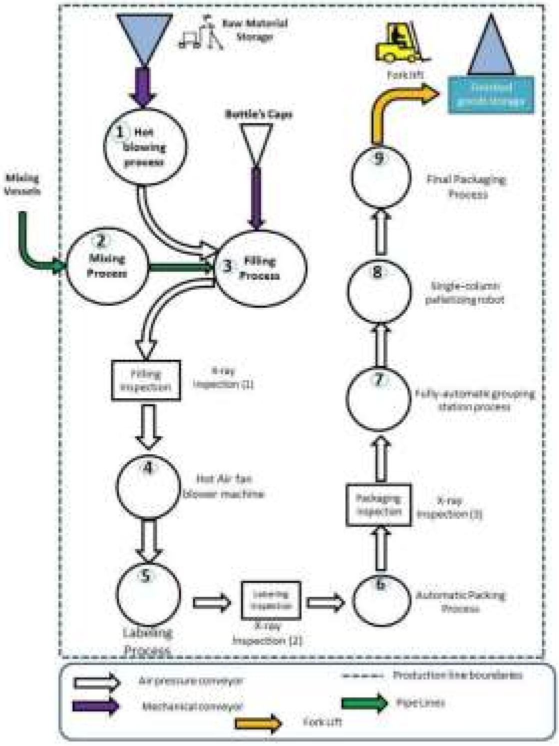
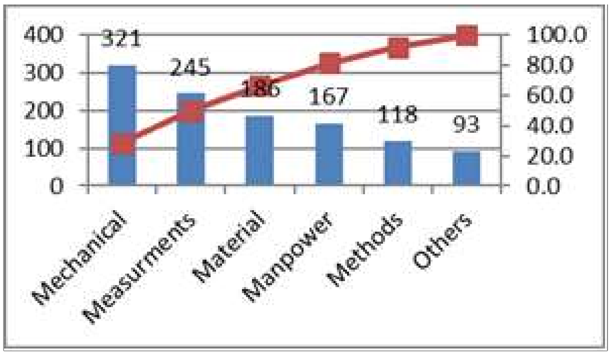


Figure 1: Flow Diagram for production line No. five/ Al-Forat Factory [12]

Production Line No. Five Breakdown

Data are collected along two years in 2014 and 2015 respectively. Although this production line is new; but a lot of stoppages and losses occurred. The company claimed that production line number five in (Al-Forat factory) is facing the highest stoppages and losses [12]. The production line breakdowns are classified throughout 2015. The production line suffers from many breakdowns. These breakdowns vary where Pareto chart will clarify each type as shown in Figure 2. These breakdowns could be classified into;

Mechanical: all kinds of mechanical failures in machines that cause stoppage of the production line, as in hot blowing machine mold. **Measurements:** measurement breakdowns are that there is no regular stopping time for preventive maintenance and the production line is overloaded. **Manpower:** could be human errors like ignoring the fault notification at the control panel. **Methods:** means lack of training for example the application of maintenance instructions for the machines manual is not implemented correctly during breakdown maintenance. Materials: it could be a bad quality of raw materials as the ampules etc. (Others) category includes environment changes that cause failures in heating lamp in hot blowing machine furnace because it requires increasing the temperature degree to the maximum limits.



Frequency of Failure Cumulative percent

Figure 2: Pareto chart for production line breakdowns (Jan - May 2015)

From the previous Figure, it could be noticed that 50% of the failures are due to mechanical and measurements causes, keeping in mind that this line is shut down for planned maintenance according to the contract with KRONES Company. Therefore, it could be concluded that planned maintenance is not enough to resolve breakdowns, OEE, and ORE should be investigated and calculated to reveal losses in production so as to improve effectiveness elements of this production line.

