The Illusion of Capacity in Central Planning

The Challenge of Incorporating the Complexity of Wafer Fabrication "Capacity" into Traditional Supply Chain or Production Planning Models

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Evolving Requirements

- For years the consulting mantra was “lack of “executive level buy-in” was a major impediment to a successful planning process. Often this is not the primary barrier, since most executives now realize a disciplined planning process will help the bottom line. What are the top barriers? Recent studies identified one critical barrier as the lack of suitable software tools / models—which includes more **intelligent modeling of the complex nature of capacity**.

Theme for This Afternoon's Feature Presentation is

The Hunt for CAPAVAIL

(capacity available)

& CAPREQ (capacity required)

Outline (1 of 2)

- **Overview of the Demand Supply Network for the production of semiconductor based packaged goods (SBPG)**
  - **Warring factions**
  - **Post FAB complexity**
    - alternative BOMS
    - Demand priorities, etc
  - **Behind the FAB Curtain, challenges**
    - Planned lack of tool uniformity
    - Inherent variability
    - Long routes
    - Reentrant flow

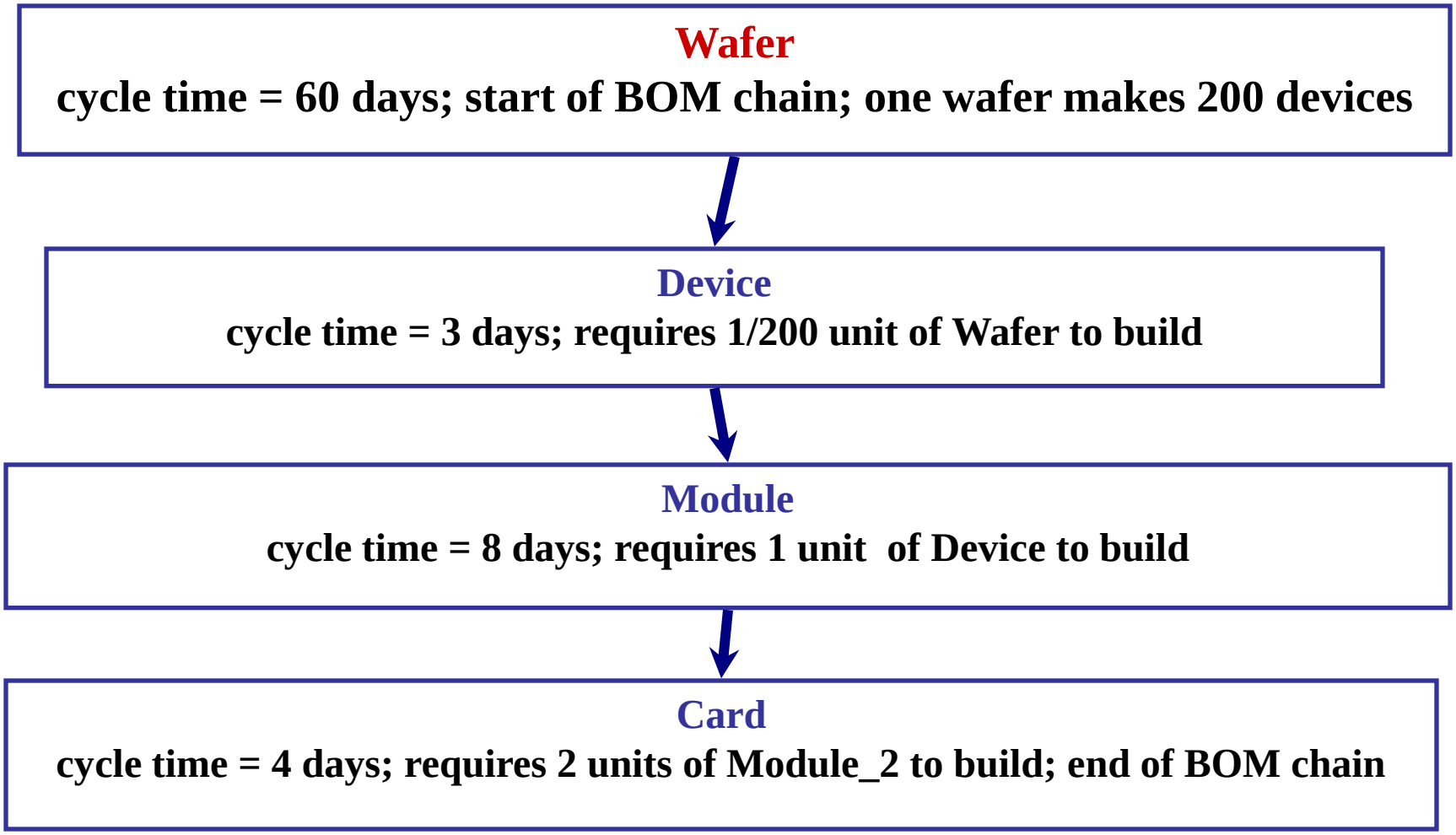
Outline (2 of 2)

- Basics of Central Planning
  - Basic Functions
  - Historical emphasis on non-FAB complexity
    - Alternate BOM for example
  - Traditional Linear Structures for capacity
    - Fixed cycle time
    - Capacity required (CAPREQ) and capacity Available (CAPAVAIL)
- Where do we find CAPAVAIL and CAPREQ in FABS
- Handle FAB Capacity with limits stated as wafer starts
  - Wafer start equivalents evolved to nested wafer starts (date effective)
  - Fixed, but date effective cycle times

Overview of Demand Supply Network for the production of semiconductor based package goods

