technische universiteit eindhoven

Modeling Manufacturing Systems

From Practice to Theory

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29 January 2003

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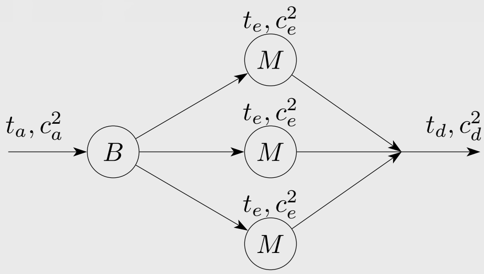
Outline

- From measurements to DES model
  - Effective Processing Times (EPT's)
  - Results from Queuing Theory
  - How to measure EPT's
  - Simulation Study
- From DES model to PDE model: some observations
  - Ramping up a wafer fab: cycle time response
  - The effects of control
  - The effects of variability

Effective Processing Times

- Why EPT's?
  - SEMI: Overall Equipment Efficiency (OEE) based on mean value analysis
  - Lot of variability present: Equipment breakdowns, setups, operator availability, batching, rework, ...
- What is EPT?
  - Time seen by lot from a logistical point of view
  - Includes all time losses due to variability

Results from Queuing Theory



- Cycle time (Pollaczek-Khintchine)

$$CT_q = \frac{c_a^2 + c_e^2}{2} \cdot \frac{u^{\sqrt{2(m+1)}-1}}{m(1-u)} \cdot t_e$$

- Linking equation

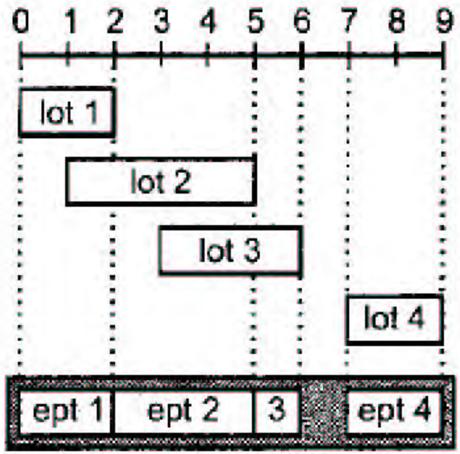
$$c_d^2 = (1-u^2) \cdot c_a^2 + \frac{u^2}{\sqrt{m}} \cdot c_e^2 + (1 - \frac{1}{\sqrt{m}})u^2$$

How to measure EPT?

EPT: Total amount of time a lot *could have been*, or actually was, processed on a machine.

Single machine: FIFO dispatching

time	lot	event
0	1	Arrival
1	2	A
2	1	Depart
3	3	A
5	2	D
6	3	D
7	4	A
9	4	D



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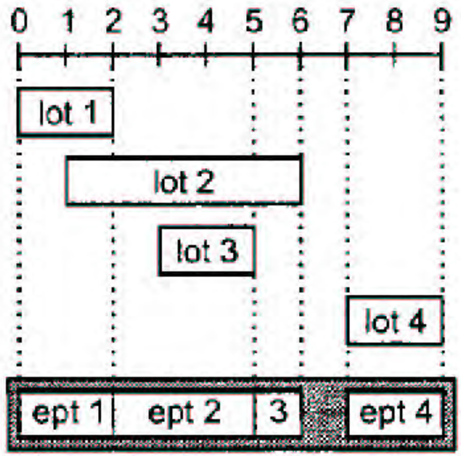
How to measure EPT? (continued)

EPT: Total amount of time a lot *could have been*, or actually was, processed on a machine.

