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Automated Monitoring and Measuring Improvement of Production System Performance

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Abstract: *Overall equipment effectiveness OEE represents a set of key characteristics that allows monitoring the efficiency and productivity of the manufacturing processes. The main purpose of any OEE initiative is to become the most efficient, most effective manufacturer within a market, minimizing the main losses. Overall line effectiveness OLE is another OEE related to measure productivity of production line. It is a powerful metric of manufacturing performance incorporating measures of the availability, performance efficiency, and quality of a given processes along the manufacturing line. There are many methods exist by which productivity could be analyzed and improved, such simulation software that allows users to monitor and identify the problems faced for improving the productivity of the company.*

In the present paper a simulation program (OLE analyzer program) developed to monitor production system and identify the line based on OLE. The methodology depends on developing the OLE metrics to be more accurate and suitable for implementing on a production line that all involving number of machine arranged in series and parallel. It deals with each machine in the production line with its actual performance. The proposed methodology was applied to a case study where the OLE metric were 46.84% related to the six big losses (breakdown, setup, idle time, reduced speed, time loss, reject on startup, and production reject), and low development of losses improvement were assessed.

The study suggested the area of weakness suffer from lack of learning orientation that is ought to be improved and at the same time, a variety of specific recommendations are provided. After implement the computer software methodology, the improvements plan the OLE value increased to 68.94%.

Keywords: *Overall equipment effectiveness – overall line effectiveness – OLE analyzer program.*

I. Introduction

Markets competitions challenges are facing companies to implement various productivity improvement efforts to meet the needs of ever changing market demands. The total productive maintenance paradigm, launched by Nakajima **[1],** has provided a quantitative metric for measuring productivity of an individual production component. The purpose of Overall Equipment Effectiveness OEE was firstly defined. OEE utilized to evaluate the progress of the Total Productive Maintenance TPM philosophy through the measure of individual equipment. Nakajima recognized and categorized the main losses related to availability, performance, and quality. He established the “six big losses” as follows:

1- Start up and yield losses at the early stage of production,
2- Setup and adjustment for product mix change,
3- Production losses when temporary malfunctions occur,
4- Differences in equipment design speed and actual operating speed,
5- Defects caused by malfunctioning equipment, and
6- Poor productivity and lost yield due to poor quality.

However, due to it is widely spreading in industrial use and effectiveness as a performance measurement for individual equipment. Further research has attempted to expand the application scope of OEE to entire processes, workshops, factories and production planets. In addition, its evaluating scope has also been expanded through the inclusion of more detailed elements of performance than just availability, performance and quality. Sherwin **[2]** proposed overall process effectiveness to measure the performance of whole production processes. Nachiappan and Anantharam **[3]** introduce a definition of Overall Line Effectiveness, to evaluate the effectiveness of a continuous product line manufacturing system. They used a systematic methodology based on overall equipment effectiveness OEE metrics to model the productivity of a line manufacturing system in terms of OLE. Computer simulation was carried out for the evaluation of the OLE, identifying the bottle-neck machines and the effect of specific contributing parameter for improvement. Braglia et al. **[4]** presented overall equipment effectiveness of a manufacturing line to assess the performance of a production line. Oechsneret al.

[5] proposed overall FAB effectiveness to measure the performance of an entire factory. On the other hand, Garza-Reyes **[6]** developed Overall Resource Effectiveness, which also considers material efficiency and variations in material and process cost as part of the evaluation of overall effectiveness, see also Garza-Reyes et al. **[7]**. Although OEE was mainly designed to monitor and control performance, Dal **[8]** suggests that the role of OEE goes far beyond the task of just monitoring and controlling. This is because OEE takes into account process improvement in iterative, prevents the sub-optimization of individual machines or production lines, provides a systematic method for establishing production targets, and incorporates practical management tools and techniques in order to achieve balanced view of process availability, performance and quality. Moreover, OEE can be used as an indicator of process improvement and as an approach to achieve it. Dal et al. **[9]** used it to measure the improvement of a process within a manufacturing environment. Bamberet al. **[10]** remark that OEE is often used as a driver for improving the performance of a business by concentrating on quality, productivity and machine utilization issues and hence aimed at reducing non-valued adding activities often inherent in manufacturing processes. In the case study by Dal et al. **[9]**, it was reported that OEE not only helped to measure the improvement in the area in which it was implemented but also that it enabled new levels of performance measurement to be introduced.

There are software package **[13-14-15]** can be used to calculate OEE automated like CMMS, ShopVue OEE, and GainSeeker. This software's can determine the OEE value and plot the charts of its quality, availability, and performance.

In the present study a computer software package is created to calculate OEE, OLE values through calculate the losses in time for process of the productivity line and give a percentage chart for this losses times. Also the charts of availability, performance, and quality values can be draw before and after improvement processes to make the comparison for this process losses time easy. The report for productivity line for each shift can be get daily, weekly, and monthly. Finally the software can draw a chart value for each losses times during the productivity process.

To implement automated monitoring a real world industrial case is studied. A case study (Ideal Standard Egypt- Company of bathtubs version Florida) used to applied the software in each productivity process to decrease the time losses during this process to increase the productivity range.

II. Case Study Specifications

The company included 6 departments (Heating, Forming, Coating, Drying, Trimming, Finishing, and Testing & Packing) as show in **Figure1** working 24 hours daily in 3 shifts at 5 separated product lines and the production rate for each line is 80 bathtub/shift.

