
**Question:**
- Can CT be reduced using SW processing?
- At what cost? ⇒ in high volume setting.

**Approach:**
- Conventional Fabs vs. Single Wafer Fabs
  - Survey to check hypothetical fab
  - Batch & standalone tools ⇒ integrated SW tools
  - Simulate CT, min CT
  - Add cost modeling

**Changes:** Conventional → Alternative
- Batch furnaces → SW Thermal Processors
- Wet benches in BEOL → SW wet clean cells
- Litho, Plasma, & Thermal processes integrated
- In-line process monitors → in-situ monitors

**Key Points:**

- Move beyond TQM - Total Quality Management. New focus on TPM - Total Productive Maintenance.
- Need a way to monitor and identify where productive time is lost.
- Should make these measurements so that info can also be used for planning/scheduling.

**Basic Metrics in Use Today**

1. **Equipment Availability**  
   - % time machine capable or actually performing work  
   - Actual unavailable time is "down time".
2. **Equipment Utilization**  
   - % total time actually engaged in processing.

**But**

- Availability not % of time  \(\Rightarrow\) does not count idle time losses.
- Utilization counts idle loss, but \(\Rightarrow\) does not count speed losses.
  
e.g. 100% utilized but not provide 100% theoretical productivity.

**Key Idea**  

\(\Rightarrow\) Should compare production time against some standard  
"should take" time!
**OVERALL EQUIPMENT EFFICIENCY**

\[ \text{OEE} = \frac{S}{T} \]

- \( S = \) "should take" time for work completed on machine, based on theoretical rates.
- \( T = \) observation period

- This aggregate measure is relatively easy to compute, BUT...
  - does not help in IDENTIFYING where losses occur or improvements needed
  - \ (~20\% - 60\% \) \( \Rightarrow \) substantial room for improvement

**DATA COLLECTION REQUIREMENTS**

1. Equipment Tracking DB: - changes in equip. state
2. WIP Tracking DB: - actual lots produced
3. Machine Event Logs: - recipes performed
   - # units processed
   - elapsed time in various cycles
4. Signal for when actually processing

**MINIMUM NEEDED:**

- Total down time, prod. time, idle time
- Total # lots started into processing
  - Total # lots/loafer completing each step on each tool
- Sequence of lots - calculate batch sizes between equip. changes (used for capacity, not OEE)
EQUIPMENT STATE DEFINITIONS

**SEMI EID**

1. NonSched Time
2. Down Time
3. Standby Time
4. Prod Time
5. Engineering Time

**This Paper**

1. Down Time
   - down EID
   - ENG EID
   + 2. Idle Time
   + 3. Production Time
   = Total Time - Unsched. Time

**NOTES**

EID: Changeovers & Setups ⇒ Down Time
HERE: Include ⇒ Prod. Time

* Idle Time ⇒ Waiting/due to scheduling

HERE: Down Time
- Failures & Repairs
- Delays for "
- Follow-on Calibration, Quals, etc.
- PM
- Source Replenishments
- Scheduled Cleanas
- Engineering

**ISSUE:** Hard to track/account for short duration events ⇒ rec. automation where possible.
**OEE CALCULATION**

1. **DT** = % time lost for **DOWNTIME**
2. **IT** = % time lost for **IDLE TIME**
3. **Productive Losses** ??

**RE = A** **RATE EFFICIENCY** - inferred machine speed

**DE = B** **DEMAND EFFICIENCY** - losses for processing wrong product

**RQA = C** **RATE OF QUALITY** - losses for product scrap

\[
OEE = \left( \frac{1}{1} - DT - IT \right) (RE) (DE) (RQA)
\]

**A  RATE EFFICIENCY** - ratio of **observed machine process time** to **theoretical machine rate**

Ex: I/I

\[
\text{Beam-time} = 1.6 \times 10^{-13} \times \text{Dose} \\
\times \left( \frac{\text{Area}}{\text{Beam-current}} \right) \times \frac{1}{60}
\]

\[\Rightarrow \text{TIE to RECIPE DATABASE!}\]
2. **DEMAND EFFICIENCY**

- When production control is weak - may process products NOT planned or demanded

\[ DE = \frac{\sum_{i=1}^{n} \min (WS_i, PP_i) (EPT_i)}{\sum_{i=1}^{n} (WS_i)(EPT_i)} = \% \text{ time spent producing demanded products} \]

\( \text{"Effective Processing Time" (TBA)} \)

- Capture effect of changeovers, load sizes, rework that vary by product/step

3. **RATE OF QUALITY**

- Account for losses due to SCRAP or REWORK

\[ RQ = \frac{\sum_{i=1}^{n} (WF_i)(EPT_i)}{\sum_{i=1}^{n} (WS_i)(EPT_i)} \]

\( \text{"Wafers Finishing" Step} \)

\( \text{Wafers Starting Step} \)

- Note: this is a MACHINE oriented quality loss measure, not a PROCESS oriented measure.