Analysis of Production Line Five

Planned downtime is the time that the production line is down because of; Cleaning, Inspection of machine, Lubrication and tightening, Changing the product type or changing speed and audit. Breakdown time is the time that the production line is down because of failure. Actual production time is the time that production line is producing products. Actual production is the amount of defective and non-defective products. The Designed operating time in mentioned table is calculated as; (24 hr. /day × 30 days / month = 720 hr. /month).

From Table 2 it can be seen that:

- Designed operating time is fixed at (720 hr. /month) except for December 2014 and March 2015 which is (168 hr. /month) since only one week is left before planned maintenance execution.
- Planned downtime value is fluctuating in each month during both years where the highest panned downtime is on April and the least is on December 2014 and that's an indicator that the company does not have a clear program for planned stoppages.
- It can be seen that the breakdown time gets increased whenever the actual production increased until reaching (293hr.) in October 2014 before implementing planned maintenance in December for the same year. Then it gets decreased in fluctuating values until April (196 hr.) where the biggest breakdown time in 2015.
- Max. Actual production time is in August (427 hr.) in 2014 and (516 hr.) on February 2015.
- The maximum actual production in both years is in August 2014 (1098452 bottles) which has almost the least planned downtime value. This clarifies that the planned downtime has a great effect on the productivity.

Table 2: Production Data during (2014) and (2015) years

	Month	Designed Operating Time (hr.)	Planned Downtime (hr.)	Breakdown Time (hr.)	Actual Prod. Time (hr.)	Actual Production Quantity (bottles/hr.)	Defects (bottles)
	Jan	720	422	109.7	188.3	452837	7510
	Feb	720	250	170	342.3	792392	13380
	Mar	720	295	127.7	297.3	808618	15139
	Apr	720	444	96	180	446309	9277
2014	May	720	343	197	180	1031792	16065
	June	720	272	141	307	812994	12882
	July	720	381	212	127	890014	17679
	Aug	720	87	206	427	1098452	18984
	Sep	720	113.5	246	360.5	1019091	16271
	Oct	720	233.5	293	193.5	1041701	15013
	Nov	720	189	260	271	753247	11425
	Dec	168	82	39	47	158868	2790
	Ave		260	175	244	775526	13035
	Jan	720	112	141	467	603869	10269
	Feb	720	87	117	516	743679	14899
	Mar	168	88	25	55	550016	10448
	Apr	720	209	196	315	951767	17883
	May	720	295	108	317	406082	8318
2015	June	720	152	187	381	758366	17061
	July	720	120	95	505	480314	14271
	Aug	720	113	190	417	867154	23596
	Sep	720	114	96	510	501762	12574
	Oct	720	311	171	238	736183	22339
	Nov	720	192	76	452	177148	5322
	Dec	720	336	16	400	97010	2546
	Average		160	118	381	572779	13294

Figure 3 describes production data during 2015. From this figure it could be noticed that the actual production quantity represents (2%) of the designed production quantity (in bottles), and the planned is (8%) of the designed quantity. While Figure 3B shows, the percentage of the actual production times is about (28%).

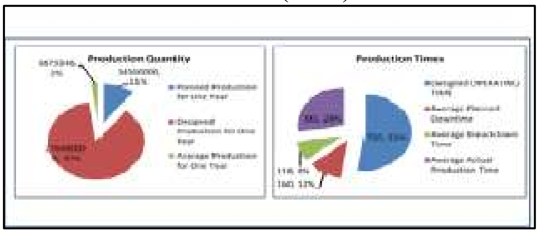


Figure 3: Production data

OEE Tool for Line Five

The collected data for years (2014) and (2015) are employed to calculate OEE values according to the equations 1 to 6. The results are tabulated in Table 3 and 4 below month-by-month according to speed and each factor for the years (2014) and (2015) respectively.

