Study to Compare Global and Local Perspectives in PM Planning Optimization for Semiconductor Wafer Fabricators

Jinho Shin

Department of Industrial and Systems Engineering
KAIST, South Korea

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V. Numerical study: Dataset variation

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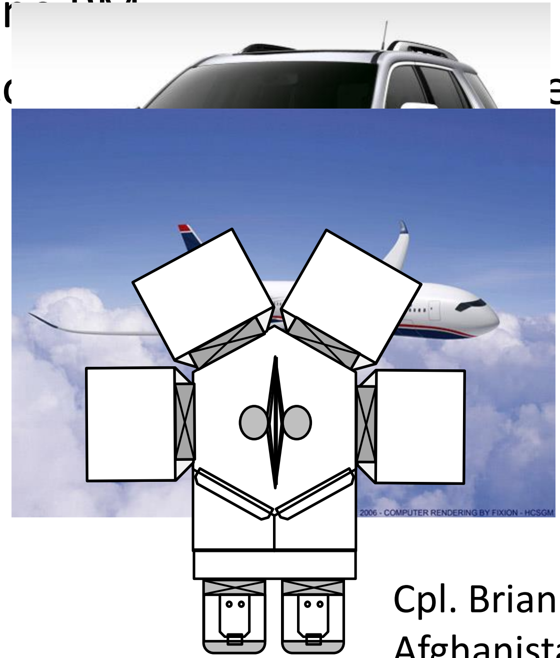
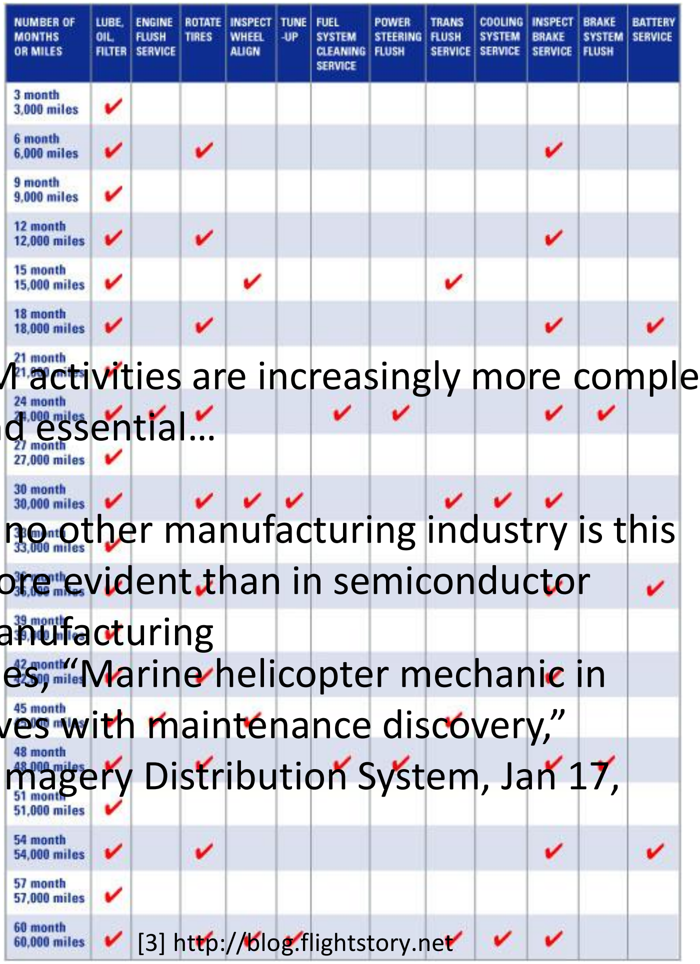
Introduction

- Brief Overview: Preventive Maintenance (1)
  - Automobile PM
  - Airplane PM
  - Semic equipme





NUMBER OF MONTHS OR MILES	LUBE, OIL, FILTER	ENGINE FLUSH SERVICE	ROTATE TIRES	INSPECT WHEEL ALIGN	TUNE -UP	FUEL SYSTEM CLEANING SERVICE	POWER STEERING FLUSH	TRANS FLUSH SERVICE	COOLING SYSTEM SERVICE	INSPECT BRAKE SERVICE	BRAKE SYSTEM FLUSH	BATTERY SERVICE
3 month 3,000 miles	✓											
6 month 6,000 miles	✓		✓							✓		
9 month 9,000 miles	✓											
12 month 12,000 miles	✓		✓							✓		
15 month 15,000 miles	✓			✓				✓				
18 month 18,000 miles	✓		✓							✓		✓
21 month 21,000 miles	✓											
24 month 24,000 miles	✓	✓	✓			✓	✓			✓	✓	
27 month 27,000 miles	✓											
30 month 30,000 miles	✓		✓	✓	✓			✓	✓	✓		
33 month 33,000 miles	✓											
36 month 36,000 miles	✓		✓							✓		✓
39 month 39,000 miles	✓											
42 month 42,000 miles	✓		✓							✓		
45 month 45,000 miles	✓	✓		✓				✓				
48 month 48,000 miles	✓		✓			✓	✓			✓	✓	
51 month 51,000 miles	✓											
54 month 54,000 miles	✓		✓							✓		✓
57 month 57,000 miles	✓											
60 month 60,000 miles	✓		✓	✓	✓			✓	✓	✓		

PM activities are increasingly more complex and essential…

In no other manufacturing industry is this more evident than in semiconductor manufacturing

Cpl. Brian Adam Jones, "Marine helicopter mechanic in Afghanistan saves lives with maintenance discovery," Defense Video and Imagery Distribution System, Jan 17, 2012