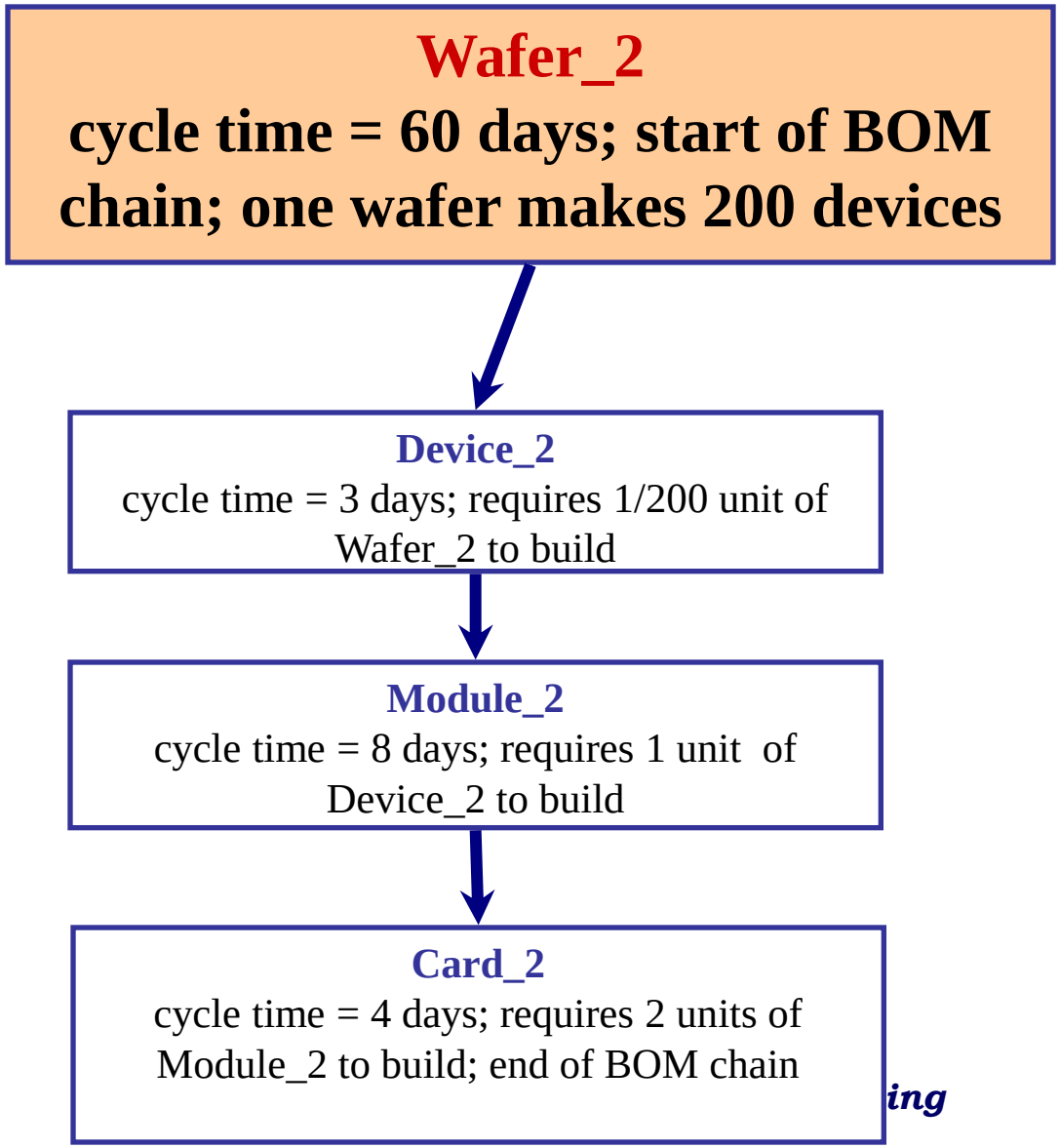
Warring factions
Different complexities

Simple view demand supply network for production of semiconductor based packaged goods



Simple view demand supply network for production of semiconductor based packaged goods

Wafer (FAB) Centric



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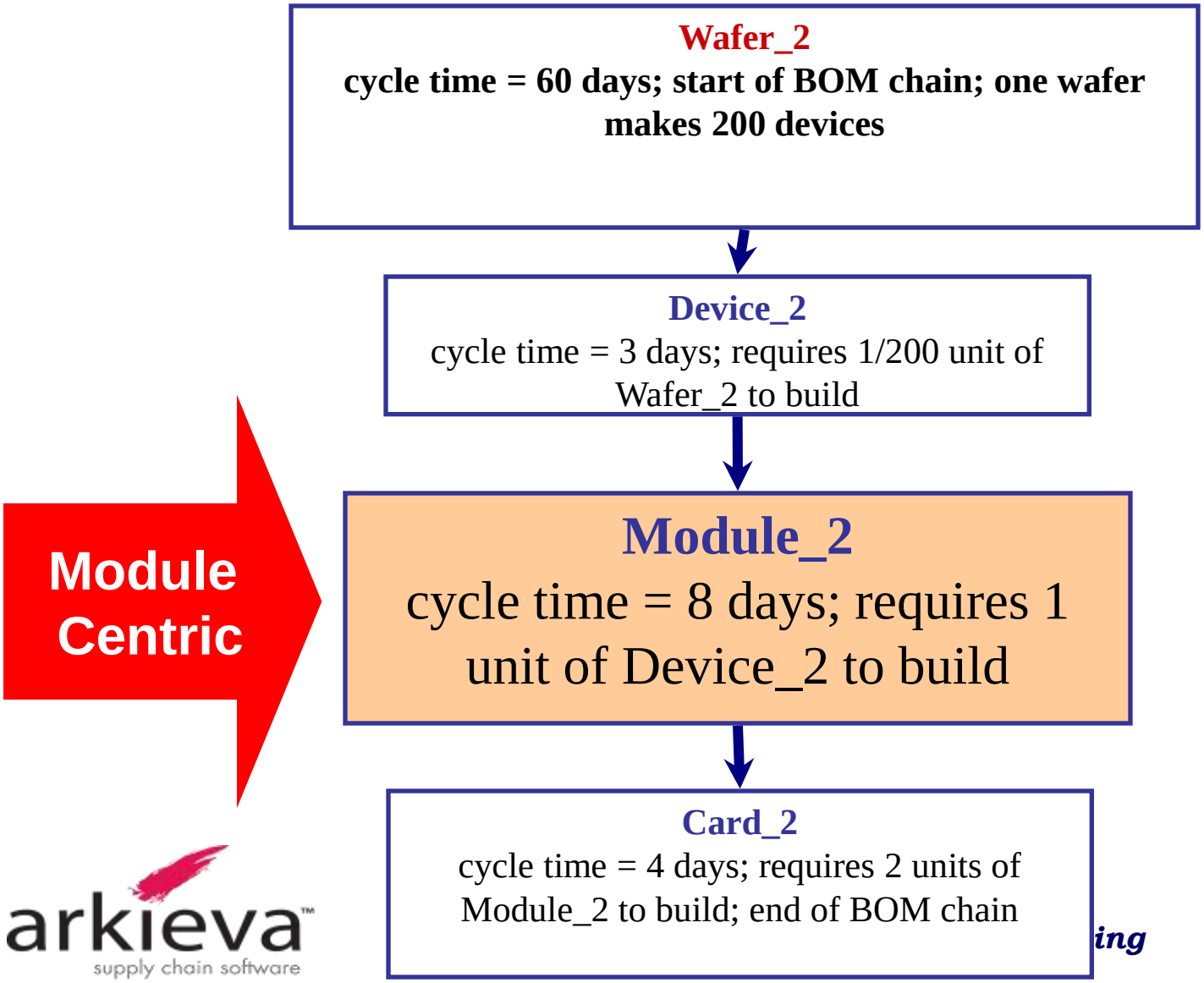
Simple view demand supply network for production of semiconductor based packaged goods



