Overall Equipment Effectiveness Analyse for Performance of CNC Milling Machine Operation

Hernadewita¹, Hermiyetti², Hendra³, Syukriah⁴, R. Astari, Br. Surbakti⁵, and Dewi Auditiya Marizka⁶

¹Industrial Engineering, University of Mercubuana, Jakarta
Jl. Menteng, Jakarta Indonesia
²Faculty of Economics, Bakrie University, Jakarta
³Mechanical Engineering Dept. University of Bengkulu, Bengkulu
⁴Industrial Engineering University of Malikussaleh, Lhokseumawe, Aceh
⁵PT Miaramas Plantation (Sime Darby Group), Jakarta
⁶Industrial Engineering Dept. Polytechnic of Management Industry Jakarta
Co: Email: hadeita@yahoo.com, h7f1973@yahoo.com, hermi_yetti99@gmail.com,

Abstract. Overall equipment efficiency (OEE) is a large part of the maintenance system used by Japanese companies; Total Productive Maintenance (TPM). The value of OEE is affected by the often problematic production activities in machinery/production equipment such as damage to machine components resulting in reduced production, lowering engine production speed, preparation length and adjustment time, resulting in defective products and operating machines but not producing products. This paper will focus on the overall equipment efficiency of CNC Milling machine. The indicators of data parameter are used planned downtime, ideal cycle times, real-time cycles and daily operator reports (daily schedule controls) and direct data retrieval in the field. Where OEE calculation depends on availability, performance of efficiency, and rate of quality. The result has shown that the value of availability is 87%, performance of efficiency is 93% and OEE is 74%.

1. Introduction
The automotive and steel industries use several heavy equipment and control component in facilitating the transportation of components [1-2]. Roller, tube, excavator, etc. include heavy equipment that were often used in handling of component on production line, where heavy equipment and components which produced by machining and casting process [3-6]. For controlling the quality and movement component, it can be done by using PLC, microcontroller and other control system [7-8]. machining process was requires machine tools such as lathe, milling machine, shape machine, CNC milling machine, drilling machine and other auxiliary equipment [3]. All types of machines and equipment require regular maintenance and repair. The routine of maintenance schedule or repairing process is sometimes could not come and touching the cause of machine utility. This might be affected to the quality and quantity of products. For this reason, the proper use of maintenance in the case of machine tools and auxiliary equipment should applied to meet the quality and quantity of products based on standard [9]. Use of routine maintenance in periodic maintenance scheduling and checking the state of each component in the machine tools (prevention and prediction) so that the improvements can be made to the efficiency of machine tools.
The proposed improvements to machine tools are expected to be implemented effectively and efficiently. Effective and efficient improvements can be made by measuring machine performance and production equipment in the form of overall equipment effectiveness (OEE) [10]. Overall equipment efficiency (OEE) is a large part of the maintenance system used by Japanese companies, total maintenance productive (TPM) [11]. The value of OEE is affected by the often problematic production activities in machinery/production equipment such as damage to machine components resulting in reduced production, lowering engine production speed, preparation length and adjustment time, resulting in defective products and operating machines but not producing products.

This paper will focus on the effectiveness of the entire equipment of weight-bearing activities using the CNC Manufacturing process. The indicators used are the data on planned downtime, ideal cycle times, real-time cycles and daily operator reports (daily schedule controls) and direct data retrieval in the field. Where OEE calculation depends on availability, performance of efficiency, and rate of quality. The value of OEE for each company will meet the world-class standards if they meet the following criteria: 90% availability, 95% performance, 99.9% quality, so that the average world class standard is 85% OEE.

2. Method
Experimental method is used in this research. Collected data by measurement time of operation process of CNC Milling machine. Analysis data has done by calculated the overall equipment effectiveness (OEE) depend on the time of processing process of product such as work time, delay time, breakdown time (maintenance time), downtime (set up time and adjustment time), availability value (loading time, down time, operation time), cycle time, normal time, standard time, performance efficiency, rate quality and overall equipment effectiveness (OEE).