From Tables 3 and 4 it can be seen that;

- In 2014 the company was using two operational speeds are; (4000bottle/hr.) and (2333 bottle/hr.) until March 2015 where they used only the high speed to increase the productivity due to the increase in market demand.
- In August 2014 the maximum OEE values is reported while the least of quality for both speeds, that's because this month is the hottest month in the summer season and the demand for cold drinks increases.
- Although the availability is increased from 37% (average value) in 2014 to 40% (average value) in 2015, the OEE average value is decreased by 2% (from 11% on 2014 to 9% on 2015), while quality average is constant.
- Throughout the two years of this study, indicate the effect of performance (decreased from 28% to 22%) knowing that the production line speed is almost 4000 bottle/hr. (highest production speed). On the other hand, Figure 4 shows the total OEE values for each month in 2014 and 2015, which can be seen that The OEE values are decreasing in both years for the last five months. August 2014 has the maximum percentage, while it is the least in May 2015 in which OEE percent is (2%) noticing that the planned maintenance activities have been employed in March where production rate is expected to increase, that means that the company needs to boost maintenance activities to overcome these low production values. The availability factor for both years is not acceptable and so as for the performance factor as compared to the world class percentage. These two factors have the greatest effect on OEE percentage due to the losses when compared to world class OEE values as shown in Table 5 below.

Table 3: OEE Values for production line five during 2014

Month	Speed [bottle/hr.]	Availability %	Performance %	Quality %	OEE %
Jan.	4000	27	14	98	4
	2333	23	17	97	5.5
Feb.	4000	40	19	97	7
	2333	29	33	97	9
Mar.	4000	31	19	98	5
	2333	49	43	97	20
Apr.	4000	18	10.5	97	1
	2333	43.5	36.5	97	15
May.	4000	41	31.4	98	12.6
	2333	31	28.5	98	8
Jun.	4000	33	23.3	98	7
	2333	62.3	38.6	97.5	23.4
Jul.	4000	36	28.2	97.5	9
	2333	20	15.5	97.5	3
Aug.	4000	60	45.3	96	26.4
	2333	56.3	45.6	96	25
Sep.	4000	48.7	34.5	98	16.4
	2333	50	40	97.5	19.5
Oct.	4000	36.7	32	98	11.5
	2333	36	22	98	7
Nov.	4000	29.3	24.6	97	6
	2333	37	29	97	10
Dec.	4000	26	16	97	4
	2333	31	23	98	6

Average	37	28	97	11

Table 4: OEE Values for production line five during 2015

	Month	Speed [bottle/hr.]	Availability %	Performance %	Quality %	OEE %
	Jan.	4000	38.3	25.3	98	9
		2333	36	27	97	9
	Feb.	4000	31.2	25	97	7
		2333	45.6	30.3	97	13
	Mar.	4000	23	26.4	98	5
2015	Apr.	4000	39	27	98	10
	May.	4000	19.3	14.6	97	2
	Jun	4000	32	22	97	7
	July	4000	35	21	97	8
	Aug.	4000	51	34	97	16
	Sep.	4000	56	27	97	14
	Oct.	4000	52	18	96	9
	Nov.	4000	47	8	97	3
	Dec.	4000	60	8	97	4
	Average		40	22	97	9