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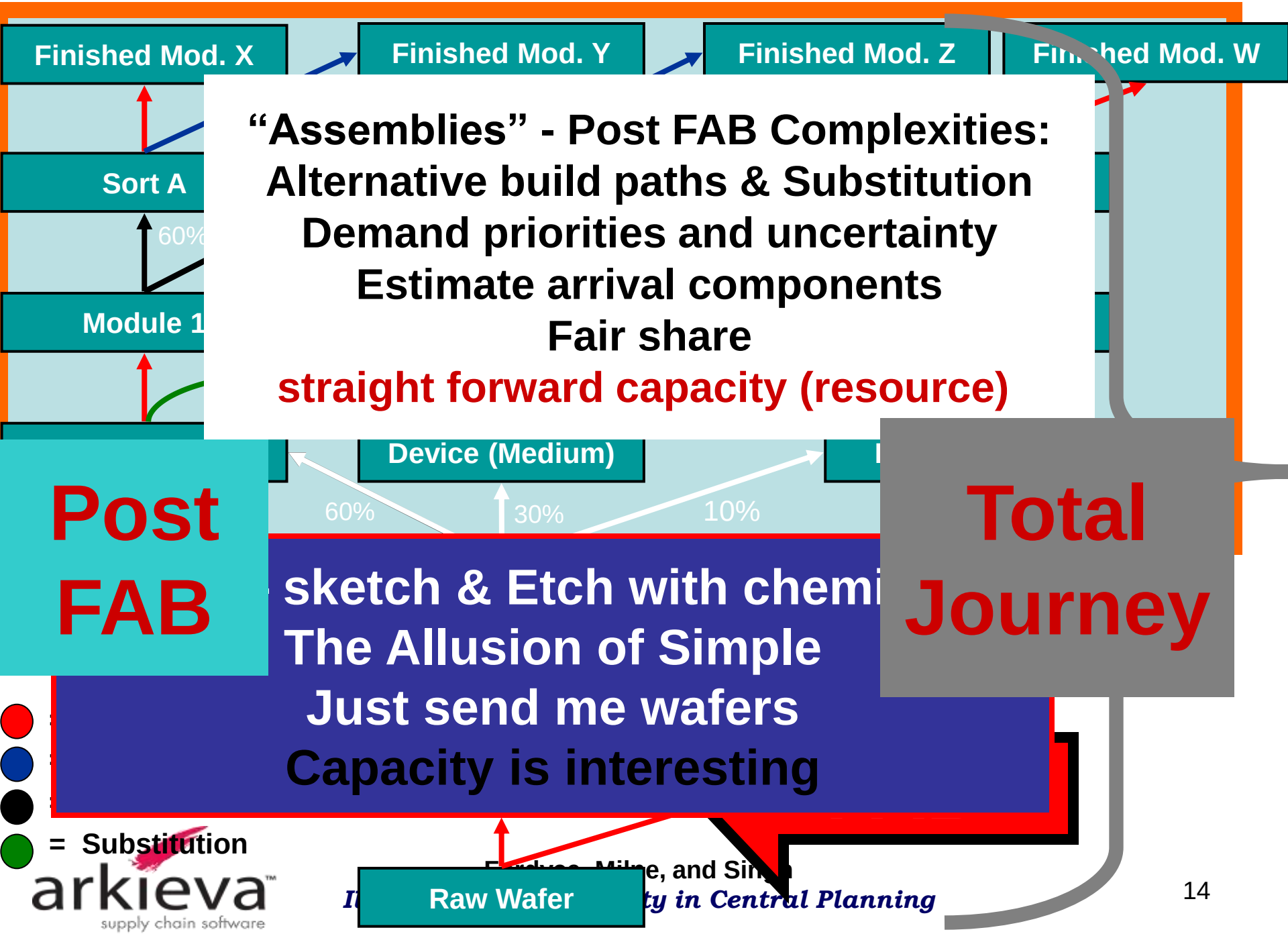

"Assemblies" - Post FAB Complexities:
Alternative build paths & Substitution
Demand priorities and uncertainty
Estimate arrival components
Fair share
straight forward capacity (resource)

Post FAB

Total Journey

sketch & Etch with chemi
The Allusion of Simple
Just send me wafers
Capacity is interesting