Calculation of OEE depend on availability, performance efficiency and rate of quality. Calculation formula of OEE can be seen by Equation 1.

\[
OEE\% = \text{Availability}\% \times \text{Performance efficiency}\% \times \text{Quality rate}\% \quad [1]
\]

Where:

- Availability is:
  \[
  \text{Availability} = \left( \frac{\text{loading time} - \text{downtime}}{\text{loading time}} \right) \times 100\% \quad [2]
  \]

- Performance of efficiency is:
  \[
  \text{Performance efficiency} = \left( \frac{\text{Processed amount} \times \text{Ideal cycle time}}{\text{Operation time}} \right) \times 100\% \quad [3]
  \]

- And rate of quality is:
  \[
  \text{Rate of Quality} = \left( \frac{\text{Processed amount} - \text{Defect amount}}{\text{Processed amount}} \right) \times 100\% \quad [4]
  \]

3. Results and Discussions
In data processing in the overall Equipment Efficiency Survey (OEE) research, data has been collected on CNC Manufacturing machines such as planned leisure data, ideal cycle times, actual cycle times and daily operator reports (daily schedule controls) and direct data retrieval in field.

3.1 Production data of door 3 Assy.
Data production of door 3 assy can be seen in Table 1. Table 1 shows that the total product, gross product and defect for 1 year. As shown in Table 1, the total of gross product is 1101 pieces and defect product is 90 pieces. Product defects depend on 71 pieces rework and 19 pieces scrap.

3.2 Work time and delay time of machine
Availability work time data depend on total work day/month and total work time per day (24 hours). Availability work time can be calculated by formula:

\[
\text{Availability time/month} = \frac{\text{Total Work D/M} \times \text{Total Work Time (h)} \times \text{Time (min)}}{21 \text{ day/month} \times 24 \text{ h} \times 60 \text{ min}}
\]

\[
\text{Availability time/month} = \frac{30240 \text{ minute}}{21 \text{ day/month} \times 24 \text{ h} \times 60 \text{ min}} = 0.30240 \text{ hour}
\]

Total annual data can be seen in the Table 2.
Total delay time for machine consist on the cleaning time, planned downtime, warm up time, general breakdowns, machine break and power cut-off. Total delay time machine in this research is 138548 minute as shown in Table 3 where the value of cleaning time are 3610 minute, 100035 minute for planned downtime, 3542 minute for warm up time, 8002 minute for general breakdown, 21988 minute for machine break and 1371 minute for power cut off. This value shows that the effect of planned downtime and machine break give more value for total delay time. Therefore the value of total delay time for machine is larger due to time for planned downtime and general breakdowns increased.

| Month | Total Product (pieces) | Gross Product (pieces) | Defect (pieces) |
|-------|------------------------|------------------------|-----------------|
|       |                        |                        | Rework | Scrap | Total |
| March | 106                    | 98                     | 6      | 2     | 8     |
| Apr   | 102                    | 95                     | 6      | 1     | 7     |
| Mei   | 95                     | 86                     | 7      | 2     | 9     |
| June  | 100                    | 94                     | 4      | 2     | 6     |
| July  | 81                     | 73                     | 6      | 2     | 8     |
| August| 97                     | 90                     | 6      | 1     | 7     |
| Sept  | 104                    | 95                     | 7      | 2     | 9     |
| Oct   | 99                     | 92                     | 5      | 2     | 7     |
| Nov   | 88                     | 76                     | 10     | 2     | 12    |
| Dec   | 106                    | 100                    | 5      | 1     | 6     |
| Jan   | 110                    | 105                    | 4      | 1     | 5     |
| Feb   | 103                    | 97                     | 5      | 1     | 6     |
| Total | 1191                   | 1101                   | 71     | 19    | 90    |

| Month | Total Work Days/Month | Available time (minute) |
|-------|-----------------------|-------------------------|
| March | 21                    | 30240                   |
| Apr   | 21                    | 30240                   |
| Mei   | 20                    | 28800                   |
| June  | 22                    | 31680                   |
| July  | 16                    | 23040                   |
| August| 22                    | 31680                   |
| Sept  | 21                    | 30240                   |
| Oct   | 21                    | 30240                   |
| Nov   | 22                    | 31680                   |
| Dec   | 20                    | 28800                   |
| Jan   | 21                    | 30240                   |
| Feb   | 20                    | 30240                   |
| Total | 247                   | 357120                  |