[1] http://www.qualitytune-upshops.com/services/preventative_maintenace.html

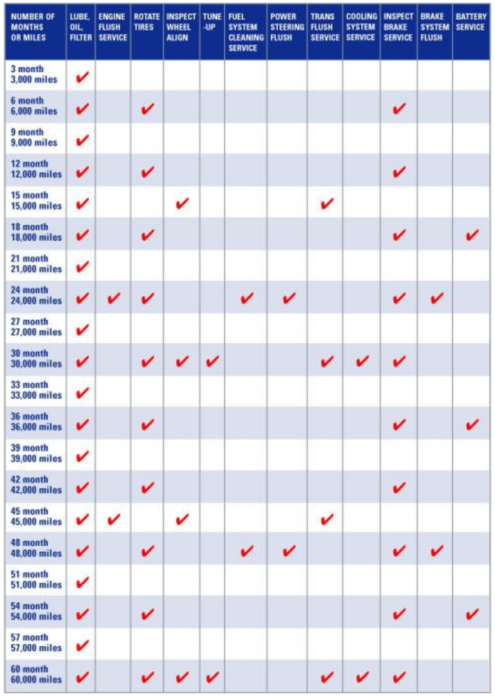
[2] http://www.gmc.com/terrain-small-suv/colors.html,

[3] http://blog.flightstory.net

[4] http://www.dvidshub.net/news/82456/marine-helicopter-mechanic-afghanistan-saves-lives-with-maintenance-discovery

Introduction

- Brief Overview: Preventive Maintenance (2)
  - Planned PM activities
    - **Increase planned downtime**
    - **Overall equipment availability ↑**
    - **Equipment reliability ↑**
    - **Unplanned tool failures ↓**
  - Complexity of PM activities
    - With the increasing cost and complexity of semiconductor manufacturing equipment, PMs have become more complex, with more tasks and longer durations.

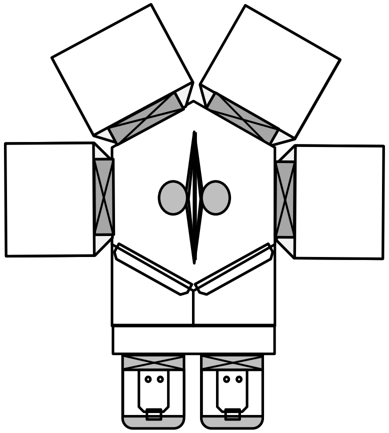


NUMBER OF MONTHS OR MILES	LUBE, OIL, FILTER	ENGINE FLUSH SERVICE	ROTATE TIRES	INSPECT WHEEL ALIGN	TUNE -UP	FUEL SYSTEM CLEANING SERVICE	POWER STEERING FLUSH	TRANS FLUSH SERVICE	COOLING SYSTEM SERVICE	INSPECT BRAKE SERVICE	BRAKE SYSTEM FLUSH	BATTERY SERVICE
3 month 3,000 miles	✓											
6 month 6,000 miles	✓		✓							✓		
9 month 9,000 miles	✓											
12 month 12,000 miles	✓		✓							✓		
15 month 15,000 miles	✓			✓				✓				
18 month 18,000 miles	✓		✓							✓		✓
21 month 21,000 miles	✓											
24 month 24,000 miles	✓	✓	✓			✓	✓			✓	✓	
27 month 27,000 miles	✓											
30 month 30,000 miles	✓		✓	✓	✓			✓	✓	✓		
33 month 33,000 miles	✓											
36 month 36,000 miles	✓		✓							✓		✓
39 month 39,000 miles	✓											
42 month 42,000 miles	✓		✓							✓		
45 month 45,000 miles	✓	✓		✓				✓				
48 month 48,000 miles	✓		✓			✓	✓			✓	✓	
51 month 51,000 miles	✓											
54 month 54,000 miles	✓		✓							✓		✓
57 month 57,000 miles	✓											
60 month 60,000 miles	✓		✓	✓	✓			✓	✓	✓		

PMs are essential for manufacturing performance… need careful consideration

Introduction

- Consider a major PM in a cluster tool
  - Service activities
    - 30 primary components to service
    - 2 hours/component on average
    - Each must be conducted once every month
  - Setup activities
    - Cool down, vent, pump, conditioning, qualification
    - Duration about 6 hours total each time



- How many components should we service in each PM?
  - How many setups do we have per month?
  - What is the resulting tool availability?

Introduction

One month cycle: 30 separate PMs (1 component each)

Setup: 6 hrs

Tool uptime: 16 hrs

1 component PM: 2 hrs

Tool availability = 66.7%

…

One month cycle: 1 PM (All 30 components at once)

Setup: 6 hrs

Tool uptime: 654 hrs

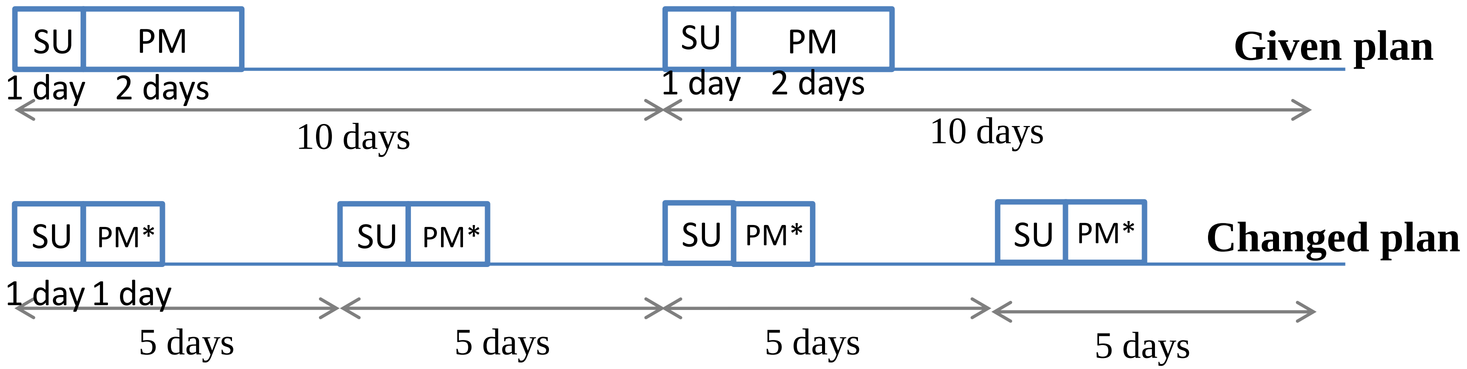
30 component PM: 60 hrs

Tool availability = 90.8%

- Tradeoffs
  - Fewer setups → Increased availability
  - Fewer setups → Large WIP bubbles
- **Goal:** Determine how often we plan to take tool down for PM

Introduction

- PM planning
  - Original PM plan is given from fab ➔ Change the each PM interval.
  - PM interval changes ➔ PM duration changes, Setup time fixed.