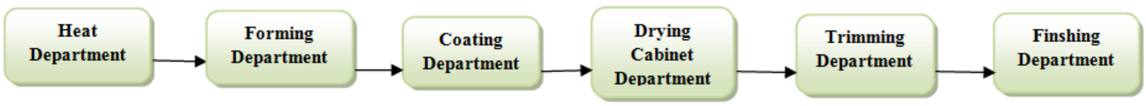


Figure 1: Schematic Layout of the Manufacturing Departments

There are big time losses related to;

- Startup rejects (acrylic sheet defect, heated acrylic sheets rejects, bathtub defects, bathtub reject, visual bathtub inspection, and final test for bathtub reject).
- Idle time (waiting for material, forklift, heated sheet, mould, bathtub, grease the machine, and operator unavailable).
- Setup and adjustment (setup preparation, cleaning sheet, adjustment sheet, changing tools, balance adjustment, cleaning, mix the chemical material for coating, visual inspection for acrylic sheet, bathtub, wooden frame, jigsaw, and product inspection).
- Production rejects (scrap, and rework).
- Speed loss (low temperature, slow evacuations, speed of fan, blinder, moving belt, saw machine, drilling machine, emery machine, and stretching machine).
- Breakdown (failure of oven, fan, forming machine, dry cabinet, moving belt, drilling machine, saw machine, emery machine, spray gun, air pump, and stretching machine).

This losses cause a lost time in the all departments within 24-146 hr/week as show in **Table1**.

Table 1: Time Losses during a Working Week for the Manufacturing Department

Manufacturing Department	Big Time Losses (hr/week)						Total Time Loss for each Department (hr/week)	Run Time for each department (hr/week)
	Startup Rejects	Idle Time	Setup and Adjustment	Production Rejects	Speed Loss	Breakdown		
Heating	-	13	18	2	4	10	47	120
Forming	-	31	95	6	4	10	146	120
Coating	3	39	22	4	2	48	118	120
Drying Cabinet	4	7	8	1	2	2	24	120
Trimming	2	8	12	2	1	6	31	120
Finishing, Testing, and Packing	3	8	11	8	0.5	4	34.5	120
Sum of Big Loss Time (hr/week)	12	106	166	23	13.5	80	400.5	720

Compared with the actually run the time loss found within range 1.7% (related to startup reject) and 23.2% (related to setup and adjustment). Six big time losses for the manufacturing departments through one week working time show in **Figure2**.

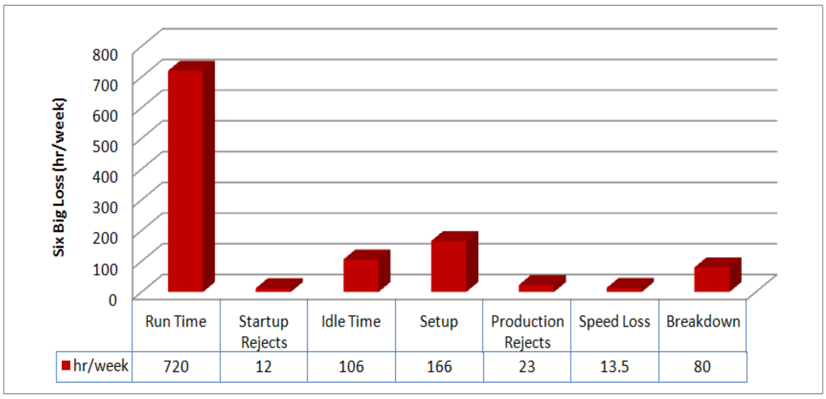


Figure 2: Big Six Time Losses for Manufacturing Departments through One Week

Table 2: Quantity Losses during a Working Week for the Manufacturing Department

Manufacturing Department	Big Losses		Quantity Products Losses for each Department (piece/week)
	Startup Rejects	Production Rejects	
Heating	19	10	29
Forming	11	25	36
Coating	15	44	59
Drying Cabinet	-	22	22
Trimming	10	34	44
Finishing, Testing, and Packing	13	54	67

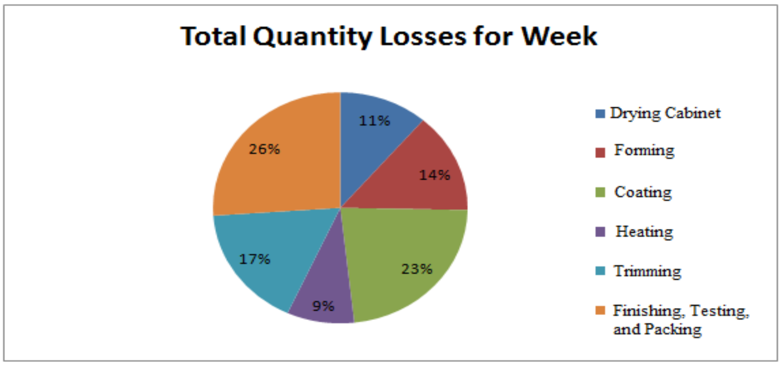


Figure3: Quantity Losses for each Department Weekly

As show in Table 2 during working week the quantity pieces lost were within 22-67 piece/department. The biggest losses in quantity were found in finishing department and the lower value was found in drying cabinet department as **Figure 3** explained.

The created software package is developed by Visual basic program; it's helpful for any industry which is willing to implement the overall equipment effectiveness (OEE) concept. This software depends on implement automated monitoring and collects continuous measurements manually to improve the productivity of the industry company.