3.3 Breakdown
Data of breakdown is get by measurement time before and after maintenance as seen at Table 4.

3.4 Availability
The downtime calculation for production processing get by using formula:
Downtime = Breakdown + Setup Time + Adjustment
Downtime = 605 minute + 600 minute + 292 minute = 1497 minute.
Table 3. Annual Data Work Time and Delay Time of CNC Milling Machine

| Month | Work time available (minute) | Cleaning time (minute) | Planned downtime (minute) | Warm up time (minute) | General breakdowns (minute) | Machine Break (minute) | Power cut-off (minute) | Total delay (minute) |
|-------|------------------------------|------------------------|--------------------------|----------------------|-----------------------------|-----------------------|----------------------|---------------------|
| March | 30240                        | 310                    | 8505                     | 292                  | 605                         | 2890                  | 120                  | 12722               |
| Apr   | 30240                        | 240                    | 8505                     | 288                  | 651                         | 2142                  | 108                  | 11934               |
| Mei   | 28800                        | 270                    | 8100                     | 275                  | 744                         | 1680                  | 111                  | 11180               |
| June  | 31680                        | 240                    | 8910                     | 312                  | 715                         | 1980                  | 114                  | 12271               |
| July  | 23040                        | 360                    | 6480                     | 312                  | 560                         | 1440                  | 120                  | 9272               |
| August| 31680                        | 270                    | 8910                     | 332                  | 733                         | 1584                  | 120                  | 11949               |
| Sept  | 30240                        | 330                    | 8505                     | 275                  | 639                         | 1764                  | 108                  | 11621               |
| Oct   | 30240                        | 330                    | 8505                     | 280                  | 717                         | 1512                  | 108                  | 11452               |
| Nov   | 31680                        | 360                    | 8910                     | 292                  | 823                         | 2244                  | 120                  | 12749               |
| Dec   | 28800                        | 270                    | 8100                     | 292                  | 605                         | 1680                  | 114                  | 11061               |
| Jan   | 30240                        | 300                    | 8505                     | 300                  | 602                         | 1512                  | 108                  | 11327               |
| Feb   | 28800                        | 330                    | 8100                     | 292                  | 608                         | 1560                  | 120                  | 11010               |
| Total  | 355680                      | 3610                   | 100035                   | 3542                 | 8002                        | 21988                 | 1371                 | 138548              |

Table 4. Breakdown at CNC milling machine.

| No  | Type of Damage            | Time for Report of Damage | Time of Maintenance | Breakdown time (s) |
|-----|----------------------------|---------------------------|---------------------|-------------------|
| 1   | Alarm 3 : Area Working Limit | 20:15                     | 20.20               | 21.20             | 3900              |
| 2   | Alarm GPU Sack holder      | 8:47                      | 8.47                | 9.00              | 1080              |
| 3   | Alarm GPU Sack holder      | 15:37                     | 15.41               | 15.55             | 1080              |
| 4   | Alarm 3 : Area Working Limit | 7:18                     | 7.22                | 8.25              | 4020              |
| 5   | Alarm Machine SV01 Y data Error | 7:03                   | 7.33                | 8.10              | 2400              |
| 6   | Alarm GPU Sack holder      | 11:02                     | 11.06               | 11.20             | 1080              |
| 7   | Monitor Error              | 9:00                      | 9.06                | 9.30              | 1800              |
| 8   | Alarm GPU Sack holder      | 17:32                     | 17.350              | 17.500            | 1080              |
| Total of breakdown time |                            |                          |                     | 16440             |

Table 5 has shown that the total value of downtime is 15303 minute. The maximum value of downtime happen in November namely 1745 minute as shown in Table 5. This case due to the breakdown time in November is larger than other month. Breakdown time give a big effect in the maintenance and also needed long time for maintenance. Breakdown can be done by reparation or changing of component or part of machine so need time for finishing this activity. Set up time depend on the clean area, reading the engineering drawing of product, tools preparation, and set up equipment.

After downtime calculation thus the loading time calculation by using formula:

\[
\text{Loading Time} = \text{Availability Time} - \text{Planned Downtime}
\]

\[
\text{Loading Time} = 30240 \text{ minute} - 8505 \text{ minute} = 21735 \text{ minute}
\]

Total annual loading time calculation can be seen on Table 6.

Availability value on the March is:

\[
\text{Availability} = \frac{(\text{loading time} - \text{downtime})}{\text{loading time}} \times 100\% = 93\%
\]

Availability value for annual year can be seen at Table 6.
Total annual downtime can be seen in the Table 5.