Single machine: general dispatching

time	lot	event
0	1	Arrival
1	2	A
2	1	Depart
3	3	A
5	3	D
6	2	D
7	4	A
9	4	D

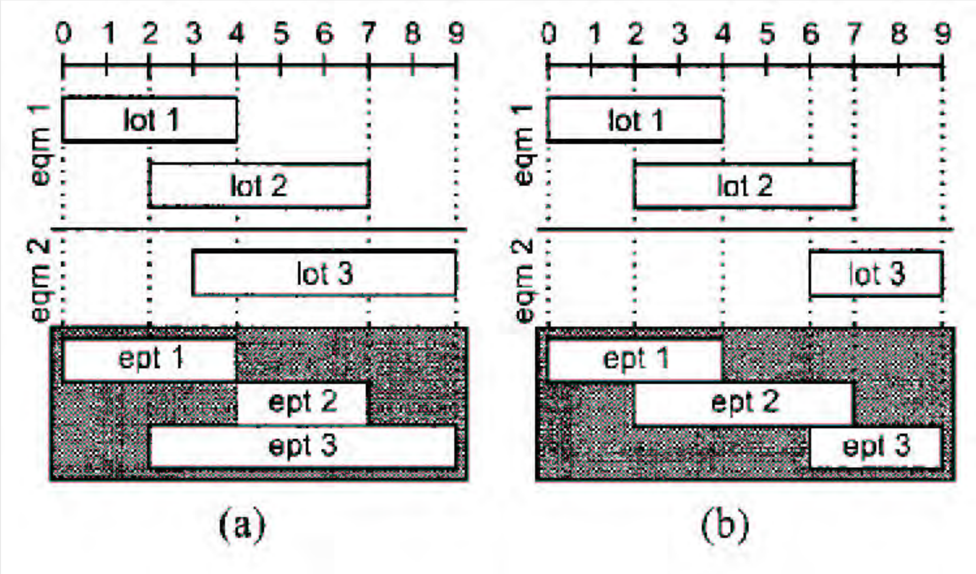


Algorithm (single machine)

$$
\begin{array}{l}
\;\; n := 0 \\
;\, *[\, \mathsf{true} \\
\quad \longrightarrow ?\langle \tau, ev \rangle \\
\qquad ;\, [\, ev = A \longrightarrow [\, n = 0 \longrightarrow s := \tau \\
\qquad\qquad\qquad\qquad\quad\; \|\, n > 0 \longrightarrow \mathsf{skip} \\
\qquad\qquad\qquad\qquad\quad\;] \\
\qquad\qquad\qquad\qquad\quad ;\, n := n + 1 \\
\qquad\quad \|\, ev = D \longrightarrow !\tau - s \\
\qquad\qquad\qquad\qquad\quad ;\, n := n - 1 \\
\qquad\qquad\qquad\qquad\quad ;\, [\, n = 0 \longrightarrow \mathsf{skip} \\
\qquad\qquad\qquad\qquad\quad\; \|\, n > 0 \longrightarrow s := \tau \\
\qquad\qquad\qquad\qquad\quad\;] \\
\qquad\quad] \\
\quad]
\end{array}
$$

Multiple machine case

Multiple machines



Example: Unreliable Machines

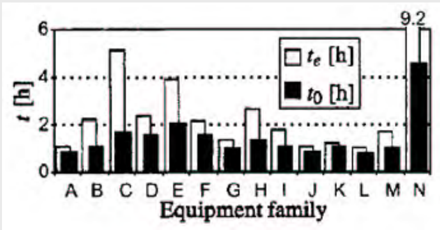
- Poisson arrival
- 2 identical Mach.: $t_0 = 0.8$, $c_0^2 = 0.25$
- Exponential failure/repair. Availability 80%

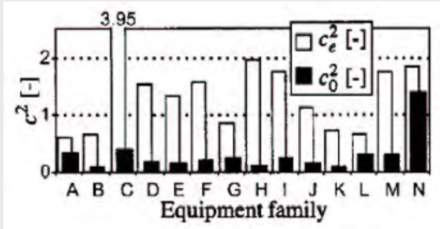
t_f/t_r	r_a	t_e	c_e^2	CT	CT^*
0.8/0.2	1.0	1.000	0.330	1.227	1.230
	1.4	1.000	0.331	1.642	1.653
	1.8	1.000	0.330	3.822	3.839
8.0/2.0	1.0	0.999	1.047	1.315	1.341
	1.4	1.000	1.049	1.968	1.984
	1.8	0.999	1.052	5.192	5.367
16.0/4.0	1.0	0.999	1.844	1.398	1.460
	1.4	1.000	1.844	2.266	2.254
	1.8	1.000	1.849	6.998	6.910

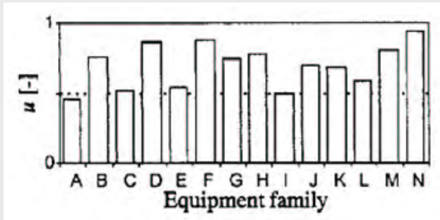
Case study

Philips Semiconductors

- $\geq$ 400 machines
- over 1.5 million track-in and track-out events







Paper (Best paper award)

J.H. Jacobs, L.F.P. Etman, J.E. Rooda, E.J.J. van Campen. Quantifying operational time variability: the missing parameter for cycle time reduction. *Proceedings of the IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, pages 1–10, 2001.