III. Theoretical Equations Used In the Program

The OEE, and OLE values can be calculating theoretically using David's equations **[16].**

OEE = A × P × Q (1)

Where;
A = Availability
P = Performance efficiency
Q = Quality rate

$$\textbf{Availability}\ \% = \frac{\text{Loading time} - \text{breakdown} - \text{setup}}{\text{Loading time}} \times 100 \quad (2)$$

Where;
Loading time = planned production time - breaks - planned maintenance time
Loading time: is the time that the machinery planned to be in operation.
Planned downtime: refers to the amount of downtime officially scheduled in the production plan.
Breaks: is the lunch time or rest time.
Breakdown: equipment downtime involves equipment stoppages losses resulting from failures.
Setup: setup and adjustment procedures or the exchange of dies.

$$\textbf{Performance}\ \% = \frac{\text{Run time} - \text{Minor stoppages} - \text{Reduced speed}}{\text{Run time}} \times 100 \quad (3)$$

Where;
Run time: it refers to the time during which the equipment is actually operating.

$$\textbf{Quality}\ \% = \frac{\text{amount of produced units} - \text{amount of defect units} - \text{amount of reprocessed units}}{\text{amount of produced units}} \times 100 \quad (4)$$

OLE = $A_{line} \times P_{line} \times Q_{line}$ (5)

Where;
A_{line} = Line Availability
P_{line} = Line Performance Efficiency
Q_{line} = Line Quality Rate

$$\mathbf{A}_{\boldsymbol{line}} = 1 - \left[\frac{\sum_{i=1}^{n} \mathrm{T}bi - \sum_{i=1}^{n} \mathrm{T}si}{\sum_{i=1}^{n} \mathrm{SL}i + \sum_{i=1}^{n} \mathrm{B}i - \sum_{i=1}^{n} \mathrm{PD}i}\right] \times 100 \quad (6)$$

Where;
n: number of equipment per line
$\mathbf{T}_{bi}$**:** breakdown time of machine number *i*
$\mathbf{T}_{si}$**:** setup time of machine number *i*
$\mathbf{PD}_i$ **:** Planned down time for machine *i*
$\mathbf{SL}_i$**:** scheduled time of operation for machine *i*
$\mathbf{B}_i$**:** scheduled time of breaks for machine *i*

$$\boldsymbol{P_{line}} = 1 - \left[\frac{\sum_{i=1}^{n} \mathrm{T}rdi - \sum_{i=1}^{n} \mathrm{T}rsi - \sum_{i=1}^{n} \mathrm{T}rpi}{\sum_{i=1}^{n} \mathrm{T}oi}\right] \times 100 \quad (7)$$

Where;
$\mathbf{T}_{oi}$**:** Operating time of machine number *i*
$\mathbf{T}_{rdi}$**:** Idle time of machine number *i*
$\mathbf{T}_{rsi}$**:** Reduced speed time of machine number *i*
$\mathbf{T}_{rpi}$**:** Time loss for repair product produced from machine number *i*

$$\boldsymbol{Q_{line}} = 1 - \left[\frac{\sum_{i=1}^{n} \mathrm{P}rji}{\sum_{i=1}^{n} \mathrm{P}pi}\right] \times 100 \quad (8)$$

Where;
P_{pi}: Total pieces of machine number *i*
P_{rji}: Reject pieces of machine number *i*

Overall Line Effectiveness Value before improvement can get from equation (5) as follow;
OLE = $A_{line} \times P_{line} \times Q_{line}$
Availability (A_{line}) = 64.17%
Performance (P_{line}) = 77.73%
Quality (Q_{line}) = 93.9%
OLE = 0.6417 x 0.7773 x 0.939 = 0.4684 = 46.84%

IV. Oee Analysis Program

Implementation a monitoring process on a production line and measuring time loss during production processes to be collected into OEE analysis computer program. This program used for reporting the measured and collected data to help in detecting the value of losses during production processes, calculate OEE and factors value. The program also shows results in a main report, shift losses report, and result report. These results used for higher production line effectiveness and for higher productivity. OEE analysis program's flow chart shown in **Figure4**.