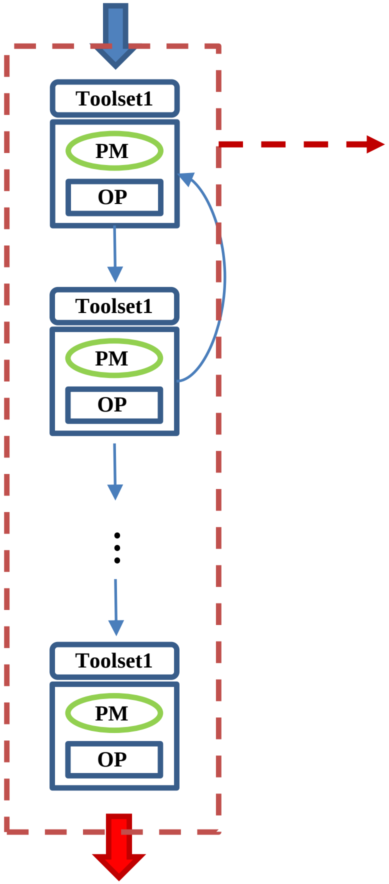
  - Because of incurred setups, PM interval has impact on some variables.
    - Tool availability ↓ (ex. 7/10 ➔ 3/5)
    - Mean downtimes ↓ (ex. 3 ➔ 2)
    - …

➔ Find the optimal intervals resulting in improving total productivity.

Contents

Method description

- Graphical representation of global optimization



Toolset1

PM

OP

Toolset1

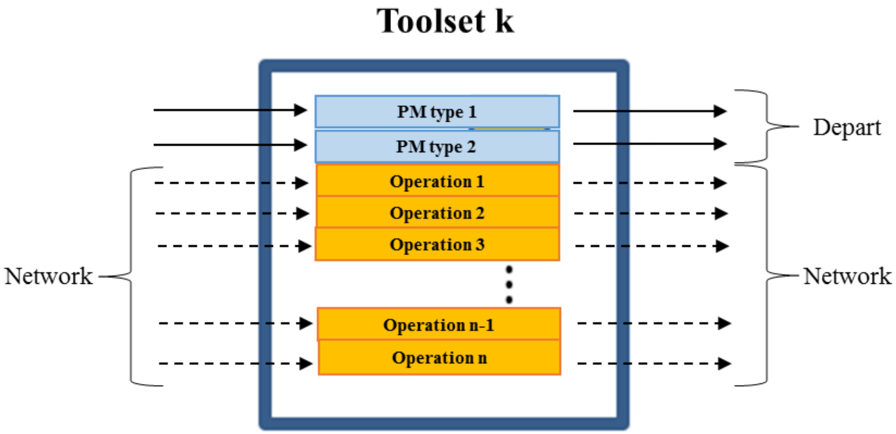
PM

OP

Toolset1

PM

OP



Toolset k

PM type 1

PM type 2

Operation 1

Operation 2

Operation 3

Operation n-1

Operation n

Depart

Network

Network

1. Ca^2 values for all operations are generated from queueing network approximation. The mean waiting time for each toolset is calculated.
2. Optimize the PM plan which minimize the mean total cycle time.
3. Advised PM plans are generated

Method description

- Global perspective
  - Waiting time approximation (Shin et al, MASM 2016)

$$Wq_k \approx \frac{(\sum_{i\in T_k} \rho_{\sigma(i),i})^{\sqrt{m_k - 1}}}{m_k^2} \frac{\sum_{i\in T_{k,O}} \left(Ca_i^2 + Cs_i^2\right)\left(\lambda_i {S_i}^2\right) + \sum_{i\in T_{k,PM}} \left(\mathrm{C}^2_{a,PM_i} + CD_i^2\right)\left(\lambda_{i,PM} {D_i}^2\right)}{2\left(1 - \sum_{i\in T_k} \rho_{\sigma(i),i}\right)\left(1 - \sum_{i\in T_{k,PM}} \rho_{\sigma(i),i}\right)}$$

  - Total cycle time approximation (Shin et al, IJIETAP 2016)

$$TC_i = \sum_{j\in O}\{n_{i,j} S_j\} + \sum_{k\in T}\{n_{i,k} Wq_k\}, \quad \text{for } \{i: \lambda_i^{EX} > 0\}$$

Using G/G/m queueing network approximation, calculates mean waiting time of lots before entering each toolset. Then gets approximated mean total cycle time.

Method description

- Global perspective
  - Nonlinear optimization model for PM planning (Shin et al, IJIETAP 2016)

$$Minimize \ \sum_i \left[\frac{\lambda_i^{EX}}{\sum_i \lambda_i^{EX}} \sum_{j \in O} \{n_{i,j} S_j\}\right] + \sum_i \left[\frac{\lambda_i^{EX}}{\sum_i \lambda_i^{EX}} \left\{\left(\sum_{j \in T_{k,O}} n_{i,j}\right) \cdot Wq_k(\lambda_{PM})\right\}\right] , \qquad \text{for } \{i$$

subject to

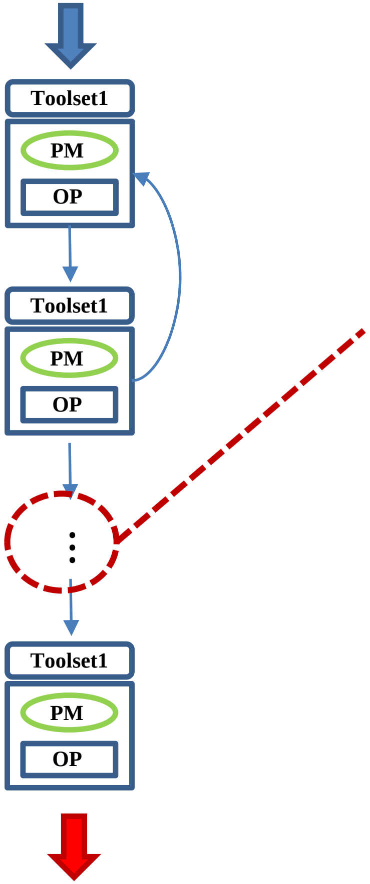
$$0 \leq \sum_{i \in T_k} \rho_i \leq 1, \qquad \text{for all k} \in \mathrm{T}$$