Table 5. Annual calculation of downtime

| Month | Breakdown (minute) | Setup Time (minute) | Adjustment Time (minute) | Total Downtime (minute) |
|-------|--------------------|---------------------|--------------------------|-------------------------|
| March | 605                | 600                 | 292                      | 1497                    |
| Apr   | 651                | 606.6               | 288                      | 939                     |
| Mei   | 744                | 637.5               | 275                      | 1019                    |
| June  | 715                | 681                 | 312                      | 1708                    |
| July  | 560                | 600                 | 312                      | 1472                    |
| August| 733                | 648                 | 332                      | 1713                    |
| Sept  | 639                | 637.5               | 275                      | 914                     |
| Oct   | 717                | 606.6               | 280                      | 997                     |
| Nov   | 823                | 630                 | 292                      | 1745                    |
| Dec   | 605                | 600                 | 292                      | 1497                    |
| Jan   | 602                | 621.4               | 300                      | 902                     |
| Feb   | 608                | 654.9               | 292                      | 900                     |
| Total |                    |                     |                          | 15303                   |

Table 6. Calculation of loading time and Availability Value for Annual Year

| No. | Month | Available Time (minute) | Planned Downtime (minute) | Loading Time (minute) | Downtime (minute) | Operation Time (minute) | Availability Rate |
|-----|-------|-------------------------|---------------------------|-----------------------|-------------------|------------------------|-------------------|
| 1   | March | 30240                   | 8505                      | 21735                 | 1497              | 20238                  | 0.93              |
| 2   | Apr   | 30240                   | 8505                      | 21735                 | 1546              | 20189                  | 0.93              |
| 3   | Mei   | 28800                   | 8100                      | 20700                 | 1657              | 19044                  | 0.92              |
| 4   | June  | 31680                   | 8910                      | 22770                 | 1708              | 21062                  | 0.92              |
| 5   | July  | 23040                   | 6480                      | 16560                 | 1472              | 15088                  | 0.91              |
| 6   | August| 31680                   | 8910                      | 22770                 | 1713              | 21057                  | 0.92              |
| 7   | Sept  | 30240                   | 8505                      | 21735                 | 1552              | 20184                  | 0.93              |
| 8   | Oct   | 30240                   | 8505                      | 21735                 | 1604              | 20131                  | 0.93              |
| 9   | Nov   | 31680                   | 8910                      | 22770                 | 1745              | 21025                  | 0.92              |
| 10  | Dec   | 28800                   | 8100                      | 20700                 | 1497              | 19203                  | 0.93              |
| 11  | Jan   | 30240                   | 8505                      | 21735                 | 1523              | 20212                  | 0.93              |
| 12  | Feb   | 28800                   | 8100                      | 20700                 | 1555              | 19145                  | 0.92              |
|     | Total | 355680                  | 100035                    | 255645                |                   |                        | 0.93              |

3.5 Calculation of the performance of efficiency and rate quality

Calculation on performance of efficiency depend on the cycle time, operation time and processed amount. The value can be calculated by using formula:

Performance of efficiency = net operating rate x operating speed rate

\[ \text{Performance efficiency} = \frac{\text{Processed amount} \times \text{Ideal cycle time}}{\text{Operation time}} \times 100\% \]
Table 7. Normal and standard time of CNC Milling machine operation for annual year

| Month | Work element | Cycle Time (minute) | Rating Factor | Normal Time (minute) | Allowance | Standard Time (minute/unit) |
|-------|--------------|---------------------|---------------|----------------------|-----------|-----------------------------|
| March | + CNC Milling | 123.09 | 0.15 | 141.55 | 22.00% | 172.69 |
| Apr   | + Machine Operation | 123.36 | 0.15 | 141.86 | 22.00% | 173.07 |
| May   | + Machine Operation | 123.91 | 0.15 | 142.50 | 22.00% | 173.85 |
| Jun   | + Machine Operation | 123.08 | 0.15 | 141.54 | 22.00% | 172.68 |
| Jul   | + Machine Operation | 122.70 | 0.15 | 141.11 | 22.00% | 172.15 |
| August| + CNC Milling | 122.77 | 0.15 | 141.19 | 22.00% | 172.25 |
| Sept  | + Machine Operation | 123.42 | 0.15 | 141.93 | 22.00% | 173.16 |
| Oct   | + Machine Operation | 123.58 | 0.15 | 142.12 | 22.00% | 173.38 |
| Nov   | + Machine Operation | 124.44 | 0.15 | 143.11 | 22.00% | 174.59 |
| Dec   | + Machine Operation | 120.40 | 0.15 | 138.46 | 22.00% | 168.92 |
| Jan   | + Machine Operation | 123.04 | 0.15 | 141.50 | 22.00% | 172.63 |
| Feb   | + Machine Operation | 122.41 | 0.15 | 140.77 | 22.00% | 171.74 |