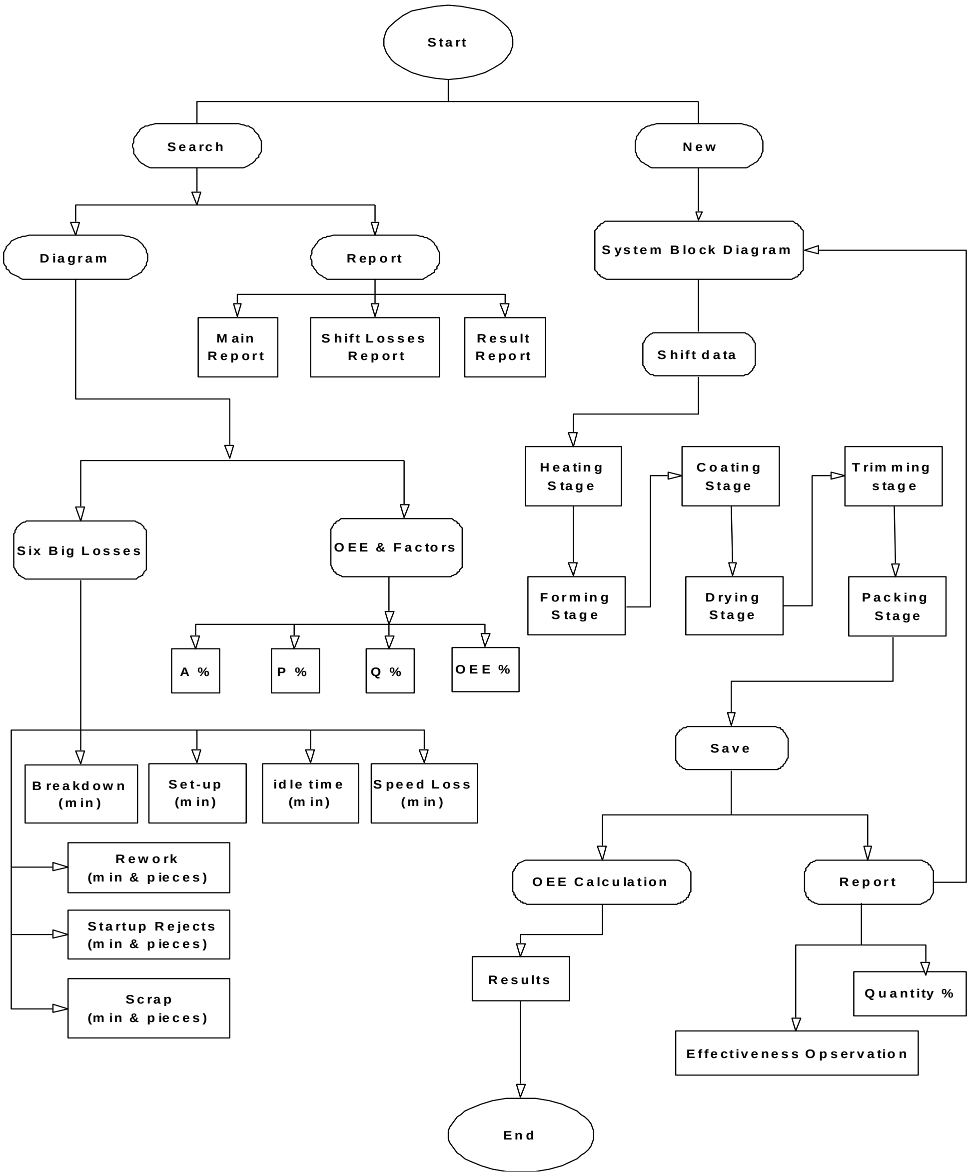


Figure 4: Flow Chart of the OEE Analysis Program

The software forms as shown in **Figure 5** contain the access to make the new and search processes. New process mean run new operation, which is input measured data during production processes per shift into system block diagram forms. Search process mean run a search for the stored data.

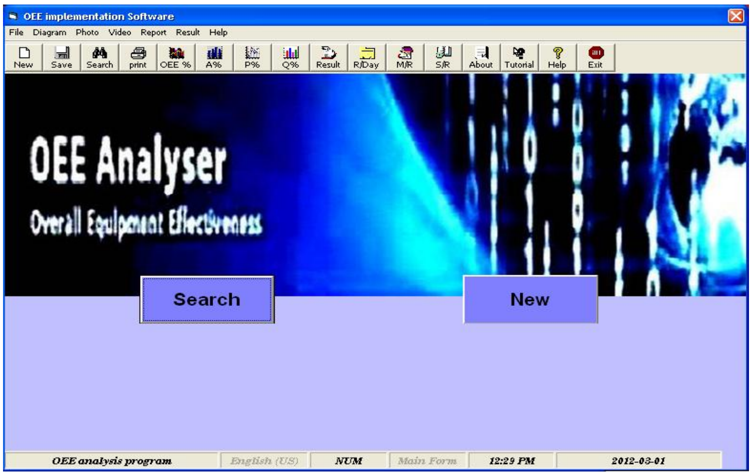


Figure 5: Start Form Window

The new process have a several forms to explain the block diagram of the manufacturing processes and the time losses for each process also as shown in **Figures 6, 7**. Also the shift time losses and OEE values calculated in forms shown in **Figures 8, 9**.