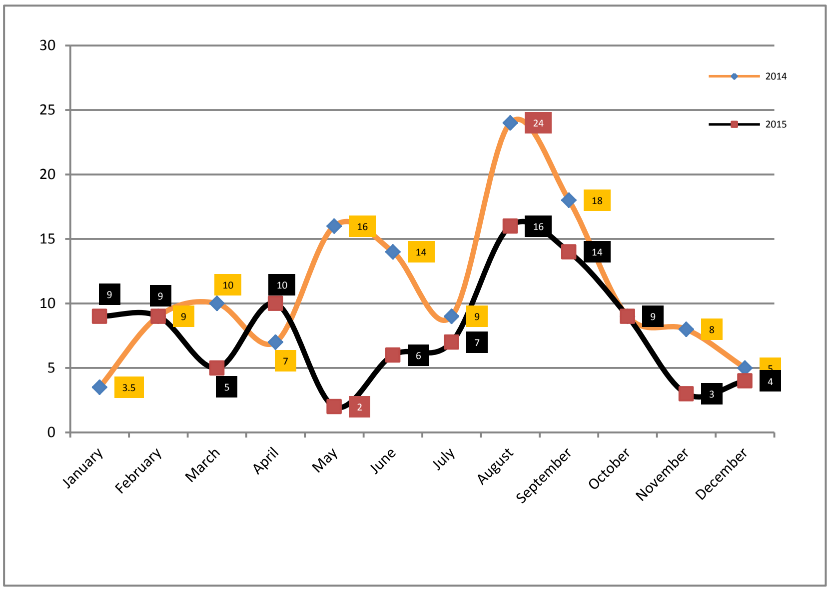


Figure 4: Total OEE during 2014 and 2015

Table 5: Comparison between OEE world class and the resulting values for line five

OEE Factor	Company OEE For 2014	Company OEE for 2015	World Class [12]
Availability	37%	40%	90%
Performance	28%	22%	95%
Quality	97%	97%	99%
OEE	11%	9%	85%

ORE Tool for Line Five

For detailed analysis since ORE measurements process, seven factors are needed; (Readiness, Availability of Facility, Availability of Materials, Availability of Manpower, Changeover efficiency, Performance efficiency and Quality rate). It worth mentioning that some of these factors are already calculated in OEE tool therefore, sample of calculation is conducted for January 2014 according to equations (7 to 17):

1- Readiness (R) for Line Five;

From Table 2 the total time (Planned Operating Time) for January is (720hr.) and the planned downtime is (422hr.), therefore;
Planned production time = 720 – 422 = 298 hr.
R = 298/ 720 = 0.41 = 41 %
2- Availability of Facility (Af) for Line Five;
Loading time = 298 – 109.7 = 188.3 hr.
Af = 188 / 298 = 0.63 = 63%
3- Changeover efficiency (C) for Line Five;
From Table 6, the set-up and adjustments time for January is (15.5 hr.).
Operating time = 188 – 15.5 = 172.5 hr.
C = 172.5 / 188 = 0.91 = 91%

Table 6: Set-Up time for (2014) and (2015) years

Month	Set-Up Time (2014) hrs	Set-Up Time (2015) hrs
January	15.5	14
February	22.5	6.5
March	28.5	2
April	20.5	8
May	29	17
June	45	43
July	90	37
August	36.5	18
September	32.5	12
October	34.5	16
November	12.5	9
December	8	2