Whereas:

\[
\text{Operating speed rate} = \frac{\text{Ideal cycle time}}{\text{Actual cycle time}} \times 100\%
\]

\[
\text{Net Operating rate} = \frac{\text{Processed amount} \times \text{actual cycle time}}{\text{operation time}} \times 100\%
\]

Normal time can be calculated by:

\[
\text{Normal Time} = \text{Observation time} \times \frac{\text{Rating factor \%}}{100}\%
\]

\[
\text{Normal Time} = 123.09 \text{ minute} \times (1+\frac{15}{100})
\]

\[
\text{Normal Time} = 141.55 \text{ minute}
\]

Table 7 shows that the value of normal and standard time of CNC Milling machine operation for annual years.

Standard time or ideal cycle time for March is:

\[
\text{Standar time} = \text{Normal time} \times \frac{100\% - \text{Allowance \%}}{100}\%
\]

\[
\text{Standar time} = 141.55 \text{ minute} \times (1+0.22)
\]

\[
\text{Standar time} = 172.69 \text{ minute/unit}
\]

Calculation on actual cycle time for March is:

\[
\text{Actual cycle time} = \frac{\text{Operation time}}{\text{Processed amount}}
\]

\[
\text{Actual cycle time} = \frac{20.238 \text{ minute}}{106 \text{ unit}}
\]

\[
\text{Actual cycle time} = 0.190,92 \text{ minute/unit}
\]

Calculation value of actual cycle time, performance efficiency, and quality rate for annual year can be seen at Table 8.

Than calculation of performance efficiency for March is: 74%

\[
\text{Performance efficiency} = \frac{\text{Processed amount} \times \text{ideal cycle time}}{\text{operation time}} \times 100\%
\]

\[
\text{Performance Efficiency} = \frac{106 \text{ unit} \times 172.69 \text{ minute/unit}}{20.238 \text{ minute}} \times 100\% = 0,90
\]

Average of performance of efficiency is 0.87.

And rate of quality for March is found by using the formula:

\[
\text{Rate of Quality} = \frac{(\text{processed amount} - \text{defect amount})}{\text{processed amount}} \times 100\%
\]

\[
\text{Rate of Quality} = \frac{(106 \text{ unit} - 8 \text{ unit})}{106 \text{ unit}} \times 100\%
\]
Rate of Quality = 0.92

**Table 8.** Calculation of actual cycle time and performance Efficiency for annual year

| No | Month | Operation time (minute) | Processed Amount (unit) | Defect (Unit) | Actual Cycle Time (minute/unit) | Ideal Cycle Time (minute/unit) | Performance Efficiency | Rate of Quality (%) | OEE (%) |
|----|-------|-------------------------|-------------------------|--------------|---------------------------------|-------------------------------|-----------------------|---------------------|---------|
| 1  | March | 20.238                  | 106                     | 8            | 190.92                          | 172.69                        | 0.90                  | 0.92                | 0.78    |
| 2  | Apr   | 20.189                  | 102                     | 7            | 197.94                          | 173.07                        | 0.87                  | 0.93                | 0.76    |
| 3  | May   | 19.044                  | 95                      | 9            | 200.46                          | 173.85                        | 0.87                  | 0.91                | 0.72    |
| 4  | Jun   | 21.062                  | 100                     | 6            | 210.62                          | 172.68                        | 0.82                  | 0.94                | 0.71    |
| 5  | Jul   | 15.088                  | 81                      | 8            | 186.27                          | 172.15                        | 0.92                  | 0.90                | 0.76    |
| 6  | Aug   | 21.057                  | 97                      | 7            | 217.08                          | 172.25                        | 0.79                  | 0.93                | 0.68    |
| 7  | Sept  | 20.184                  | 104                     | 9            | 194.07                          | 173.16                        | 0.89                  | 0.91                | 0.76    |
| 8  | Oct   | 20.131                  | 99                      | 7            | 203.35                          | 173.38                        | 0.85                  | 0.93                | 0.73    |
| 9  | Nov   | 21.025                  | 88                      | 12           | 238.92                          | 174.59                        | 0.73                  | 0.86                | 0.58    |
| 10 | Dec   | 19.203                  | 106                     | 6            | 181.16                          | 168.92                        | 0.93                  | 0.94                | 0.82    |
| 11 | Jan   | 20.212                  | 110                     | 5            | 183.74                          | 172.63                        | 0.94                  | 0.95                | 0.83    |
| 12 | Feb   | 19.145                  | 103                     | 6            | 185.87                          | 171.74                        | 0.92                  | 0.94                | 0.80    |
|    | Average |                        |                         |              |                                 |                               |                       |                     | 0.87    |