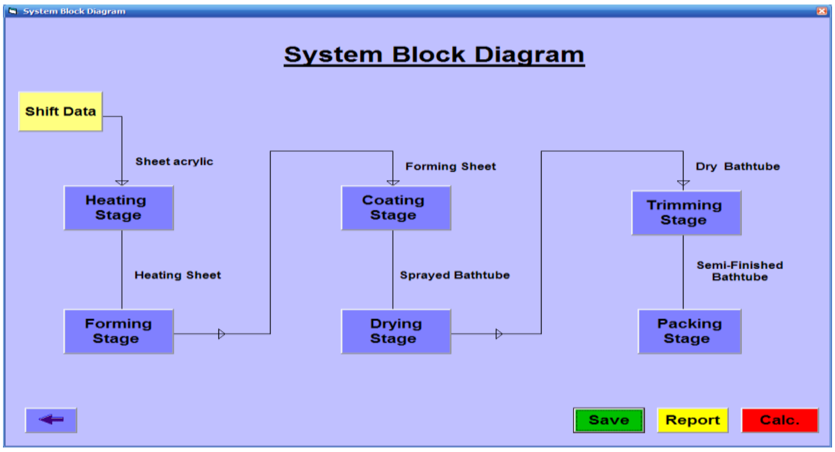


Figure 6: Manufacturing Processes Block Diagram

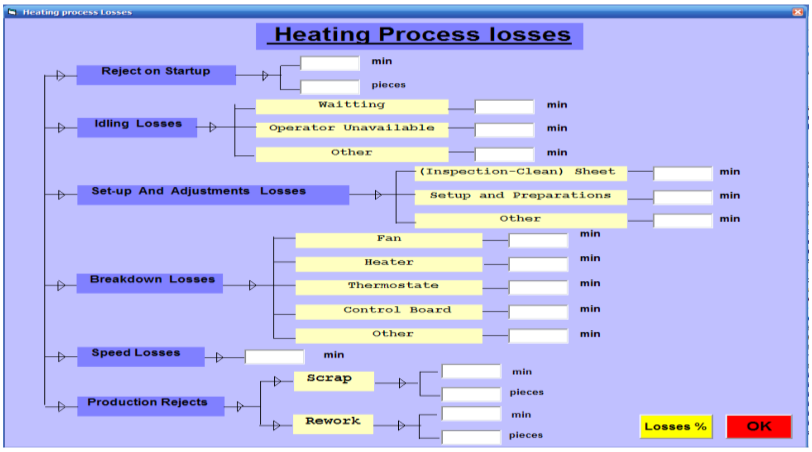
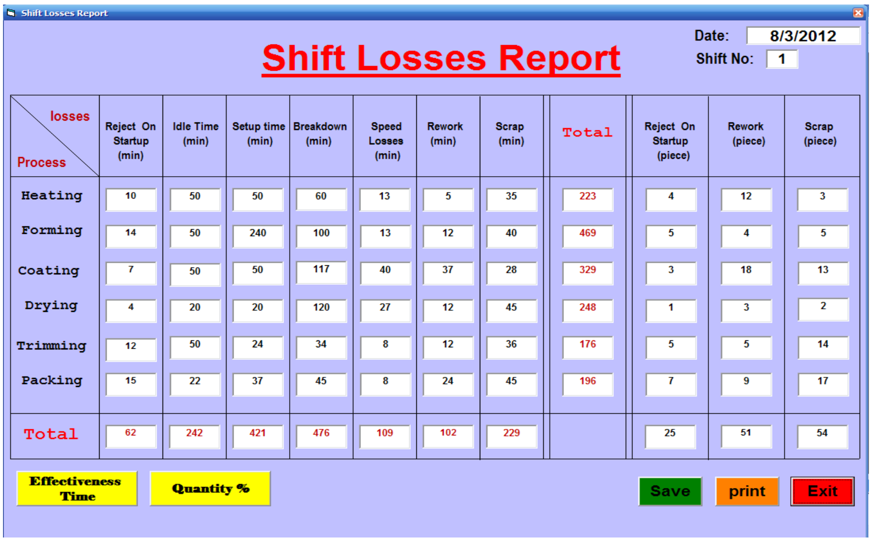


Figure 7: Losses Time during Heating Process



losses / Process	Reject On Startup (min)	Idle Time (min)	Setup time (min)	Breakdown (min)	Speed Losses (min)	Rework (min)	Scrap (min)	Total	Reject On Startup (piece)	Rework (piece)	Scrap (piece)
Heating	10	50	50	60	13	5	35	223	4	12	3
Forming	14	50	240	100	13	12	40	469	5	4	5
Coating	7	50	50	117	40	37	28	329	3	18	13
Drying	4	20	20	120	27	12	45	248	1	3	2
Trimming	12	50	24	34	8	12	36	176	5	5	14
Packing	15	22	37	45	8	24	45	196	7	9	17
Total	62	242	421	476	109	102	229		25	51	54

Figure 8: Losses Time during Manufacturing Processes

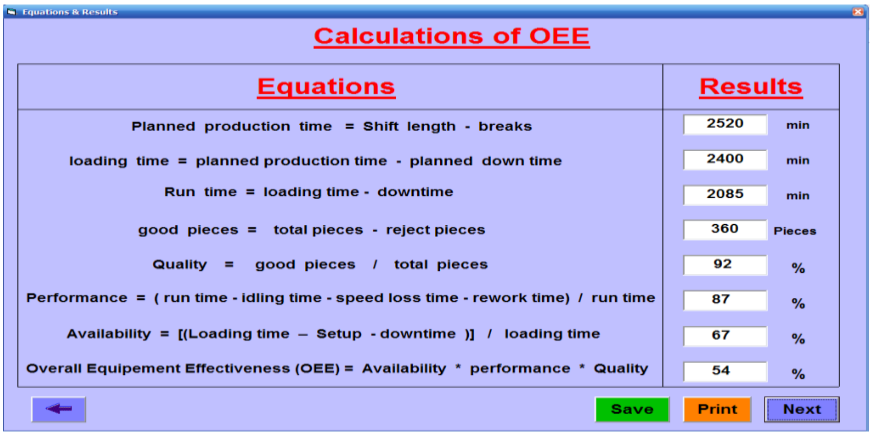


Figure 9: OEE Calculations

The search process also has form for finding any saving data and a different time of reports, main, shift losses, and result report as shown in **Figure 10**.