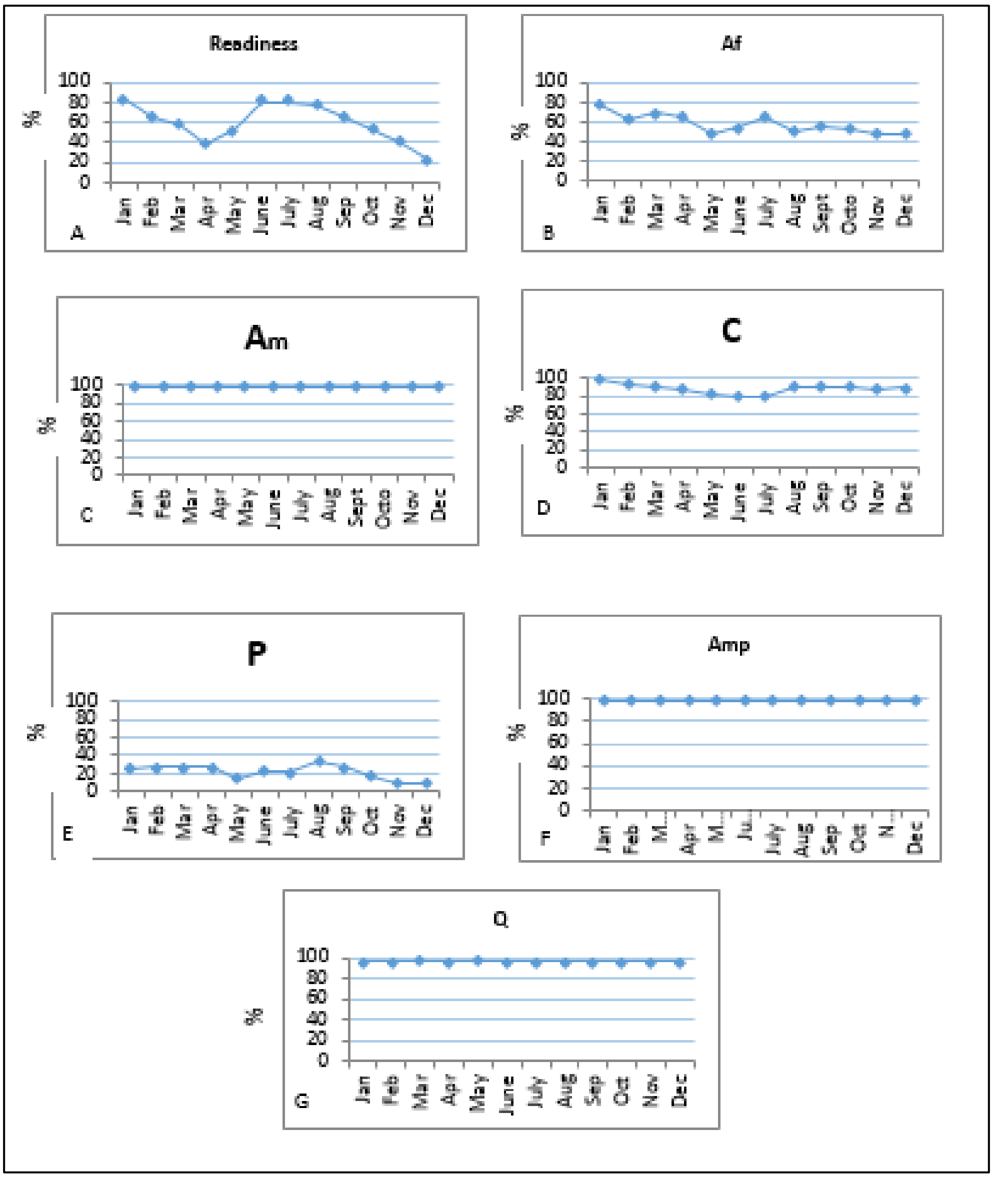
4- Availability of Material (Am) for Line Five;
As there is almost no material shortage in the production line, all the processes that need materials are already and always exist since there are many storage warehouses of different raw materials. Sometimes short delays may occur, for example in the hot blowing process when the machine reloads another package of ampules therefore the time loss due to unavailability of raw materials is assumed to be 1hr. per month.
Running time = 172.5 – 1 = 171.5 hr.
Am = 172.5 / 172.5 = 99%
Thus, this factor is almost negligible throughout research duration.
5- Availability of Manpower (Amp) for Line Five;
There is no absence of the manpower since this production line is fully automated and the operator most always exists to monitor and perform certain activity. The delays that could happen for example sometimes the machines need from operator to perform an activity to continue working, so, the Absence of operator is assumed 1hr per month.
Actual running time = 172.5 – 1 = 171.5hr.
Amp = 171.5 / 172.5 = 99%
6- Performance efficiency (P) for Line Five;
Same value as OEE as shown in Tables 3 and 4.
P = 12%
7- Quality Rate (Q) for line five;
As shown in Tables 3 and 4.
Q = 97%
ORE value is the multiplication of all the above values
ORE = 41% × 63% × 91% × 100% × 100% × 12 %× 97% = 0.027%
Tables 7 and 8 show the whole calculations of ORE tool during (2014) and (2015) respectively. From Table 7 and 8 it can be seen that the average value of ORE for 2014 is (8%) and for 2015 is (7%), this indicates decreasing in exploiting the production resources of this relatively new line. Readiness factor is fluctuating each month that is effected by planned downtime and breakdown times. In 2015, it can be seen that both the changeover efficiency and the ORE results are decreasing in spite of that the company did the planned maintenance in March then it is increased in June and July.
In order to analyze the ORE factors in detail, Figures. 5 and 6 below represent the results of ORE factors during 2014 and 2015 respectively.

