TSM, Feb. 1997

S. Wood, "Cost & Cycle Time Perf. of Fabs Based on Integ. Single Wafer Proc."

QUESTION: • Can CT be reduced using SW processing?

• At what cost? ⇒ In high volume setting.

APPROACH: Conventional Fab — survey to create hypothetical fab

vs.

Single Wafer 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

R. Leachman, "CLOSED-LOOP MEASUREMENT OF EQUIPMENT EFFICIENCY AND CAPACITY", TSM Fe[illegible] 199[illegible]

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
– ~~[illegible]~~ unavailable time is "down time"

② EQUIPMENT UTILIZATION – % total time actually engaged in processing

BUT

- availability not OE score → doesn't count idle time losses
- utilization counts idle loss, but → doesn't count SPEED losses

e.g. 100% utilized, but not provide 100% theoretical productivity

KEY IDEA ⟹ SHOULD compare production time against some standard "SHOULD TAKE" time!

OVERALL EQUIPMENT EFFICIENCY

$$\boxed{OEE \triangleq \frac{S}{T}}$$

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% ⇒ 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 <u>down</u> time, <u>prod.</u> time, <u>idle</u> time
- Total # lots started into processing
  Total # lots/wafers completing each step on each tool
- Sequence of lots — calculate batch sizes between equip. changes (used for capacity, not OEE)

EQUIPMENT STATE DEFINITIONS

SEMI E10	This Paper
[1] NONSCHED TIME	[1] DOWN TIME – down E10 – ENG E10
[2] DOWN TIME	+ [2] IDLE TIME
[3] STANDBY TIME	
[4] PROD TIME	+ [3] PRODUCTION TIME
[5] ENGINEERING TIME	= TOTAL TIME – UNSCHED. TIME

NOTES

E10 • 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 cleans
- engineering

ISSUE: hard to track/account for SHORT DURATION EVENTS
⇒ rec. automation where possible.

OEE CALCULATION

① DT ≜ % time lost for DOWN TIME

② IT ≜ % time lost for IDLE TIME

③ Productive Time Losses ??

RE ≜ → Ⓐ RATE EFFICIENCY – inferior machine speed

DE ≜ Ⓑ DEMAND EFFICIENCY – losses for processing wrong product

RQ ≜ Ⓒ RATE OF QUALITY – losses for product scrap

$$OEE = \{1 - DT - IT\}(RE)(DE)(RQ)$$

Ⓐ RATE EFFICIENCY – ratio $\frac{\text{observed machine process time}}{\text{theoretical machine rate}}$

- need theoretical processing time!

ISSUE: Equip. has many different steps/processes

APPROACH #1: single parameter

APPROACH #2: RELATE TO RECIPE INFO

Sensitive to changes in product mix.

Ex: I/I

$$\text{Beam-time} = 1.6 \times 10^{-13} \times \text{DOSE} \times \left(\frac{\text{Area}}{\text{Beam-Current}}\right) * \frac{1}{60}$$

⟹ TIE to RECIPE DATABASE!

Rate Efficiency Cont'd

$$TPT = \left\{ TPU + \left(\frac{TPL}{FLS}\right) + \left(\frac{TPML}{FML}\right) \right\}$$

- TPT: "Theoret. Process Time"
- TPU: "Time Per Unit" e.g. single wafer
- TPL: "Time Per Lot" e.g. lot overhead
- FLS: "Full Lot Size"
- TPML: "Time per Machine Load" e.g. BATCH tools
- FML: "Full Machine Load"

$$RE \triangleq \frac{\sum_{i}^{\#\,steps} (WS_i)(TPT_i)}{PT}$$

- WS_i: wafers into step i
- TPT_i: theoretical process time for that step
- PT: total reported production time

② DEMAND EFFICIENCY

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

parts planned (or demanded)

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

"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

"Wafers Finishing" Step

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

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

Ⓐ LOW-TECH: Paper Forms
- Harris
- NEC ⇒ 15' grid

Ⓑ HIGH-TECH: Machine Sensing
- Harris I/I room: attach "EKG" to tool
- Added process time calculation

② HARRIS RESULTS

- Early 1991: UTILIZ ~~OEE~~ ~ 61% - 76%, RE ≈ 72% } IMPLANT BOTTLENECK

∴ OEE ≤ 44-54% - even if 100% DE, 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! } Problem in reporting scheme ⇒ utilization does not account for all efficiency losses
- Gave up ⇒ aggregate machine speed (agg. OEE)

CONCLUSION : "CLOSED LOOP" Measurement Needed!