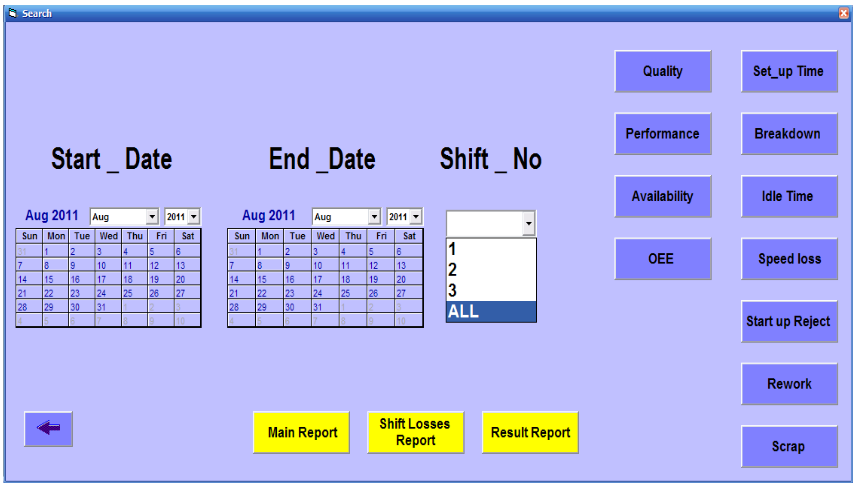
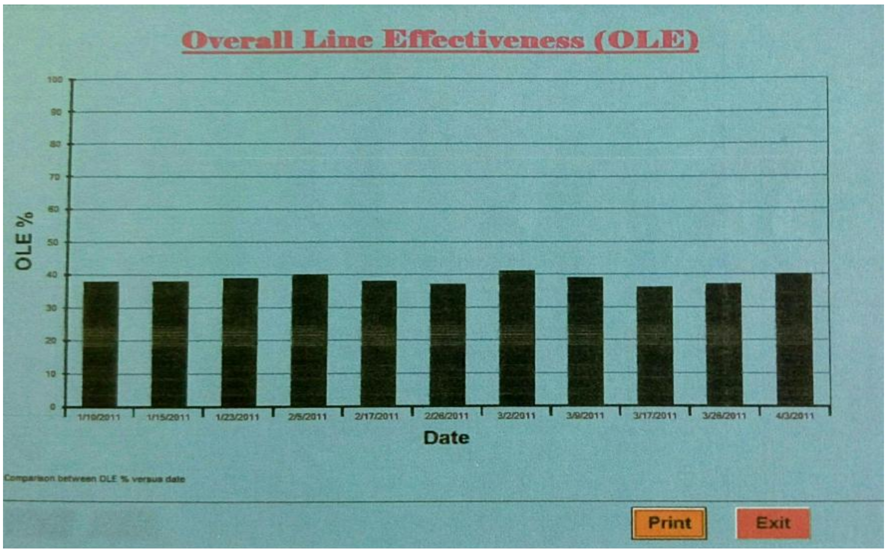


Figure 10: Search Form

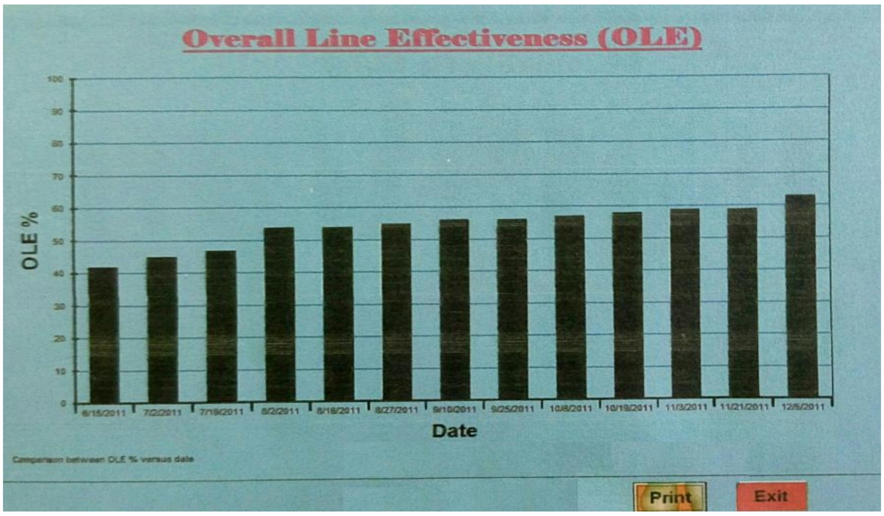
V. Results and Desiccations

By using OEE analyses software the OLE value improved as a results of decreasing the shift losses time and department quantity losses as **Figure 11 (a-b)** explained. This improvement takes around 8 months monitoring the production line after improvement gives a new data.

OLE = $A_{line} \times P_{line} \times Q_{line}$
Availability (A_{line}) = 84.03%
Performance (P_{line}) = 87. 37%
Quality (Q_{line}) = 93.9%
OLE = 0.8403 x 0.8737 x 0.939 = 0.6894 = 68.94%



(a)