Table 7: ORE values of (2014) year

Month	Readiness %	Availability of Facility %	Changeover Efficiency %	Availability of Materials %	Ava. Of Manpower %	Performance Rate %	Quality Rate %	ORE %
Jan.	41	63	91	99	99	15	97	2.7
Feb.	65	63	92	99	99	27.5	97	10.2
Mar.	59	69	90	99	99	29	98	10.4
Apr.	38	65	88	99	99	16	97	3.3
May	52	47	83	99	99	29	98	5.7
June	62	68	85	99	99	29	98	10.1
July	47	37	29	99	99	15	98	0.7
Aug.	87	67	91	99	99	45	96	22.9
Sep.	84	59	90	99	99	37	98	16.1
Oct.	67	39	82	99	99	27	97	5.6
Nov.	73	51	95	99	99	26	97	8.9
Dec.	51	54	82	99	99	20	97	4.3
Ave.	61	57	83	99	99	26	97	8

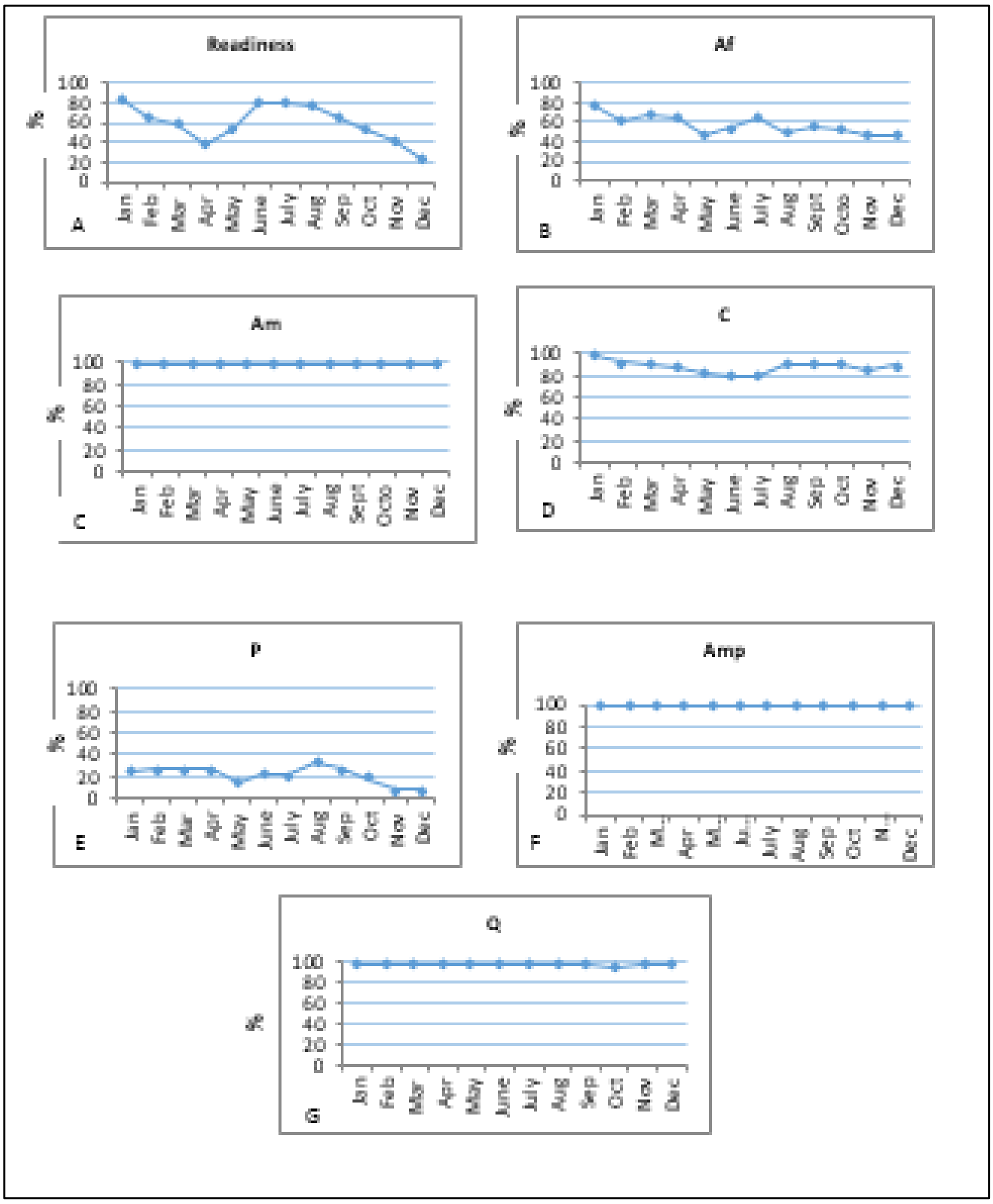
Table 8: ORE values of (2015) year

Month	Readiness %	Availability of Facility %	Changeover Efficiency %	Availability of Materials %	Availability of Manpower %	Performance Rate %	Quality Rate %	ORE %
Jan.	84	76	97	99	99	26	97	15
Feb.	65	63	92	99	99	27	97	9
Mar.	59	69	90	99	99	26.4	98	9
Apr.	38	65	88	99	99	27	97	5
May	52	47	83	99	99	14.6	98	2
June	81	54	80	99	99	22	97	7
July	81	65	79	99	99	21	97	8
Aug.	77	50	90	99	99	34	97	11
Sep.	66	56	90	99	99	27	97	8
Oct.	53	52	91	99	99	18	96	4
Nov.	42	47	86	99	99	8	97	2
Dec.	23	47	89	99	99	8	97	1
Ave.	60	58	88	99	99	22	97	7



(**A;** Readiness, **B;** Availability of facility, **C;** Avaliability of materials, **D;** Changover effecincy, **E;** Performance Rate, **F;** Avaliability of manpower, **G;** Quality Rate)

Figure 5: ORE values during 2014



(**A;** Readiness, **B;** Availability of facility, **C;** Avaliability of materials, **D;** Changover effecincy, **E;** Performance Rate, **F;** Avaliability of manpower, **G;** Quality Rate)

Figure 6: ORE values during 2015

4. Conclusions and Recommendations

Production Line Five is suffering from downtimes and defects mainly due to mechanical and measurements shared by 50%. Two important TPM metrics are used which are; OEE and ORE to reveal losses type and allocation. Result analysis shows decrease in OEE and ORE for the two years of this study, in 2014 they are (11%, 9%) respectively and for 2015 they are (8%, 7%) respectively. It has been found that following aspects has the greatest effect on productivity; Readiness, Availability of Facility, Changeover Efficiency, Performance rate, Planned and Breakdown times. While the quality rate does not reach the world class values as its average value is (97%) it is considered very acceptable and stable through 2014 and 2015 but still is less than that of PepsiCo Inc. specification of (99%). The company works using planned maintenance only which has been implemented in December 2014 and March 2015 but it is not enough to increase the productivity and eliminate losses because of the inappropriate usage of resources. Detailed analysis shows low performance rate that decreased from (28%) in 2014 to (22%) in 2015. Therefore, it is recommended to use a dedicated software that reveal day-by-day losses and their spot, also it is recommended to employ TPM in this production line to boost maintenance activities and therefore increase productivity.

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