= Substitution

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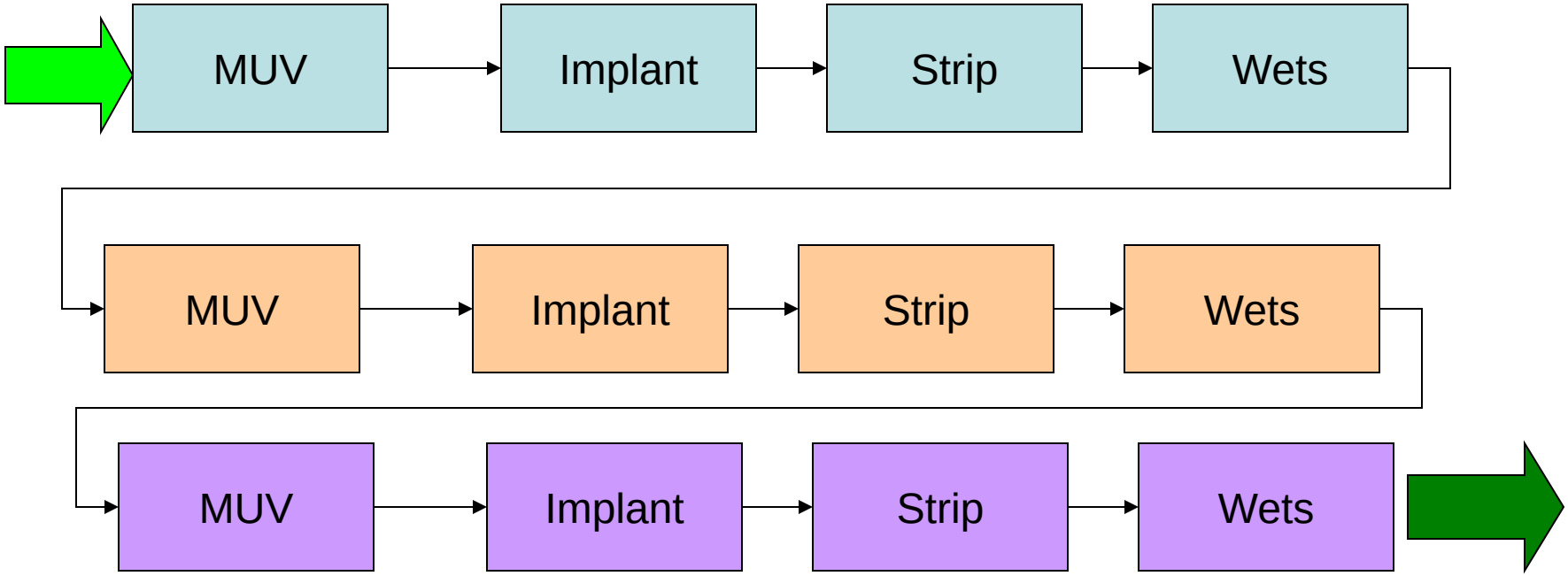
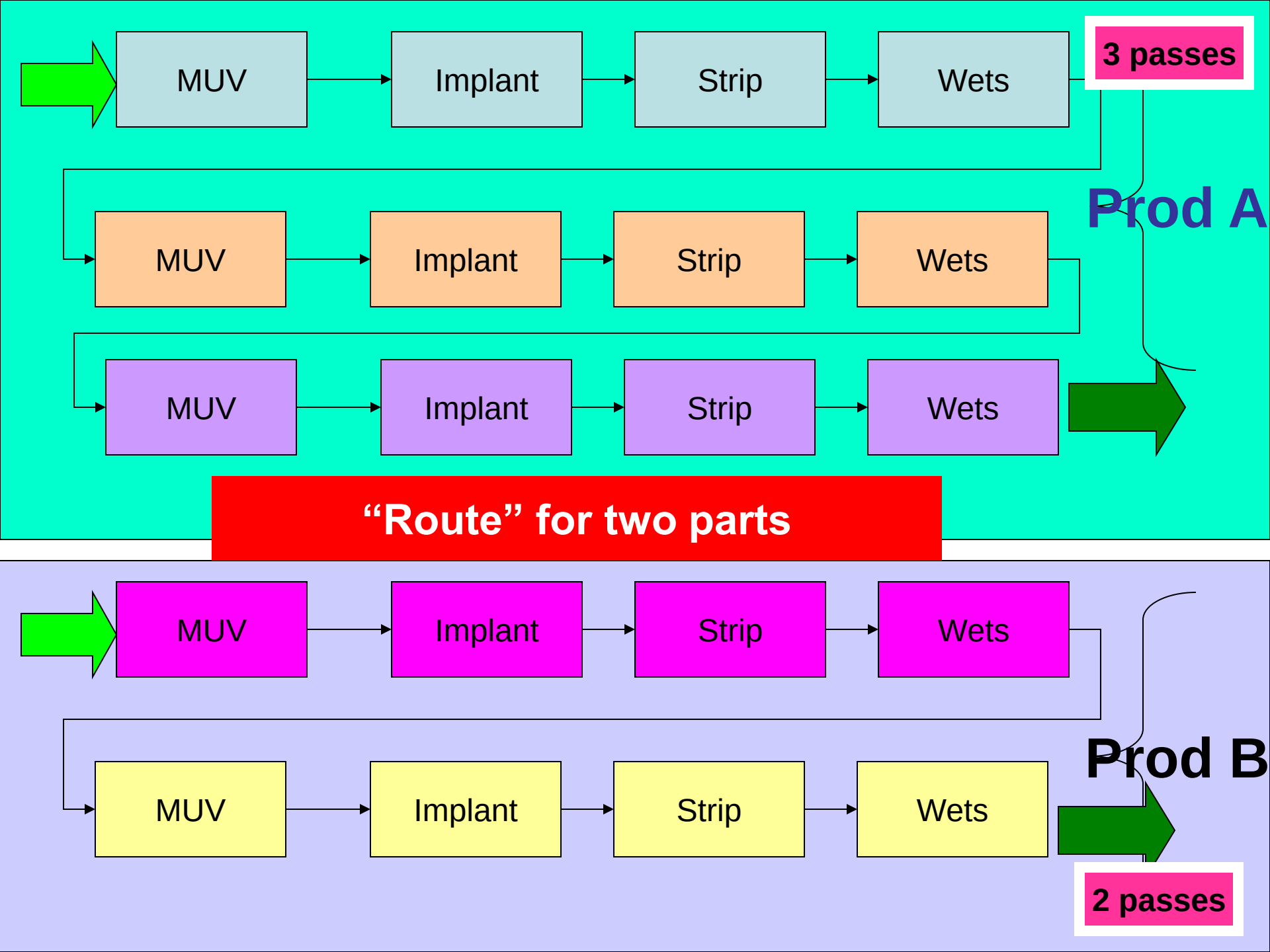
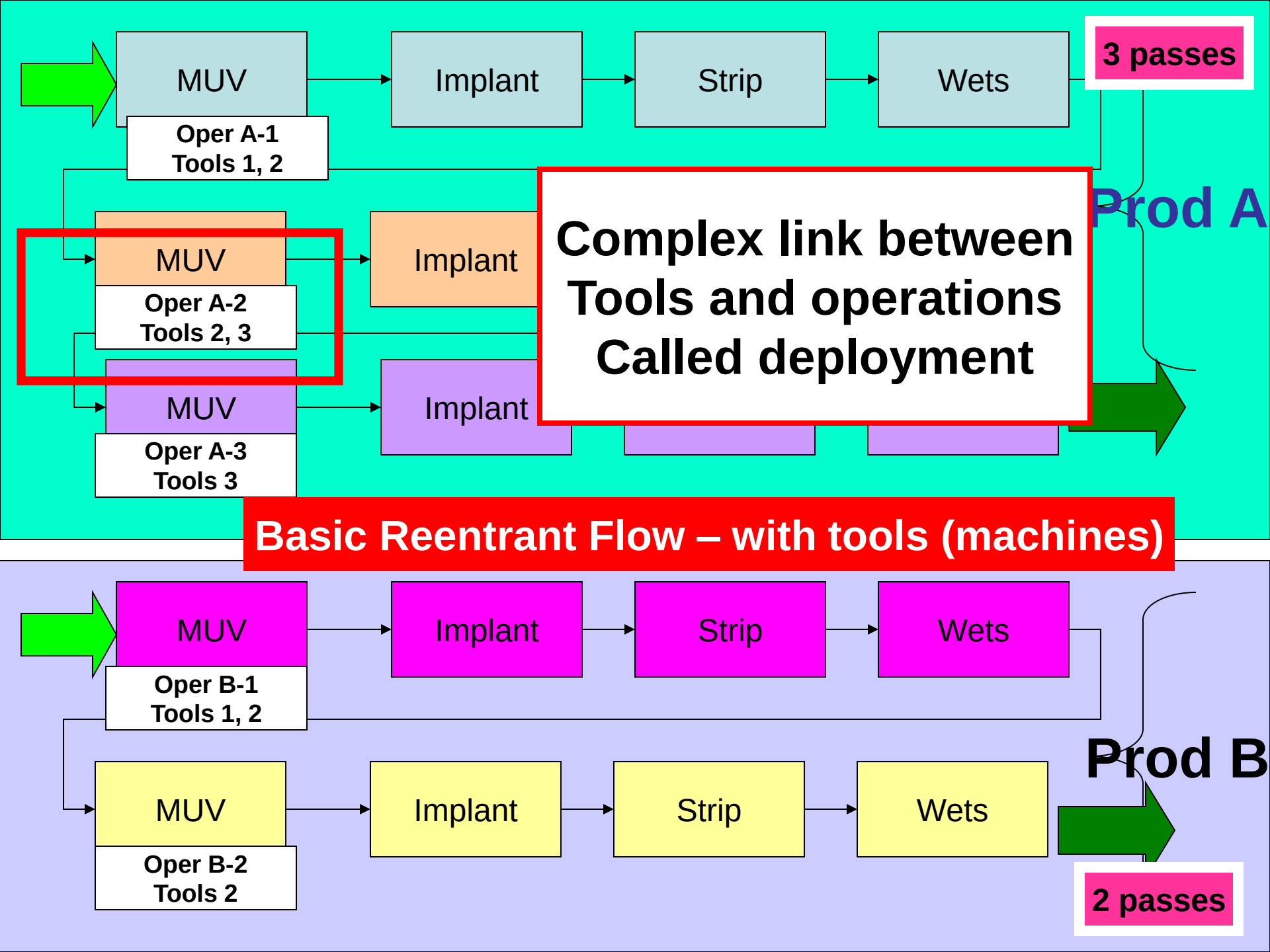
It ty in Central Planning