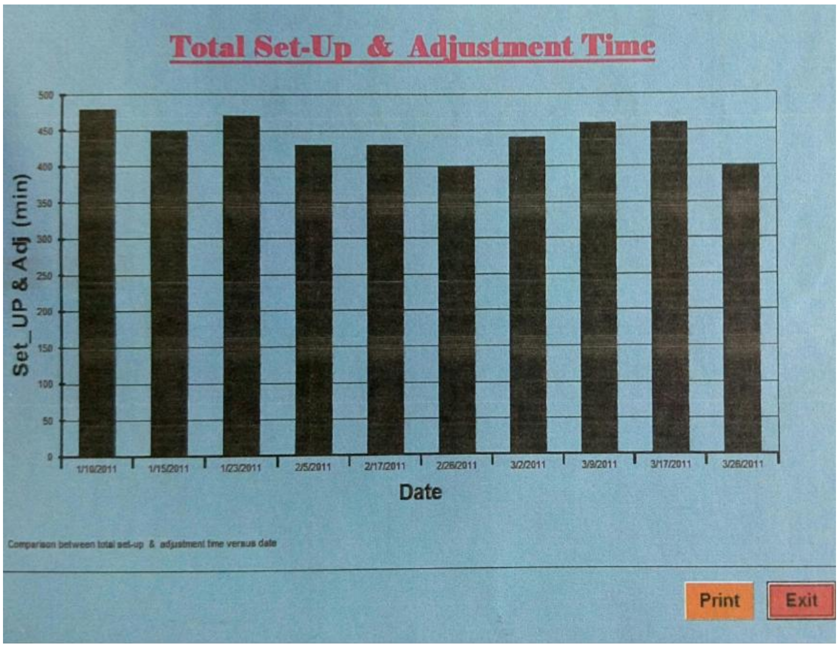


(b)

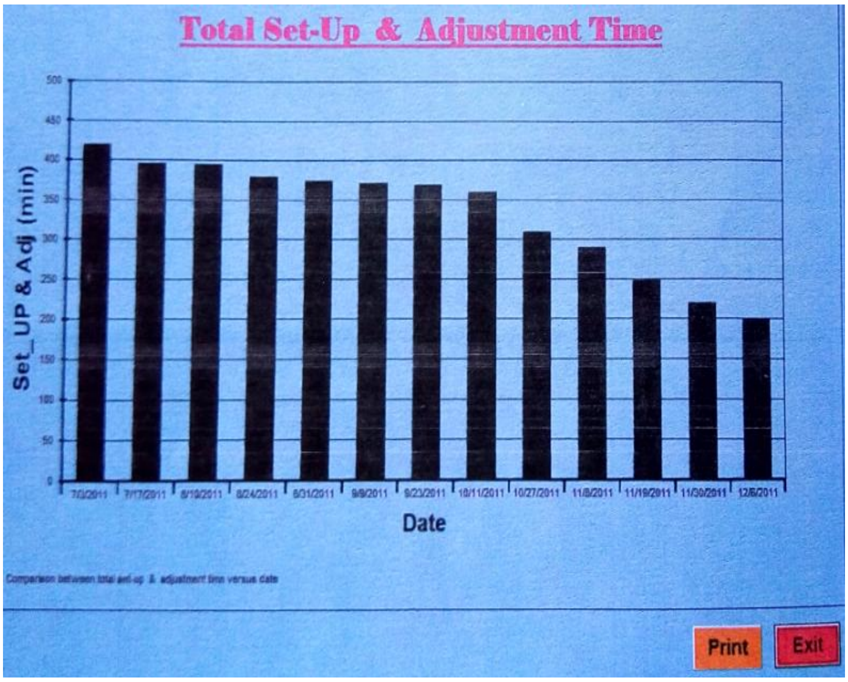
Figure 11: OLE Values **(a)** Before Improvement **(b)** After Improvement

The OLE value improves by 1.5% after using the OEE analysis software. The values of time losses also decreased after used the program. The biggest losses time values were found in set-up& adjustment, breakdown and idle losses time which also decreased after using the analysis software.

As shown in **Figure 12,** the set-up & adjustment cause time losses 410 min/shift and after using the program it decreased to 200 min/shift, it is meaning that the time set up losses time improved by 48.8% after using the analysis program.



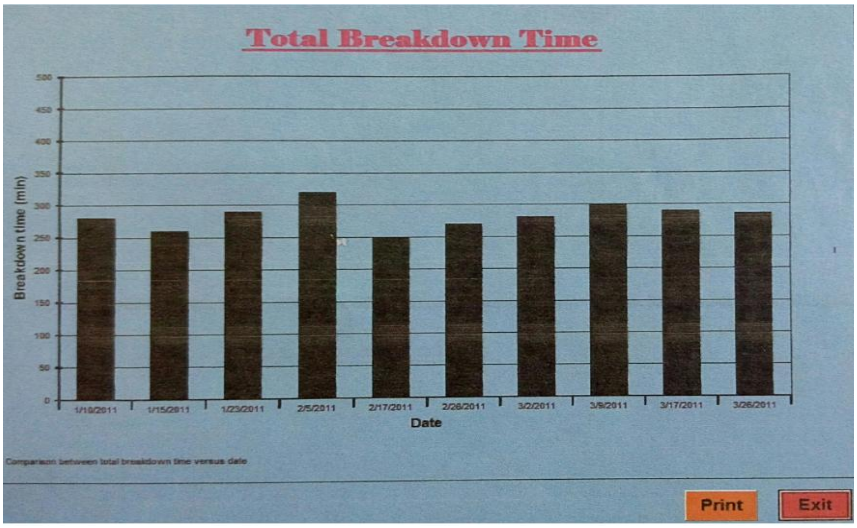
(a)