Ongoing research

- Cascade equipments
- Finite buffers (blocking/starvation)

Outline (recalled)

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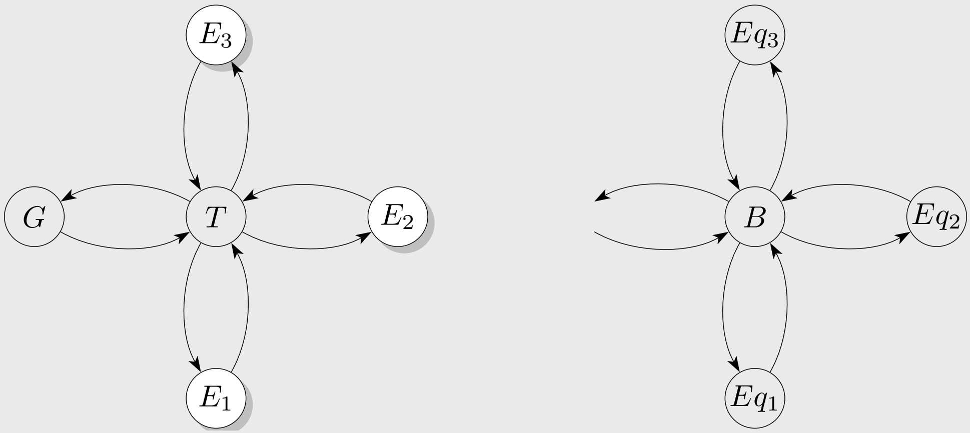
DES Model of wafer fab



G Generator and exit for lots.

T Transporter

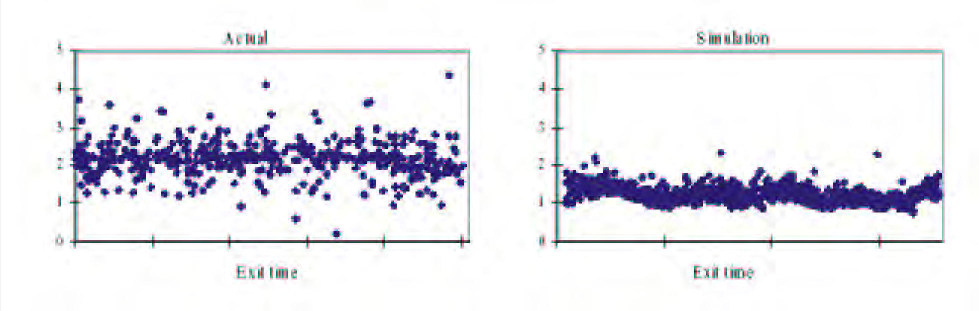
E Machine family

B Buffer

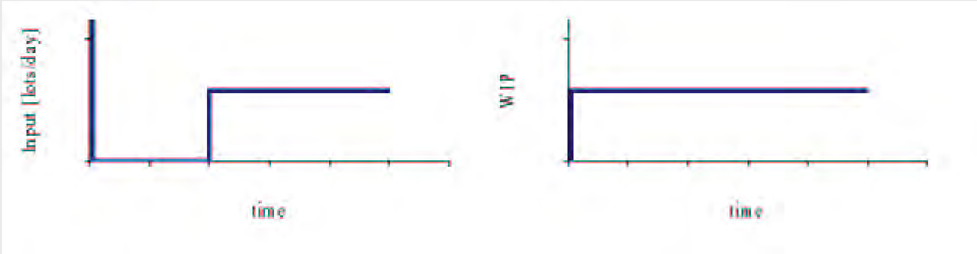
Eq Set of identical machines (either batch or cascade)

Assumptions and Validation

- Three different process flows (0.5, 0.4, 0.35 μm)
- Deterministic processing times
- Stochastic machine failures (not during processing)
- Transport times neglected (less than 2 percent)
- No scrap
- Inspection machines abundant capacity
- Operator behavior not taken into account