Scrap rate is just \( \frac{WF_i}{WS_i} \); need these for LINE YIELD calculations
EXAMPLES / CASES

1. DATA ACQUISITION
   a. LOW-TECH: Paper Forms
      - Harris
      - NEC = 15' grid
   b. HIGH-TECH: Machine Sensing
      - Harris I/I room: attach "EKG" to tool
      - Added process time calculation

2. HARRIS RESULTS
   - Early 1991: 
     UTILIZE
     OEE ~ 61% - 76%
     RE = 72%
   - OEE = 44-54% - even if 100% RE, 100% RQ
   - Careful attention ⇒ increased I/I capacity
   - NET Results: On-time Delivery 79% 91
                        95% 92-94

3. "NAMELESS" RESULTS
   - Compare utilization at various factories
     ⇒ best practices
   - UTILIZATION "increasing"
     but WAFER OUTPUT FLAT!
   - Save up
     ⇒ aggregate machine speed (e.g. OEE)
   - Problem in report may scheme
     ⇒ utilization does not account for all efficiency losses
CONCLUSION: "CLOSED LOOP" Measurement Needed!

- OEE requires TPT knowledge; w/ Theoretical times, can compute "earned" utilization

- If include Rate Efficiency (RE), then if DT or IT are unreported, they get lumped into RE

⇒ OEE correctly stated, regardless of quality of DT & IT reporting

SUB-PLOT: W/ many of same numbers, can calculate a

CAPACITY EQUIP. EFFICIENCY

Like OEE, except excludes losses for SCHEDULED IDLE TIME

... more appropriate for planning/scheduling

These allow tracking of CAPACITY losses and potential gains.
EQUIPMENT EFFICIENCY
BENCHMARKS

OE

EQUIP AVAILABILITY (1 - DT - IT)

UTILIZATION OF AVAIL TIME (OE - RO)

RATE EFFICIENCY (RE)

1. Reported Availability
   Graphs
   - 5X steppers
   - I/I
   - metallization
   @ memory, logic, ASIC

   ⇒ nearly identical availability for steppers
   BUT ⇒ very different throughputs

2. STEPPERS: RATE EFFICIENCY differentiates
   ⇒ time spent idle waiting for sample wafer inspects
   ION IMPLANTERS: AVAILABILITY
   ⇒ time spent on chucks
   METALIZATION: AVAILABILITY