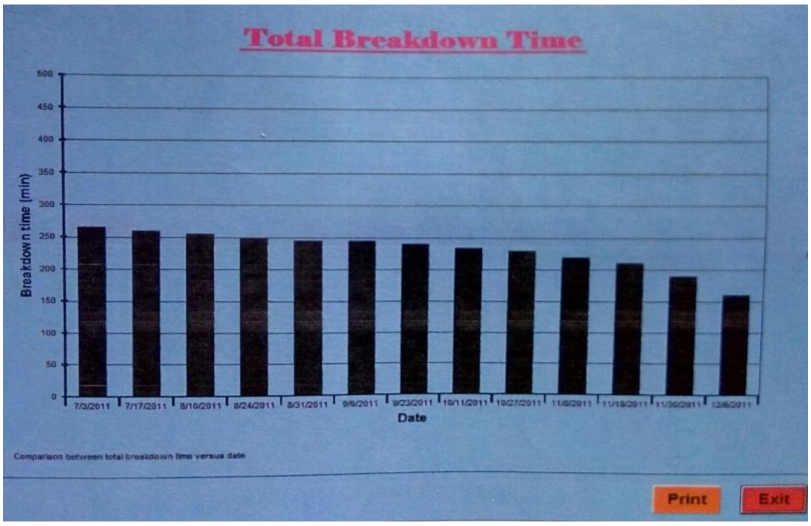
(b)

Figure 12: Set-Up and Adjustment Time Losses **(a)** Before improvement **(b)** After Improvement

Also the breakdown losses time improved by 59.3% after using the software, it decreased from 270min/shift to 160min/shift.



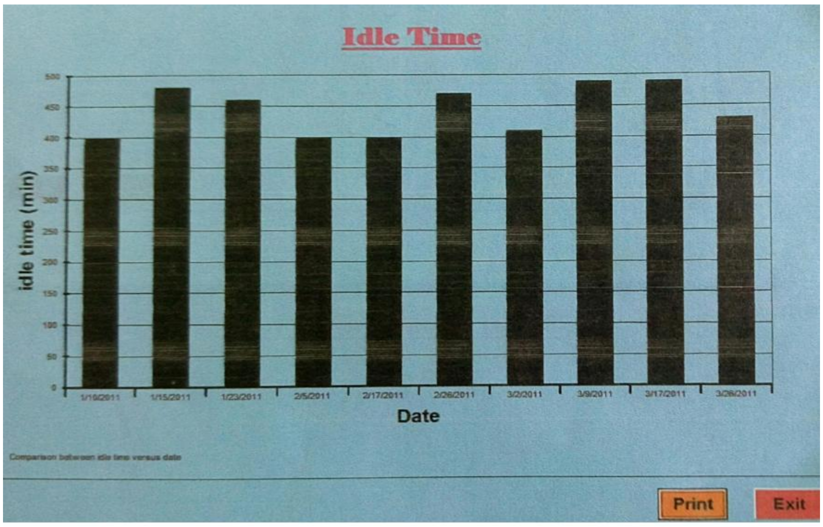
(a)



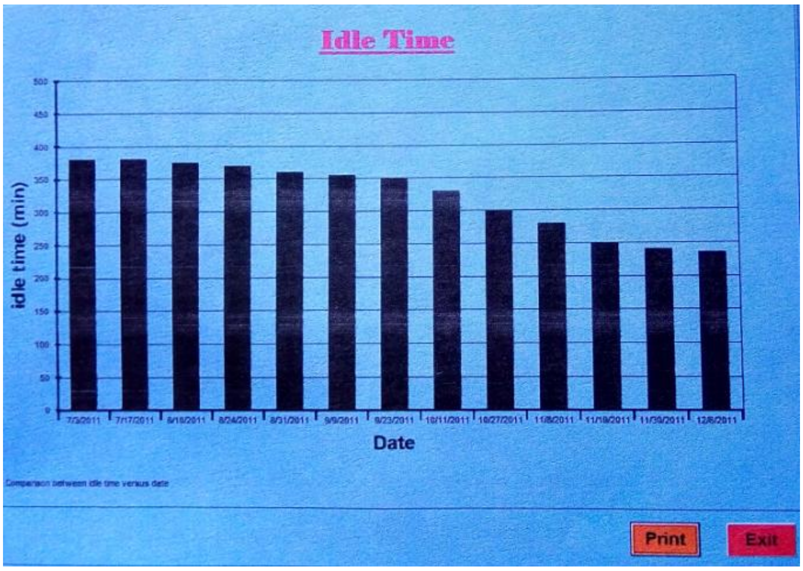
(b)

Figure 13: Breakdown Time Losses **(a)** Before improvement **(b)** After Improvement

The idle losses time decreased from 460 min/shift to 240 min/shift with decreasing percentage 52.2% after using OEE analysis software as shown in **Figure 14**.



(a)



(b)

Figure 14: Idle Time Losses **(a)** Before improvement **(b)** After Improvement

VI. Conclusion

Overall line effectiveness (OLE) analyzer using easy and popular tools. It is a good index for many organizations to help themselves to find out where is the root causes for failures and losses. Furthermore, the value of OLE can help the organizations to recognize the gap from benchmark criteria in the same industry.

Thus the main conclusion of this paper can be summarized in the following points;

- A methodology of the overall line effectiveness calculation has been developed and validated on a case study.
- Validation shows high efficiency and sensitivity of the applied methodology.
- The OLE calculation on the production line as existed shows very poor effectiveness with value 46.84%.
- The analysis of OLE parameters show big losses in setup and breakdown, improvement procedures has applied to the production line.
- The running of the new data on the OLE analyzer predicts a respect the change in OLE, its results 68.94% effectiveness. This means that the developed analysis tool is very efficient in diagnosing the problem and very sensitive to any changes.

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