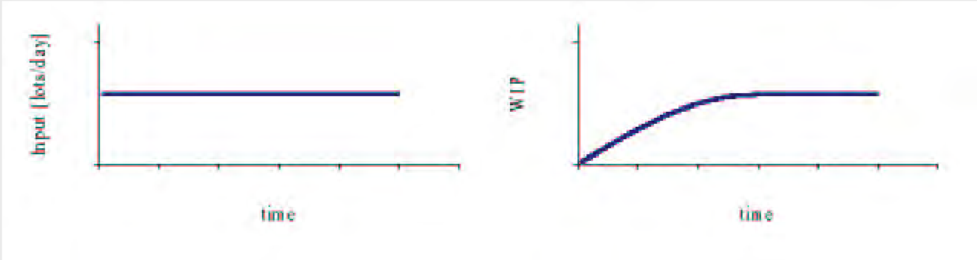


Quiz: Ramp up scenario A



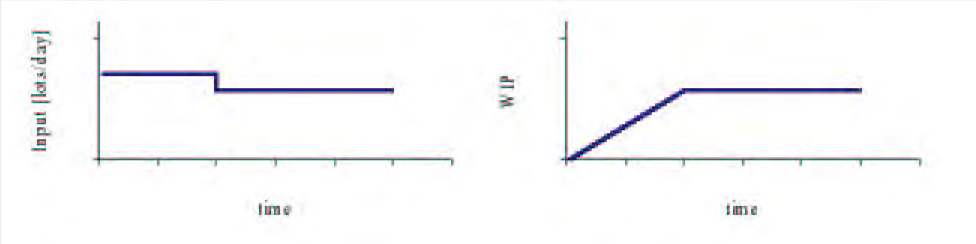
- All WIP in fab at once at $t = 0$
- Constant WIP

Quiz: Ramp up scenario B



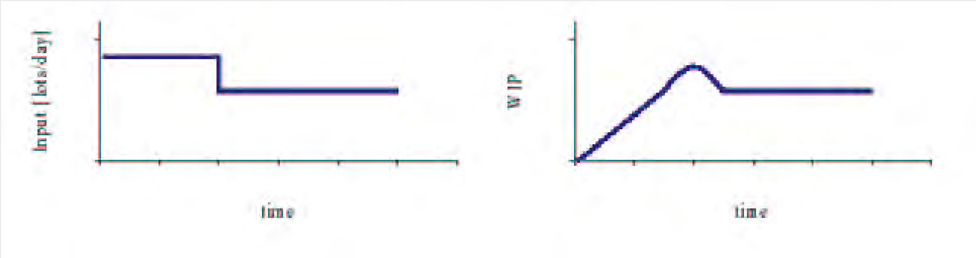
- Release lots at desired output rate

Quiz: Ramp up scenario C



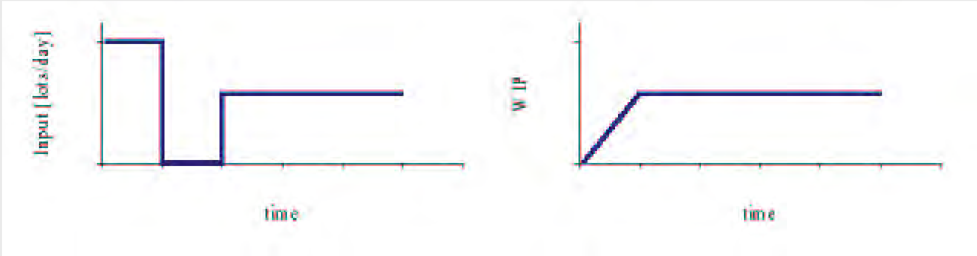
- Constant release rate such that:
- Time fab reaches desired WIP = Time first lots leaves FAB
- Then constant WIP