Behind the “FAB” Curtain



“Route” with basic “reentrant” flow


MUV
Implant
Strip
Wets
3 passes
MUV
Implant
Strip
Wets
Prod A
MUV
Implant
Strip
Wets
"Route" for two parts
MUV
Implant
Strip
Wets
MUV
Implant
Strip
Wets
Prod B
2 passes


MUV
Implant
Strip
Wets
3 passes
Oper A-1
Tools 1, 2
Prod A
MUV
Implant
Oper A-2
Tools 2, 3
Complex link between
Tools and operations
Called deployment
MUV
Implant
Oper A-3
Tools 3
Basic Reentrant Flow – with tools (machines)
MUV
Implant
Strip
Wets
Oper B-1
Tools 1, 2
Prod B
MUV
Implant
Strip
Wets
Oper B-2
Tools 2
2 passes

Deployment – Tool / Operation Link

Deployment - Relationship Operations & Tools which tools service which operations					
		tools (machines)			number of tools covering oper
		Tool-1	Tool-2	Tool-3	
operations	A-1	1	1	0	2
	A-2	0	1	1	2
	A-3	0	0	1	1
	B-1	1	1	0	2
	B-2	0	1	0	1
number of opers a tool covers		2	4	2	
* 1 tool can service this operation, 0 can not service this operation ** note lack of uniform deployment					

1 – oper/tool link active
0 – not allowed

Major Challenges From FABS

FAB Capacity Major Challenges

- Long routes with many passes through the same tool set

Reentrant flow

- Planned Lack of Uniformity - not all tools for a manufacturing process have identical profiles
  - What operations they handle
  - Their production rate
  - How does this impact **capacity available**

Deployment (alternative machines)

- Inherent Variability - in the manufacturing line forces us to plan for unused capacity (tools ready to go, but idle due to lack of WIP) to meet the lead time or cycle time objective - Operating curve
  - trade-off between utilization and cycle time
  - Trade-off between output and cycle time
  - Trade-off between wafer starts and cycle time
  - Trade-off effective **capacity available** and cycle time