3.6 Calculation of Overall equipment effectiveness (OEE)

Ideal condition of OEE is:
1. Availability ≥ 90%
2. Performance Efficiency ≥ 95%
3. Rate of Quality ≥ 99%

Formula for OEE is:

OEE (%) = Availability (%) x Performance efficiency (%) x Quality rate

Calculation OEE for March is:

OEE (%) = Availability (%) x Performance efficiency (%) x Quality rate (%)
OEE = 0, 93 x 0, 90 x 0, 92
OEE = 78%

Average value of OEE is 0.74 and for annual year can be seen at Table 8.

4. Conclusions

From the data processing result with the calculation of availability, performance efficiency, and quality rating, overall equipment effectiveness value (OEE) for annual years can be determined, 74%. Based on the ideal value standard of the Japanese Plant Maintenance Institute (JIPM) is 85%, the value of OEE 74% is considered as reasonable, but indicates that there is substantial space for improvement. The OEE 74% value should be increased by 11% so the production is considered as world class. There are three factors that affect the value of OEE, there are as follows: the value of CNC Milling Machine availability is 93%, the performance of efficiency value of CNC Machining machine is 87% and CNC Milling machine rate of quality is 92%.

References

[1] Assauri, S, 2008, *Manajemen Produksi dan Operasi, edisi revisi*, Jakarta, Lembaga Penerbit FE UI.
[2] Herjanto, E, 2015, *Manajemen Operasi, edisi ketiga*, Jakarta: PT. Grasindo.
[3] Rochim, T, 1989, *Proses Pemesinan*, ITB, Bandung.
[4] Tsuyunaru, M, Noda, NA, Hendra and Takase, Y, 2008, *Maximum Stress for Shrink Fitting System*
used for Ceramics Conveying Rollers, Transactions of the Japan Society of Mechanical Engineering, Vol. 74, No. 743, pp. 919-925 (in Japanese).

[5] Noda, NA, Hendra, Oosato, M, Suzumoto, K, Takase, Y, and LI, W, 2011, Strength Analysis For Shrink Fitting System Used For Ceramics Rolls In The Continuous Pickling Line, Key Engineering Materials Vols. 462-463, pp. 1140-1145.

[6] Noda, NA, Hendra, Takase, Y, and Li, W, 2009, Thermal Stress Analysis for Ceramics Stalk in the Low Pressure Die Casting Machine, Journal of Solid Mechanics and Material Engineering, Vol. 3, No. 10, pp. 1090-1100.

[7] Hendra, Indriani, A, Hernadewita, Rizal, Y, 2015, Assembly Programmable Logic Control (PLC) in the Rotary Dryer Machine for Processing Waste Liquid System, Applied Mechanics and Materials, Vol. 842, pp 319-323.

[8] Hendra, Yulianto, AS, Indriani, A, Hernadewita, and Hermiyetti, 2018, Control Systems of Rubber Dryer Machinery Components Using Programmable Logic Control (PLC), Material Science and Engineering, 307.

[9] Ansori, Nachnul, 2013, Sistem Perawatan Terpadu (Integrated Maintenance System), Edisi Pertama. Yogyakarta: Graha Ilmu.

[10] Hansen, Robert, C, 2001, Overall Equipment Effectiveness, A Powerful Production/Maintenance Tool for Increased Profits, Industrial Press Inc., New York.

[11] Nakajima, Seiichi, 1988, Introduction to Total Productive Maintenance, Productivity Press, Inc, Cambridge, Massachusetts.