Quiz: Ramp up scenario D



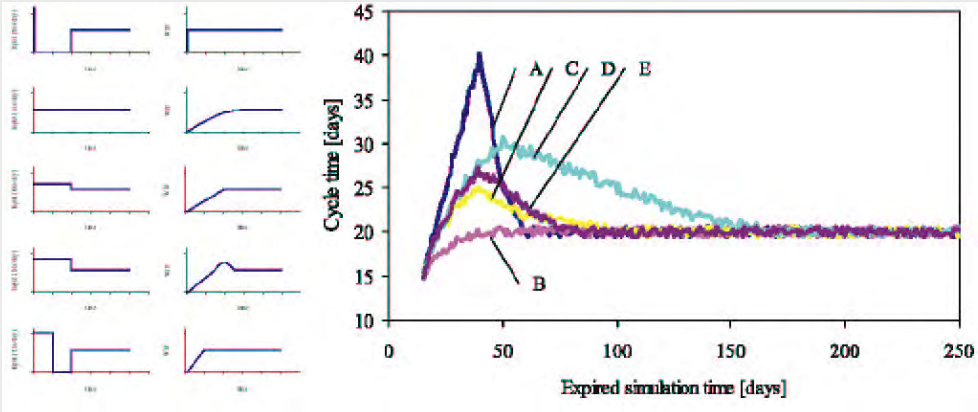
- Higher initial constant rate than C
- Until first lot leaves
- Then release at desired output rate

Quiz: Ramp up scenario E



- High release rate until desired WIP reached
- Then constant WIP

Answers to the quiz: Response of DES model of fab



The effects of control

Consider n identical machines (Exponential: rate μ)

$$\rightarrow B_1 \rightarrow M_1 \rightarrow B_2 \rightarrow M_2 \dashrightarrow B_n \rightarrow M_n \rightarrow$$

Same system, different inflow-strategy

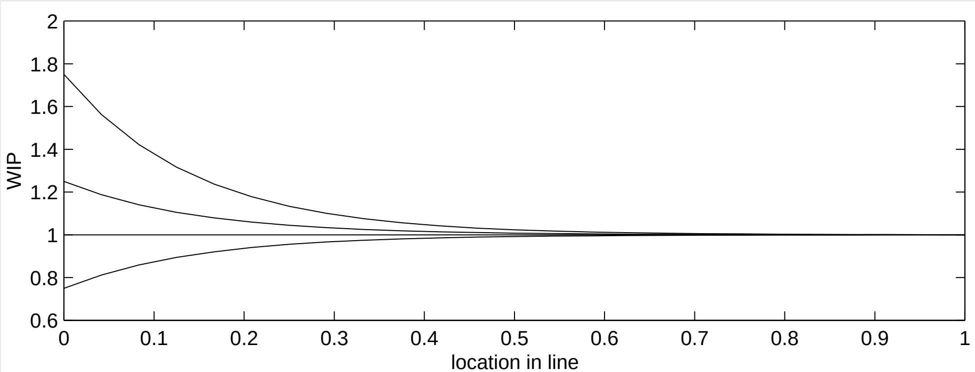
- Push: (Poisson arrival rate λ)
- CONWIP: (Constant WIP level w)

	WIP	TH	CT
Push	$\frac{n\lambda}{\mu-\lambda}$	λ	$\frac{n}{\mu-\lambda}$
Push	w	$\frac{w\mu}{w+n}$	$\frac{1}{\mu}(w+n)$
CONWIP	$\frac{(n-1)\lambda}{\mu-\lambda}$	λ	$\frac{n-1}{\mu-\lambda}$
CONWIP	w	$\frac{w\mu}{w+n-1}$	$\frac{1}{\mu}(w+n-1)$

The effects of variability

Push: $\mu = 1$, $\lambda = 0.9$, $n = 25$

- $c_a^2 = 0$ (deterministic arrivals)
- $c_a^2 = 1$ (Poisson arrivals)
- $c_a^2 = 2, 4$ (general arrivals: moderately/highly variable)



Similar results for general machines ($c_e^2 \neq 1$, $c_a^2 \neq c_e^2$)

Conclusions

- EPT's as tool for cycle time reduction
- EPT's simplify discrete event model

- More variability needs to be included in simulation model
- Issues for PDE models development
  - Ramping up a re-entrant flow line using a non-decreasing wip policy can lead to overshoot in cycle time (policy A,C,E).
  - Applying a release policy derived from PDE-model should not lead to a new PDE-model to be made.
  - Unequal WIP-distributions should be possible in steady state of PDE model.