C3M-31, 8/96
Key Practices

1. Data Collection
   - tracking UTL = steps
   - tracking AVAIL = implant, DTR, metal

2. Training
   - in-house equip, engineering
   - TPM training

3. Equip. Improvement Efforts
   - CIT (Continuous Improvement Teams)

4. Maintenance Strategy
   - operator maint
   - vendor interaction

Fab Characteristics

1. Fab Size
   - Availability
   - Large Size
   - Not come.

2. Fab Focus
   = larger throughputs
## Correlation Coefficients for Equipment Practices vs. Equipment Performance

<table>
<thead>
<tr>
<th>Practice</th>
<th>Stepper avail.</th>
<th>Implanter avail.</th>
<th>Metal avail.</th>
<th>Stepper t'put</th>
<th>Implanter t'put</th>
<th>Metal t'put</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track down time</td>
<td>-0.221</td>
<td>0.111</td>
<td>0.127</td>
<td>0.171</td>
<td>0.342</td>
<td>0.336</td>
</tr>
<tr>
<td>Track utilization</td>
<td>-0.323</td>
<td>0.040</td>
<td>0.059</td>
<td>0.407</td>
<td>0.349</td>
<td>0.316</td>
</tr>
<tr>
<td>Track setup time</td>
<td>-0.331</td>
<td>0.108</td>
<td>0.233</td>
<td>0.170</td>
<td>0.267</td>
<td>0.210</td>
</tr>
<tr>
<td>Track OEE</td>
<td>-0.017</td>
<td>0.167</td>
<td>-0.013</td>
<td>0.347</td>
<td>0.150</td>
<td>-0.112</td>
</tr>
<tr>
<td>Auto-capture perf. data</td>
<td>-0.087</td>
<td>0.007</td>
<td>0.164</td>
<td>0.352</td>
<td>0.231</td>
<td>-0.103</td>
</tr>
<tr>
<td>Auto-monitoring</td>
<td>-0.087</td>
<td>0.007</td>
<td>0.164</td>
<td>0.352</td>
<td>0.231</td>
<td>-0.103</td>
</tr>
<tr>
<td>Compare with other fabs</td>
<td>-0.168</td>
<td>0.273</td>
<td>-0.028</td>
<td>-0.216</td>
<td>0.057</td>
<td>-0.242</td>
</tr>
<tr>
<td><strong>Training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPM training of techs</td>
<td>-0.454</td>
<td>0.016</td>
<td>0.200</td>
<td>0.415</td>
<td>0.345</td>
<td>0.036</td>
</tr>
<tr>
<td>Vendor school for techs</td>
<td>0.007</td>
<td>-0.071</td>
<td>-0.266</td>
<td>-0.213</td>
<td>-0.198</td>
<td>-0.241</td>
</tr>
<tr>
<td>TPM training of oprs</td>
<td>-0.481</td>
<td>-0.021</td>
<td>0.226</td>
<td>0.374</td>
<td>0.384</td>
<td>0.064</td>
</tr>
<tr>
<td>Vendor school for oprs</td>
<td>0.064</td>
<td>0.136</td>
<td>0.406</td>
<td>0.232</td>
<td>0.222</td>
<td>0.096</td>
</tr>
<tr>
<td><strong>Eqpt improvement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of equip. engineers</td>
<td>-0.478</td>
<td>-0.044</td>
<td>0.047</td>
<td>0.467</td>
<td>0.572</td>
<td>0.399</td>
</tr>
<tr>
<td>Joint proc. &amp; eqpt. engng.</td>
<td>-0.405</td>
<td>0.085</td>
<td>0.052</td>
<td>0.253</td>
<td>0.323</td>
<td>0.405</td>
</tr>
<tr>
<td>CIT tech/opr teams</td>
<td>-0.368</td>
<td>0.089</td>
<td>0.187</td>
<td>0.363</td>
<td>0.441</td>
<td>0.107</td>
</tr>
<tr>
<td>CIT eng/tech teams</td>
<td>-0.110</td>
<td>0.133</td>
<td>-0.110</td>
<td>0.076</td>
<td>0.448</td>
<td>0.167</td>
</tr>
<tr>
<td>Eqpt modifications</td>
<td>-0.272</td>
<td>0.030</td>
<td>0.143</td>
<td>0.493</td>
<td>0.604</td>
<td>0.537</td>
</tr>
<tr>
<td>Share mods w/ other fabs</td>
<td>-0.018</td>
<td>0.174</td>
<td>0.151</td>
<td>-0.274</td>
<td>0.373</td>
<td>0.027</td>
</tr>
<tr>
<td>TPM 5 S improvements</td>
<td>-0.148</td>
<td>-0.089</td>
<td>-0.070</td>
<td>0.254</td>
<td>0.225</td>
<td>0.166</td>
</tr>
<tr>
<td>Setup time reduction</td>
<td>-0.208</td>
<td>0.135</td>
<td>-0.052</td>
<td>0.322</td>
<td>0.508</td>
<td>0.186</td>
</tr>
<tr>
<td><strong>Mice strategy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of techs per machine</td>
<td>0.008</td>
<td>0.114</td>
<td>-0.084</td>
<td>-0.315</td>
<td>0.117</td>
<td>0.011</td>
</tr>
<tr>
<td>Eqpt owner program</td>
<td>0.000</td>
<td>0.309</td>
<td>0.309</td>
<td>0.144</td>
<td>0.300</td>
<td>0.412</td>
</tr>
<tr>
<td>Opr mtce</td>
<td>-0.361</td>
<td>0.162</td>
<td>0.048</td>
<td>0.371</td>
<td>0.312</td>
<td>-0.042</td>
</tr>
<tr>
<td>Vendor contract mtce</td>
<td>-0.021</td>
<td>0.020</td>
<td>-0.428</td>
<td>-0.231</td>
<td>-0.270</td>
<td>-0.055</td>
</tr>
<tr>
<td>Nearby on-call vendors</td>
<td>0.146</td>
<td>0.192</td>
<td>-0.042</td>
<td>-0.161</td>
<td>0.374</td>
<td>0.057</td>
</tr>
<tr>
<td>Reg vendor reviews</td>
<td>0.395</td>
<td>0.357</td>
<td>0.158</td>
<td>-0.107</td>
<td>0.231</td>
<td>0.395</td>
</tr>
<tr>
<td>Coord rev w/ other fabs</td>
<td>0.094</td>
<td>0.174</td>
<td>0.069</td>
<td>-0.420</td>
<td>0.191</td>
<td>-0.157</td>
</tr>
<tr>
<td><strong>Fab characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factory utilization</td>
<td>-0.178</td>
<td>0.112</td>
<td>0.061</td>
<td>0.427</td>
<td>0.046</td>
<td>0.279</td>
</tr>
<tr>
<td>Wafer starts per week</td>
<td>-0.445</td>
<td>0.100</td>
<td>0.103</td>
<td>0.605</td>
<td>0.665</td>
<td>0.410</td>
</tr>
<tr>
<td>Wfr strts per proc flow</td>
<td>-0.115</td>
<td>0.091</td>
<td>0.178</td>
<td>0.440</td>
<td>0.476</td>
<td>0.292</td>
</tr>
<tr>
<td>Wfr strts per die type</td>
<td>0.047</td>
<td>0.036</td>
<td>-0.003</td>
<td>0.239</td>
<td>0.231</td>
<td>0.088</td>
</tr>
</tbody>
</table>