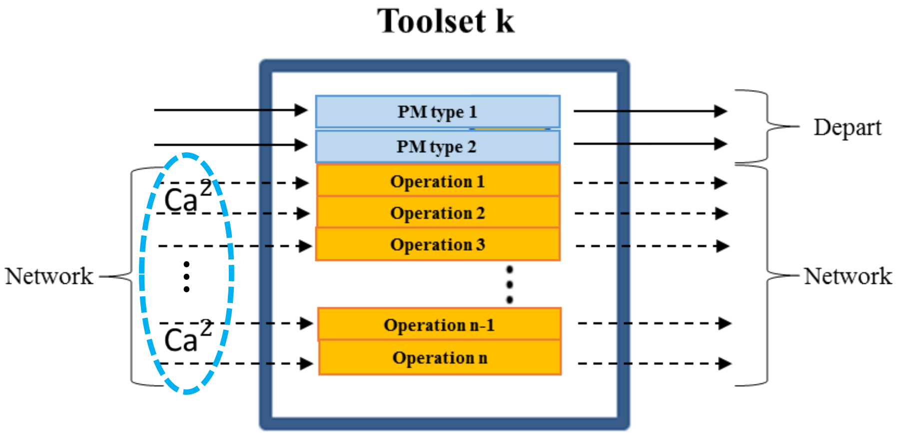
$$L_i^{min} \leq \lambda_{i,PM} \leq L_i^{max}, \qquad \text{for all } i \in T_{k,PM}, \mathrm{k} \in \mathrm{T}$$

Using the proposed nonlinear model, generates advised PM plan to minimize the mean total cycle time.

Method description

- Graphical representation of local optimization





1. Statistically generates the Ca^2 under default PM plan case via simulation data.
2. Optimize the PM plan which minimize the mean waiting time of each toolset (toolset level optimization).
3. Puts advised PM plan and gets total cycle time of customer.

Method description

- Local perspective
  - Using G/G/m queueing approximation similar to previous queueing network approximation.
  - Can't generate Ca^2 value for each operation in toolsets automatically without queueing network approximation.

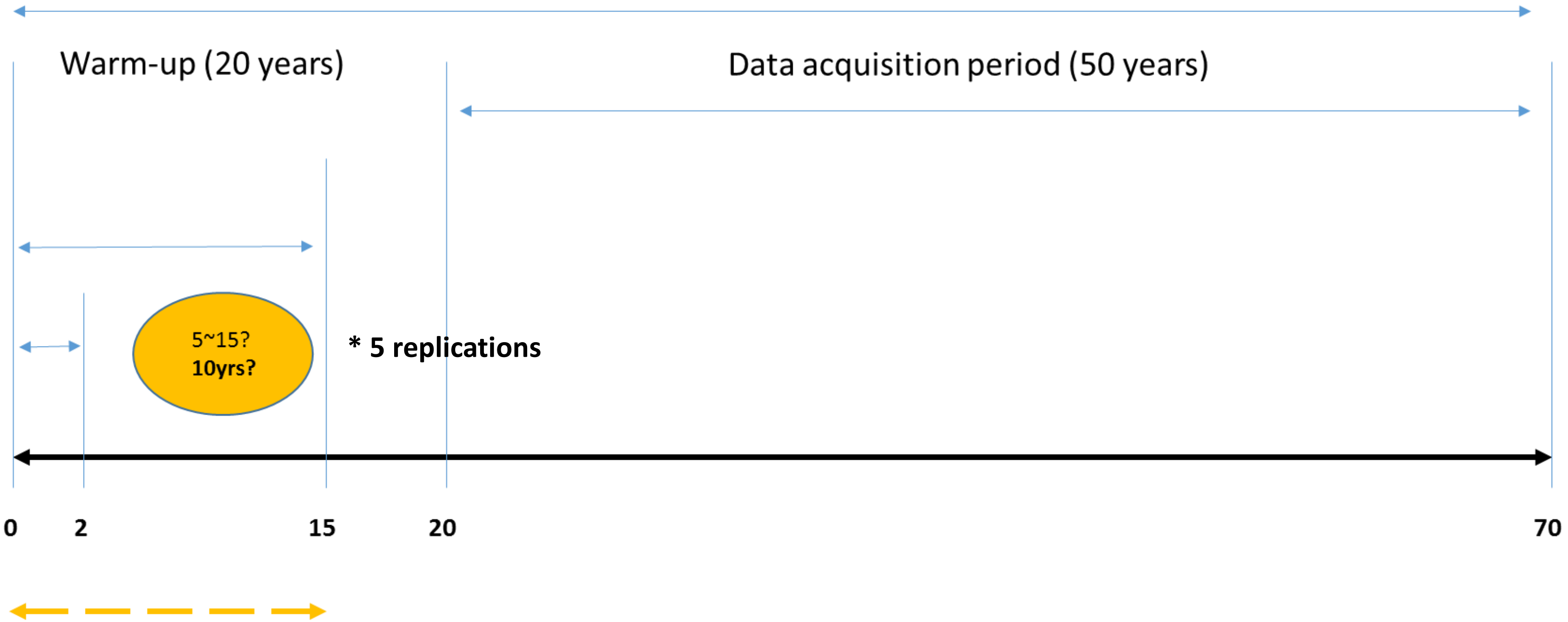
$$Ca = \frac{\sigma}{\mu}$$

$$\mu = Average\ of\ interarrival\ times\ to\ each\ operation \text{ in toolsets}$$
$$\sigma = Standard\ deviation\ of\ \mu$$

Based on statistic analysis with simulation data, generates Ca^2.