- OEE requires TPT knowledge; w/. Theoretical times, can computed "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 : With many of same numbers, can calculate a

CAPACITY EQUIP. EFFICIENCY

$$CEE \triangleq \{1 - DT - MIT\}(CRE)(DE)$$

CEE: Like OEE, except excludes losses for SCHEDULED IDLE TIME

∴ more appropriate for Planning/Scheduling

MIT: Minimum Idle Time fraction

CRE: CAPACITY RATE EFFICIENCY

$$CRE \triangleq \frac{\sum_i (WS_i)(EPT_i)}{PT}$$

These allow tracking of CAPACITY losses and potential gains.

EQUIPMENT EFFICIENCY BENCHMARKS

CSM-31, 8/96

OE

- EQUIP AVAILABILITY (1 - DT - IT)
- UTILIZATION OF AVAIL TIME (OE · RQ)
- RATE EFFICIENCY (RE)

① Reported Availability Graphs
- 5x steppers
- I/I
- metallization

} @ memory, logic, ASIC.

⟹ nearly identical availability for steppers

BUT ⟹ very different thruputs

② STEPPERS: RATE EFFICIENCY differentiator

⟹ time spent idle waiting for sample wafer inspects

ION IMPLANTERS: AVAILABILITY

⟹ time spent on change-overs

METALIZATION: AVAILABILITY

KEY PRACTICES → High OE

① Data Collection — tracking UTIL. → steppers
— tracking AVAIL, DT → implant, metal

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

③ Equip. Improvement Efforts — C.I.T (continuous improvement teams)

④ Maintenance Strategy — operator maint
— vendor interaction

FAB CHARACTERISTICS → high OE

① Fab Size ⇒ Availability NOT correl. ⇒ Large Size = larger thruputs

② Fab Focus

Correlation Coefficients for Equipment Practices vs. Equipment Performance

Practice	Equipment Performance					
	Stepper avail.	Implanter avail.	Metal avail.	Stepper t'put	Implanter t'put	Metal t'put
Data collection						
Track down time	-0.221	-0.011	0.127	0.171	*0.342*	*0.336*
Track utilization	-0.323	0.040	0.059	0.407	0.349	*0.316*
Track setup time	-0.331	-0.108	0.233	0.170	*0.267*	0.210
Track OEE	-0.017	-0.167	-0.013	0.347	0.150	-0.112
Auto-capture perf. data	-0.087	0.007	0.164	0.352	0.231	-0.103
Auto-monitoring	-0.087	0.007	0.164	0.352	0.231	-0.103
Compare with other fabs	-0.168	-0.273	-0.028	-0.216	0.057	-0.242
Training						
TPM training of techs	-0.454	0.016	0.200	0.415	0.345	0.036
Vendor school for techs	0.007	-0.071	-0.266	-0.213	-0.198	-0.241
TPM training of oprs	-0.481	-0.021	0.226	0.374	0.384	0.064
Vendor school for oprs	0.064	0.136	0.406	0.232	0.222	0.096
Eqpt improvement						
No. of equip. engineers	-0.478	-0.044	0.047	0.467	0.572	0.399
Joint proc. & eqpt. engrng.	-0.405	0.085	0.052	*0.253*	*0.323*	0.405
CIT tech/opr teams	-0.368	0.089	0.187	0.363	0.441	0.107
CIT eng/tech teams	-0.110	0.133	-0.110	0.076	0.448	0.167
Eqpt modifications	-0.272	0.030	0.143	0.493	0.604	0.537
Share mods w/ other fabs	-0.018	0.174	0.151	-0.274	0.373	0.027
TPM 5 S improvements	-0.148	-0.089	-0.070	*0.254*	0.225	0.166
Setup time reduction	-0.208	0.135	-0.052	*0.322*	0.505	0.186
Mtce strategy						
No. of techs per machine	0.008	0.114	-0.084	-0.315	0.117	0.011
Eqpt owner program	0.000	*0.309*	*0.309*	0.144	*0.300*	0.412
Opr mtce	-0.361	-0.162	0.048	0.371	*0.312*	-0.042
Vendor contract mtce	-0.021	0.020	-0.428	-0.231	-0.270	-0.055
Nearby on-call vendors	-0.146	0.192	-0.042	-0.161	0.374	0.057
Reg vendor reviews	0.395	0.357	0.158	-0.107	0.231	0.395
Coord rev w/ other fabs	0.094	0.174	0.069	-0.420	0.191	-0.157
Fab characteristics						
Factory utilization	-0.178	0.112	0.061	0.427	0.046	*0.279*
Wafer starts per week	-0.445	0.100	0.103	0.605	0.665	0.410
Wfr strts per proc flow	-0.115	0.091	0.178	0.440	0.476	*0.292*
Wfr strts per die type	0.047	0.036	-0.003	*0.239*	*0.231*	0.088