OP Curve

- Raw process time (RPT) is sequence dependent

RPT / CACTUS

Deployment

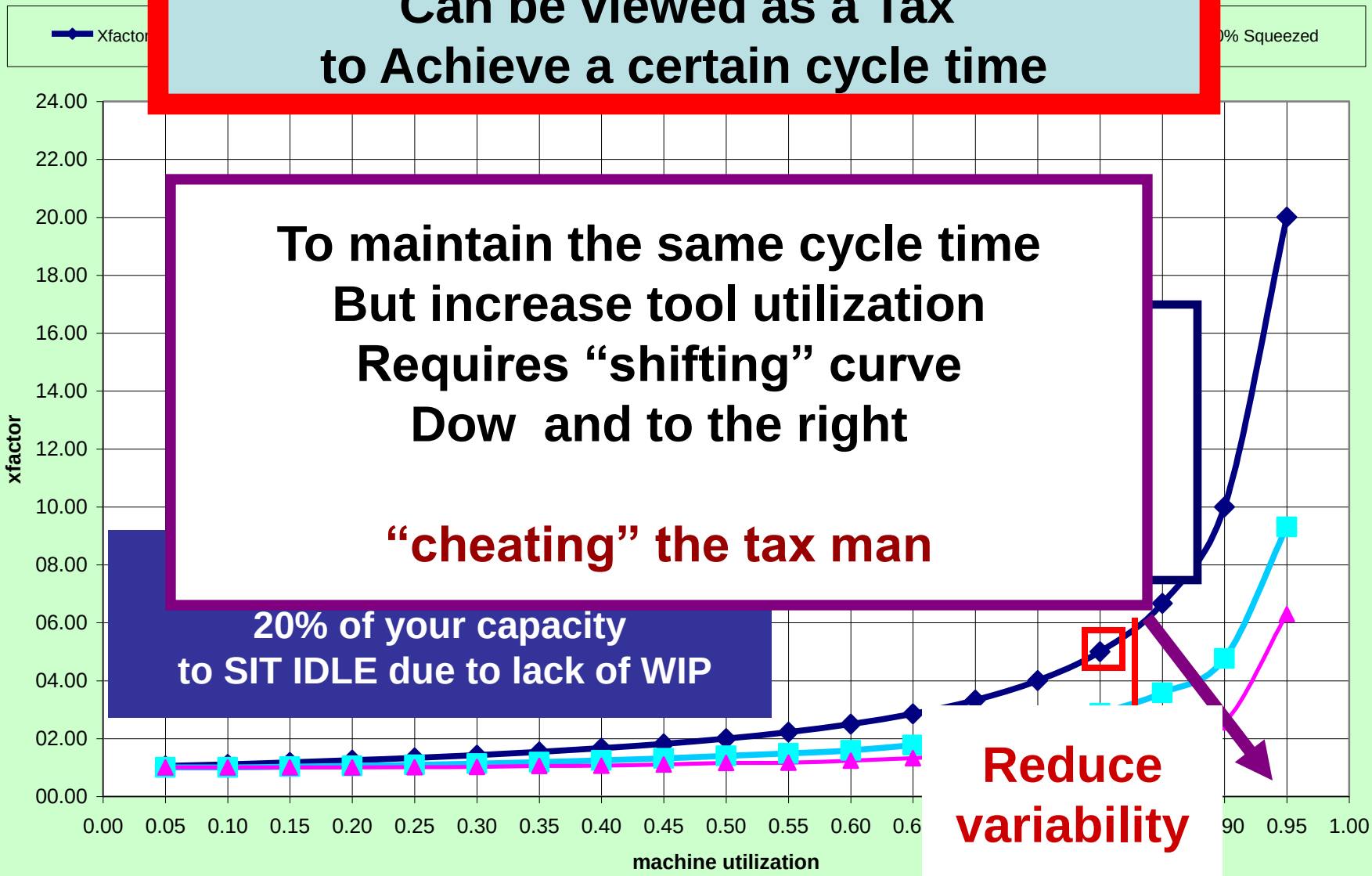
FAB Capacity includes a set of partial matches between individual resources (tools) and manufacturing activities (operations)

- Deployment decisions that restrict which manufacturing activities a tool is permitted to process
- Manufacturing engineering requirements that limit actual deployment
- Different inherent rates of production (PPH) between tools that service the same manufacturing activity
- Variation in rates day to day for the same tool depending on floor opportunities for batching, trains (operational chains), parallel factors, etc
- Variation in the percentage and distribution of tool availability

Operating Curve

- Trade off between
  - tool utilization and lead time / cycle time or
  - Output (starts) and cycle time
  - Effective capacity available and cycle time
- Move along the curve
  - Pick a cycle time, get a tool utilization / capacity available
  - Pick a tool utilization (capacity) / get a cycle time
- Shift the curve down and right
  - Less variability, lower cycle time for the same tool utilization
- Cycle time is often measured as a multiplier of raw process time (RPT) called cycle time multiplier (CTM)
  - Some times called XF (x factor – for multiplier)
- Cycle time = CTM x RPT

Required idle time without WIP
Can be viewed as a Tax
to Achieve a certain cycle time