Method description

- Local perspective: data acquisition



*** 5 replications**

Data collection for
Local optimal

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- local perspective

III. Numerical study: Total cycle time comparison

IV. Numerical study: Sensitivity analysis

V. Numerical study: Dataset variation

VI. Concluding remarks

Numerical study: Total cycle time comparison

- Dataset description
  - Industry inspired MIMAC dataset #7
  - 24 toolsets, 38 tools, 172 operations
- Simulation setup
  - Software : Autosched AP
  - Warm-up periods : 7,300 days (20 years)
  - Data acquisition : 18,250 days (50 years)
  - The number of replications : 30

Use such a long duration since PMs occur once per 3 months (for example)

Numerical study: Total cycle time comparison

- Queueing network setup for dataset
  - Arrival distribution: customer type – Exponential, PM type – Exponential
  - Service time distribution: Uniform (0.9S, 1.1S)
  - Downtime distribution: Gamma, 2
  - Default PM plan: Given
  - Setup time: 50% of given MTTR value

- Simulation results
  - Total cycle time with default PM plan: 1507.52 h
    (3.38% differences from its approximation)

  - Total cycle time with advised PM plan (**Global**): 1289.10 h
  - Total cycle time with advised PM plan (**Local**): 1277.12 h

0.93% of differences

Two methods show similar minimized total cycle time
within the range of the error arise from simulation itself.

Contents

Numerical study: Sensitivity analysis

- Experiments summary
  - Based on basic system, we target to change 3 types of variables following below.

(1) Sensitivity to bottleneck queue loading: 10 cases

(90, 91, 92, 93, 94, 95, 96, 97, 98, 99%)

(2) Sensitivity to service time distributions: 5 cases

(0.003, 0.030, 0.083, 0.163, 0.270)

(3) Sensitivity to interarrival time distributions: 6 cases

(0.0625, 0.125, 0.25, 0.5, 1, 2)

Numerical study: Sensitivity analysis

- Simulation results summary (1)

Simulation results		Total CT comparison (Simulation)				
		Default PM plan	**Advised PM plan (Global)**	Improve (%)	**Advised PM plan (Local)**	Improve (%)
Sensitivity 1. Bottleneck queue loading	90.0%	1507.52	1289.10	-14.5	1277.12	-15.3
	91.0%	1567.94	1316.41	-16.0	1302.60	-16.9
	92.0%	1628.42	1342.80	-17.5	1331.75	-18.2
	93.0%	1711.26	1368.53	-20.0	1358.08	-20.6
	94.0%	1812.17	1403.01	-22.6	1389.51	-23.3
	95.0%	1950.52	1438.34	-26.3	1430.65	-26.7
	96.0%	2134.68	1475.01	-30.9	1456.21	-31.8
	97.0%	2412.80	1515.99	-37.2	1497.37	-37.9
	98.0%	2964.00	1560.28	-47.4	1545.39	-47.9
	99.0%	4143.30	1614.86	-61.0	1592.47	-61.6
Sensitivity 2. Service time distribution	Uni10%	1507.52	1289.10	-14.5	1277.12	-15.3
	Uni30%	1512.72	1296.58	-14.3	1284.30	-15.1
	Uni50%	1525.54	1308.49	-14.2	1295.66	-15.1
	Uni70%	1546.10	1325.64	-14.3	1312.54	-15.1
	Uni90%	1570.71	1345.40	-14.3	1334.33	-15.0
Sensitivity 3. Interarrival time distribution	Gam,16	935.05	879.56	-5.9	880.95	-5.8
	Gam,8	969.45	904.73	-6.7	905.29	-6.6
	Gam,4	1034.73	953.66	-7.8	953.09	-7.9
	Gam,2	1183.55	1058.73	-10.5	1056.36	-10.7
	Gam,1	1507.52	1289.10	-14.5	1277.12	-15.3
	Gam,0.5	2179.43	1775.03	-18.6	1756.99	-19.4

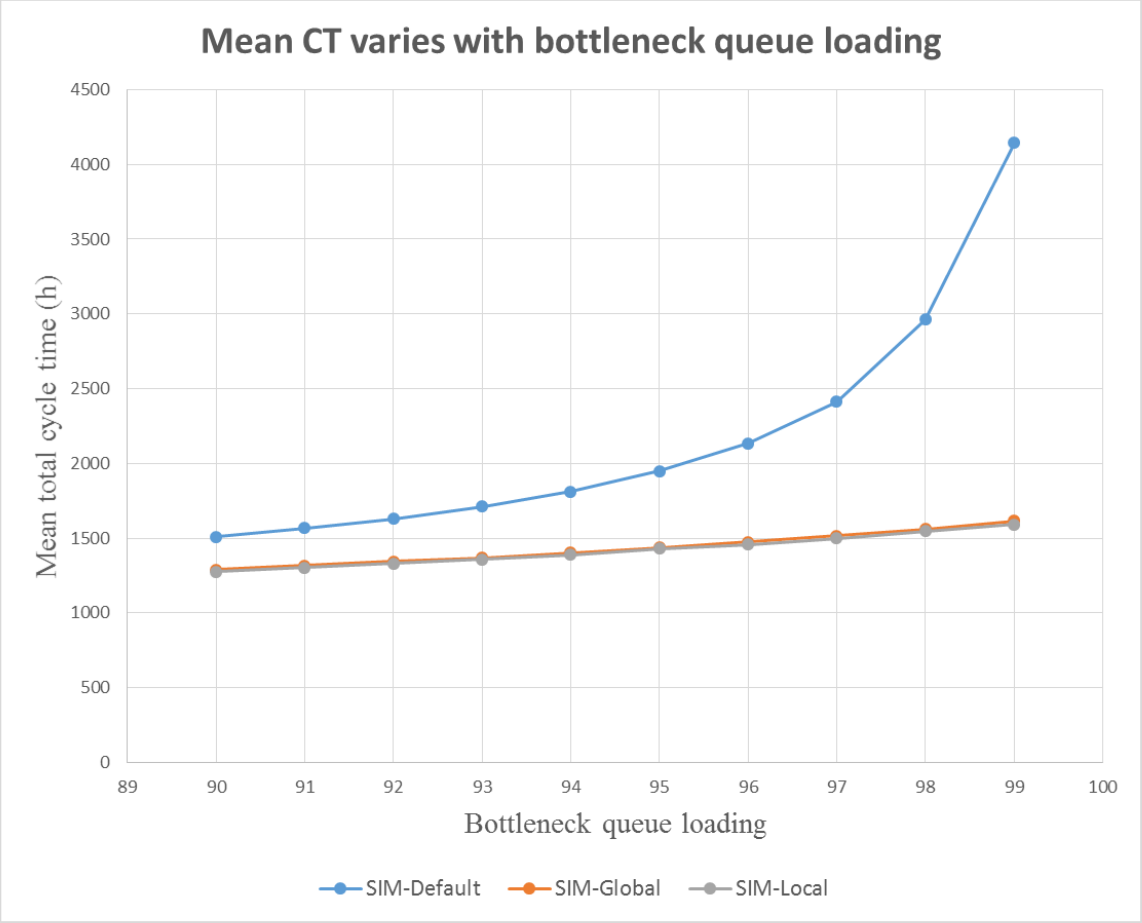
Numerical study: Sensitivity analysis

- Simulation results summary (2)

Simulation results		**Difference on total cycle time**		
		Advised PM plan (Global)	**Advised PM plan (Local)**	Differences (%)
Sensitivity 1. Bottleneck queue loading	90.0%	1289.10	1277.12	-0.93
	91.0%	1316.41	1302.60	-1.05
	92.0%	1342.80	1331.75	-0.82
	93.0%	1368.53	1358.08	-0.76
	94.0%	1403.01	1389.51	-0.96
	95.0%	1438.34	1430.65	-0.53
	96.0%	1475.01	1456.21	-1.27
	97.0%	1515.99	1497.37	-1.23
	98.0%	1560.28	1545.39	-0.95
	99.0%	1614.86	1592.47	-1.39
Sensitivity 2. Service time distribution	Uni10%	1289.10	1277.12	-0.93
	Uni30%	1296.58	1284.30	-0.95
	Uni50%	1308.49	1295.66	-0.98
	Uni70%	1325.64	1312.54	-0.99
	Uni90%	1345.40	1334.33	-0.82
Sensitivity 3. Interarrival time distribution	Gam,16	879.56	880.95	0.16
	Gam,8	904.73	905.29	0.06
	Gam,4	953.66	953.09	-0.06
	Gam,2	1058.73	1056.36	-0.22
	Gam,1	1289.10	1277.12	-0.93
	Gam,0.5	1775.03	1756.99	-1.02