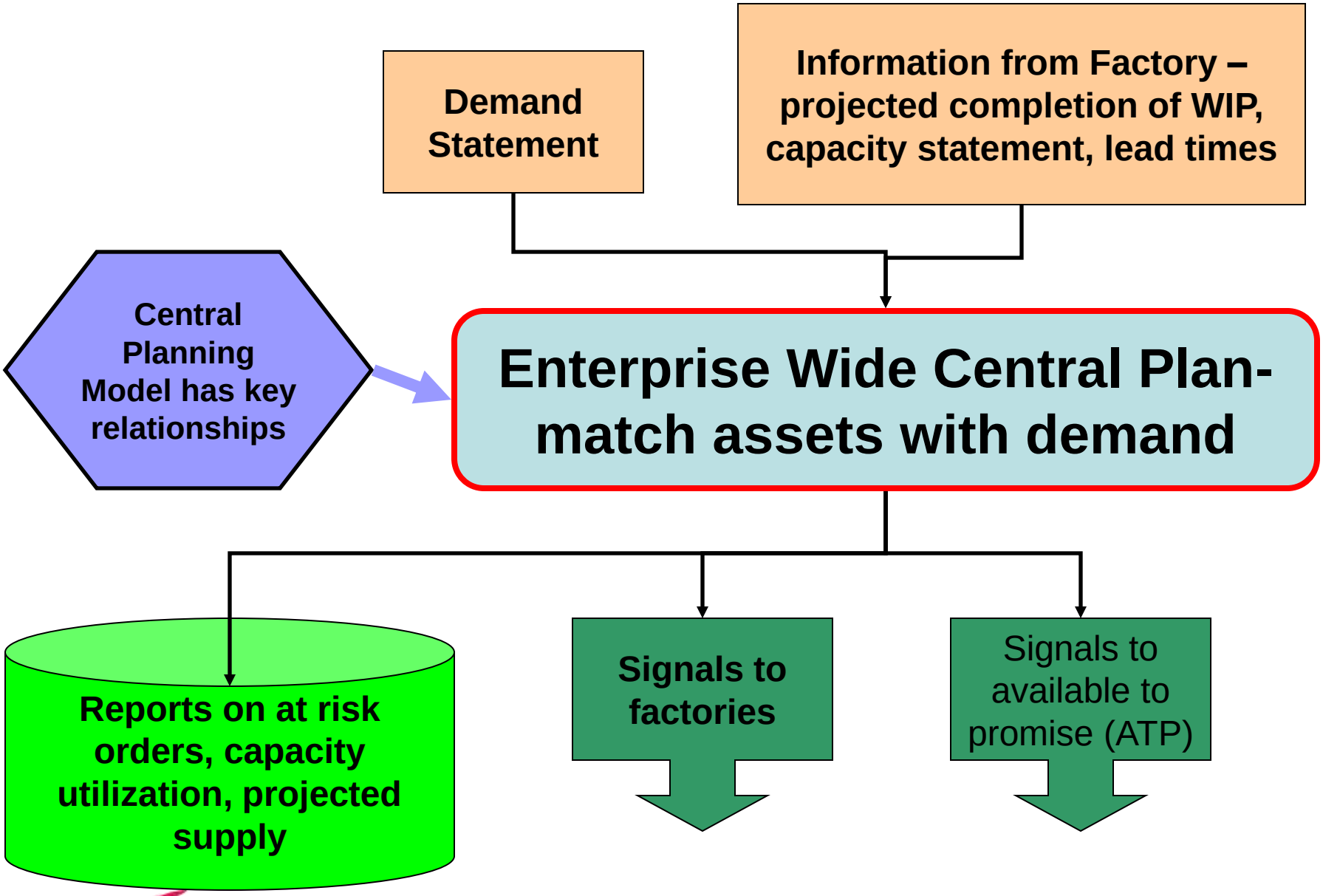
To maintain the same cycle time
But increase tool utilization
Requires "shifting" curve
Dow and to the right

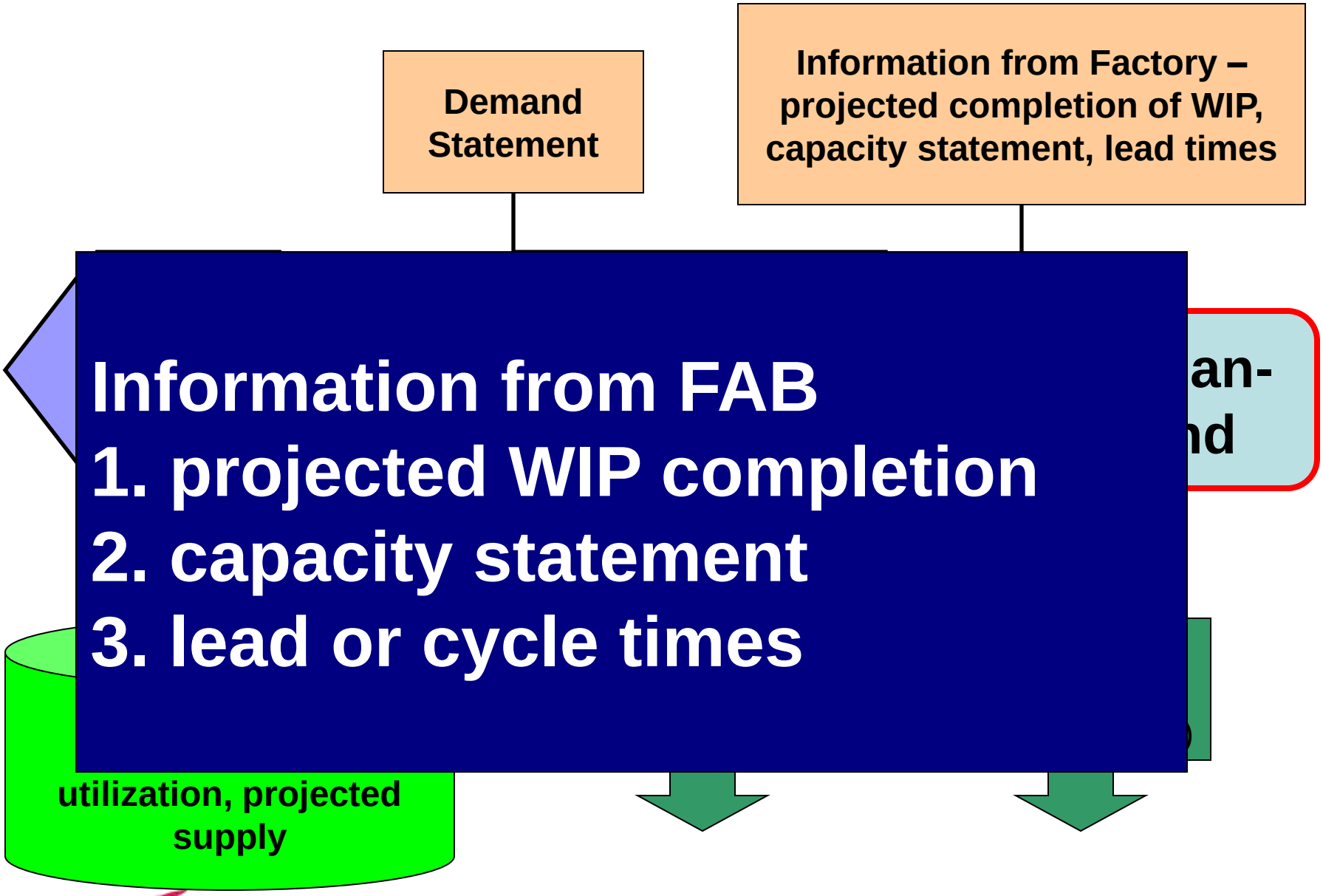
"cheating" the tax man

20% of your capacity
to SIT IDLE due to lack of WIP

Reduce variability

Basics of Central Planning
for the entire demand supply network
(supply chain)
for the production of semiconductor
based packaged goods