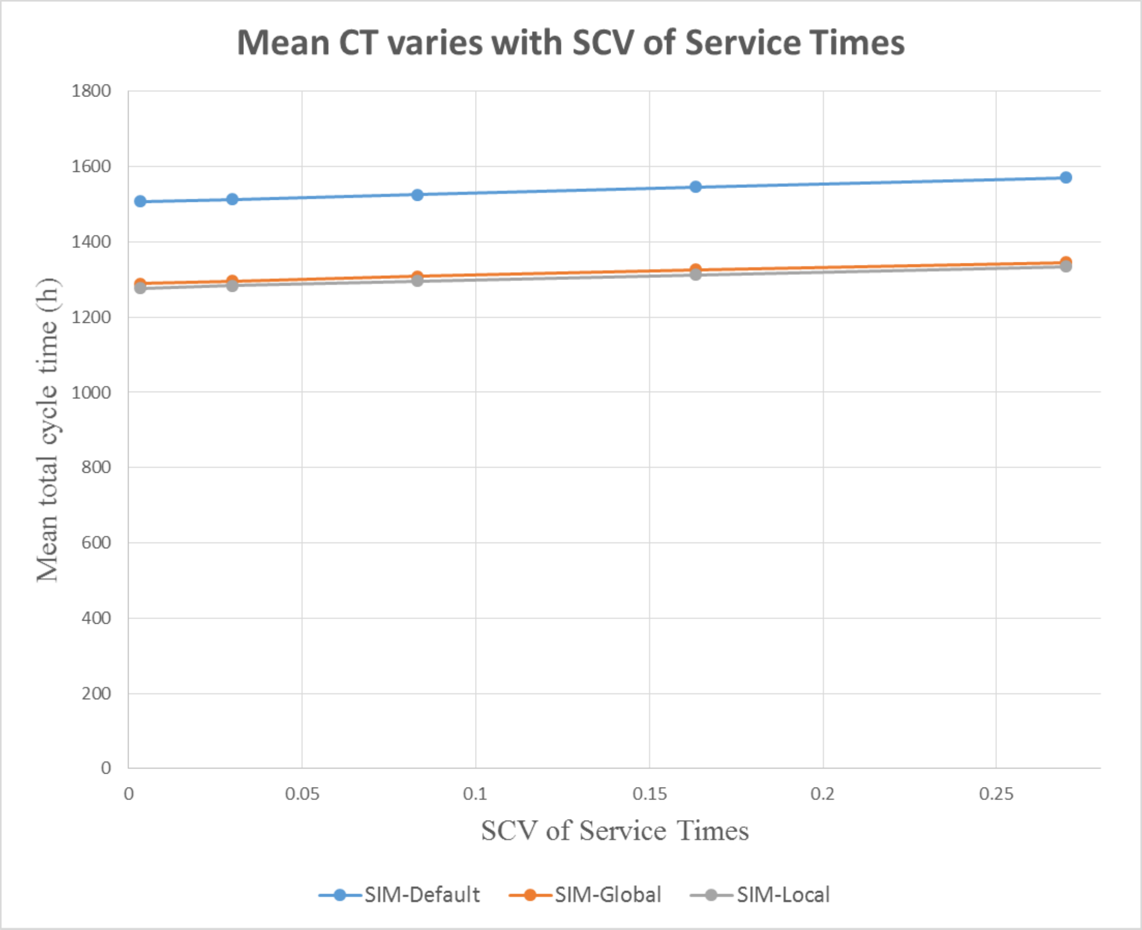
Numerical study: Sensitivity analysis

- Sensitivity analysis 1: Bottleneck queue loading



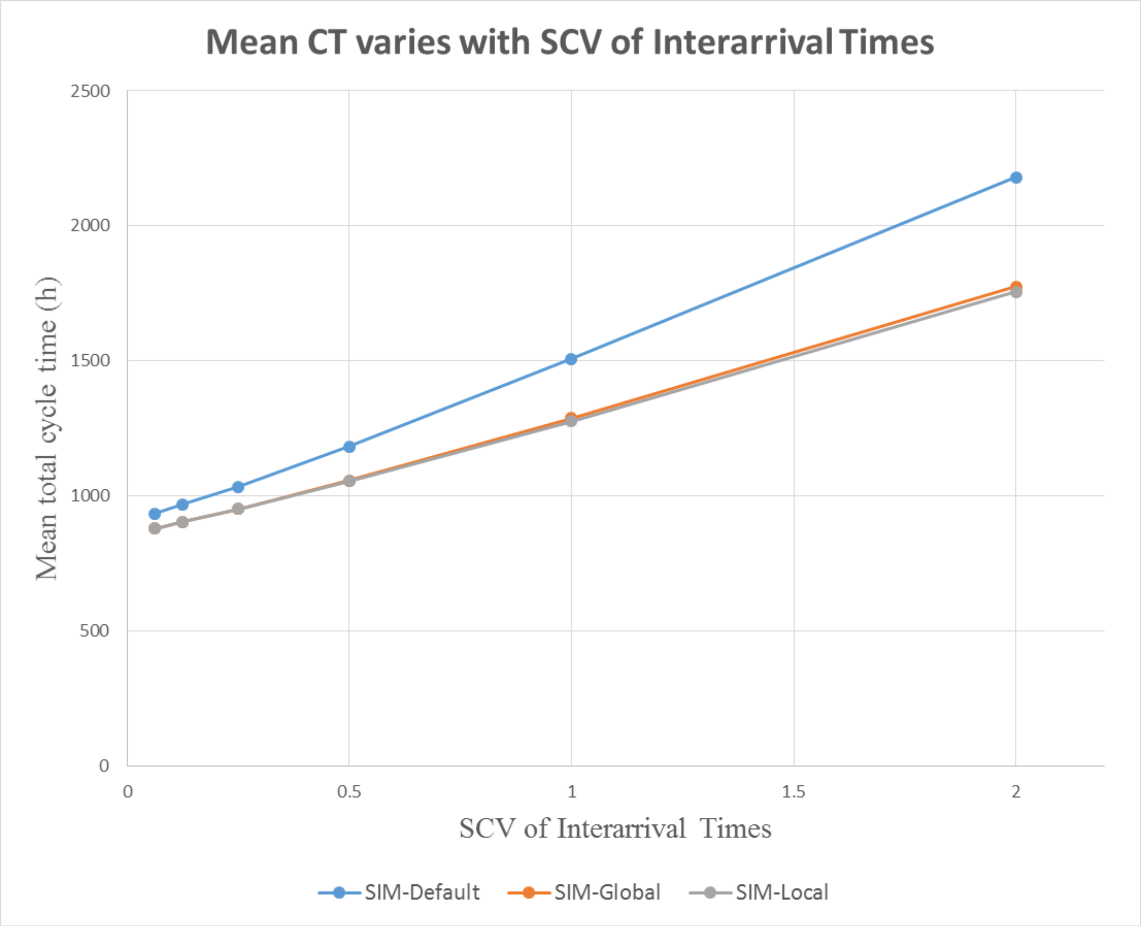
Numerical study: Sensitivity analysis

- Sensitivity analysis 2: Service time distribution



Numerical study: Sensitivity analysis

- Sensitivity analysis 3: Interarrival time distribution



Contents

Numerical study: Dataset variation

- Overview
  - Variation 1
    - 55h interval & origin MTTR & Ptime to meet 85% loading
    - 55h interval & origin MTTR & Ptime to meet 90% loading
    - 55h interval & origin MTTR & Ptime to meet 95% loading

  - Variation 2
    - 27.5h interval & origin MTTR & Ptime to meet 85% loading
    - 27.5h interval & origin MTTR & Ptime to meet 90% loading
    - 27.5h interval & origin MTTR & Ptime to meet 95% loading

  - Variation 3
    - 55h interval & Double MTTR & Ptime to meet 85% loading
    - 55h interval & Double MTTR & Ptime to meet 90% loading
    - 55h interval & Double MTTR & Ptime to meet 95% loading

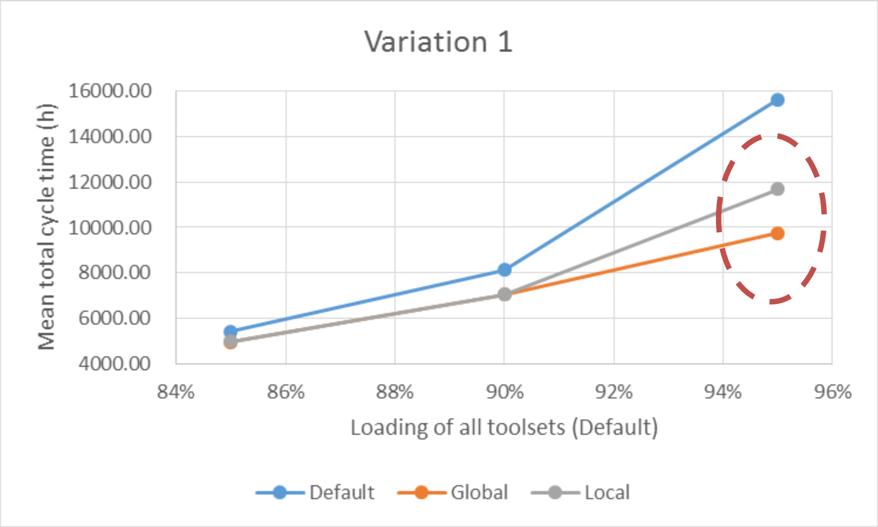
  - Variation 4
    - 27.5h interval & Double MTTR & Ptime to meet 85% loading
    - 27.5h interval & Double MTTR & Ptime to meet 90% loading
    - 27.5h interval & Double MTTR & Ptime to meet 95% loading

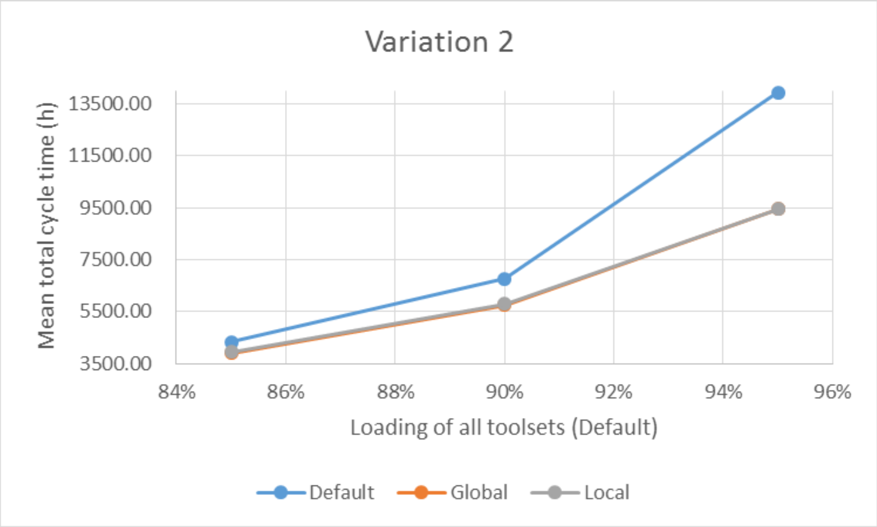
Numerical study: Dataset variation

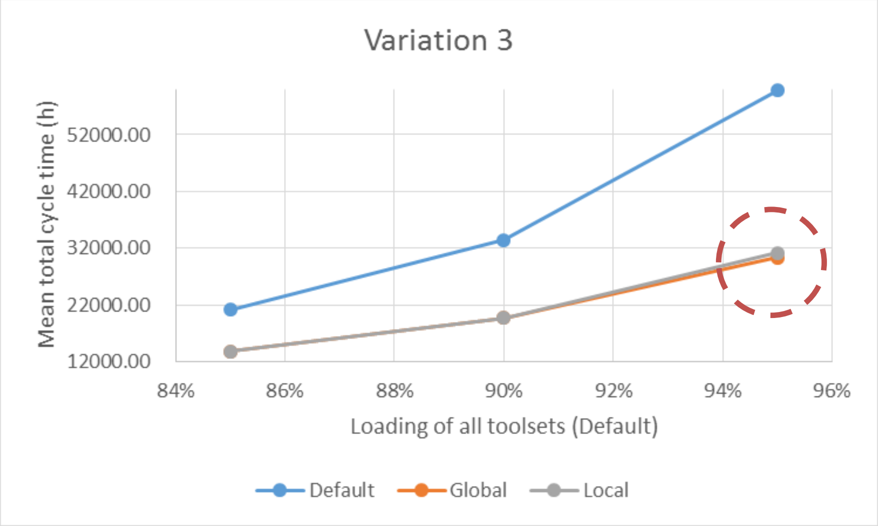
- Overview

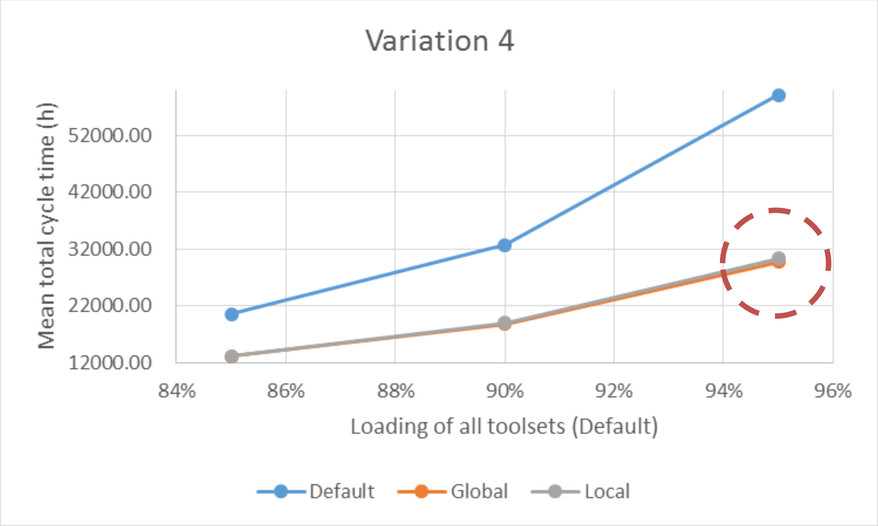
	Loading	Default (h)	Global (h)	Local (h)	Diff (%)
Variation 1	85%	5423.75	4960.24	4993.61	0.67
	90%	8135.55	7045.25	7055.83	0.15
	95%	15640.57	9745.09	11696.83	**20.03**
Variation 2	85%	4332.79	3905.86	3945.68	1.02
	90%	6762.21	5752.18	5784.36	0.56
	95%	13945.80	9440.68	9451.08	0.11
Variation 3	85%	21178.70	13818.43	13827.03	0.06
	90%	33486.57	19774.87	19725.17	-0.25
	95%	59756.87	30425.40	31187.27	**2.50**
Variation 4	85%	20506.40	13129.17	13140.53	0.09
	90%	32688.90	18811.87	19011.39	1.06
	95%	59141.27	29708.93	30376.13	**2.25**

Numerical study: Dataset variation









Contents

Concluding remarks

- Fab-level PM plan optimization
  - Opportunity to improve production efficiency.
- Global and local perspectives
  - In our dataset, two methods show similar total cycle time after PM plan optimization.
  - Local optimization requires vast amount of time and effort to generate the Ca^2 value for each operation in toolsets.
  - Global optimization which using queueing network approximation automatically generate Ca^2 and much faster to reach advised PM plan.
  - From additional analysis, we find the case that global optimization is much better than local optimization.
  - Further research will be conducted on some extreme cases.

Study to Compare Global and Local Perspectives in PM Planning Optimization for Semiconductor Wafer Fabricators

- End of the presentation -

Jinho Shin

Department of Industrial and Systems Engineering
KAIST, South Korea

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