Demand Statement
Information from Factory – projected completion of WIP, capacity statement, lead times
Central Planning Model has key relationships
Enterprise Wide Central Plan- match assets with demand
Reports on at risk orders, capacity utilization, projected supply
Signals to factories
Signals to available to promise (ATP)


Demand Statement
Information from Factory – projected completion of WIP, capacity statement, lead times
Information from FAB
1. projected WIP completion
2. capacity statement
3. lead or cycle times
an-
nd
utilization, projected supply

Basics of Central Planning Engine (CPE)

- Core task is deploy modeling methods to match assets with demand across an enterprise to create a projected supply linked with demand and synchronization signals.
- CPE has four core components:
  - represent the (potential) material flows in production, business policies, constraints, demand priorities, current locations of asset, etc., and relate all this information to exit demand.
  - capture asset quantities and parameters (cycle times, yields, binning percentages, etc.).
  - search and generate a supply chain plan, relate the outcome to demand, and modify the plan to improve the match.
  - display and explain the results.

Emphasis on Optimal Allocation of Supply to Demand

Allocate supply Of devices to Modules 1 & 2

Module_1
CT = 10 days

Dem	Due day	Amt
C	10	10
D	12	15

Supply Amt

Day	Amt
00	?
02	?
00	?
02	?
10	?

Device_12

Day	Sup
00	10
02	30
10	20

****Device Supply is starting point**

Module_2
CT = 4 days

Dem	Due day	Amt
A	05	8
B	06	2

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Illusion of FAB Capacity in Central Pl

Additional Focus Items

- Allocation of perishable (capacity) and non perishable assets (inventory) to best meet prioritized demand
- Handle binning and down grade substitution
- Complex binning, general substitution, and alternative BOM
- Lot sizing
- Sourcing
- Fair sh
- Custon
- Min sta
- Date effective parameters
- demand perishability, squaring sets, soft capacity constraints, alternative capacity, pre-emptive versus weighted priorities, splitting demand to match partial delays in supply, stability, express lots, delay assembly to test, dispatch lots
- foundry contracts

Allocation of Resource Capacity

How Do I Best Allocate a Perishable Asset

Device 12

Day	Sup
00	40

Amt Resource 12

Day	Amt
01	??
02	??
03	??

Amt Resource 12

Day	Amt
01	??
02	??
03	??

Amt Res12 Avail

Day	AVL
01	30
02	30
03	60

Module 1

CT = 1day

resource utilization = 2

Demand	Due day	Amount
C	02	10
D	04	15

Module 2

CT = 4 days

resource utilization = 3

Demand	Due day	Amount
A	02	08
B	03	19

Module 1 and Module 2 are both made from Device 12 and we have 40 units in stock. Each module consumes 1 device. The cycle time is 1 day for each Module. Module 1 needs 2 units of the Resource 12 to make a module. Module requires 3 units of Resource 12 to make a module. The demand for each module is posted.

?? How do I best allocate Resource12 to Modules 1 and 2?

Traditional way to handle capacity in CPEs
That is in supply chain or production planning

Material balance equations
Fixed cycle time
Fixed capacity or resource available
Linear resource consumption

Core Steps of Resource Allocation in Central Planning

- linking a manufacturing activity (decision node) to one more resources
- **CAPREQ** - establishing a consumption rate for each unit of production by that manufacturing activity for the selected resource(s)
- **CAPAVAIL** - providing the total available capacity for each resource.
- connecting manufacturing releases (starts) to resource consumption with a **linear relationship**
  - No batching, parallel factor, etc
  - No explicit ability to trade an increase in cycle time for an increase in output

Simple Example of Central Planning

Our factory makes two parts Tiger and Lion.
The two decision variables are:

- X_L is the number lion starts per day
- X_T is the number of tiger starts per day

The profit per unit of production for Tiger is 5 and 7 for Lion

he equations are

laximize

X_T + 7 X_L

ıbject to

$0X_T$ + 12 X_L ≤ 194

$3X_T$ + 05 X_L ≤ 100

$_T$ ≥ 5

$_T$ ≥ 7

Simple Example of Central Planning

Capacity Consumed (required)

- **Capacity Available**
  The amount of capacity available daily
  - for RES A is 194
  - for RES B is 100
-
  - **12 units of resource A and**
  - **05 units resource B.**

Magically Capacity consumed (CAPREQ) Is known

Magically Capacity Available (CAPAVAIL) Is known

Estimating
CAPREQ & CAPAVAIL for FABS
in central planning models
Present Real Challenges

focus on reentrant flow & deployment

Bypass the Operating Curve for Today

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Hunt for CAPAVAIL (& CAPREQ) in FAB Routes and Deployment

from **resource entity**

to **resource operations & tools**

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definitions

- **CAPREQ -** establishing a consumption rate for each unit of production by that manufacturing activity for the selected resource
- **CAPAVAIL** - providing the total available capacity for the resource. connecting manufacturing releases (starts) to resource consumption with a linear relationship
- **Route** – sequence of manufacturing actions
- **Deployment** – (alternative Machines); PSO – partially shared overlap between tools and operations

Table 2.1: Deployment Information for PSO Group				
	Tool A	Tool B	Tool C	no tools covering oper
oper001	1	1	0	2
oper002	1	1	0	2
oper003	0	1	1	2
oper004	0	0	1	1
oper005	0	1	1	2
oper006	1	0	0	1
oper007	1	0	0	1
number opers tool covers	4	4	3	

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Example Core Information

- **Products / Parts:**
  - Antelope
  - Gazelle
  - Lion
- **Focus Shared Tools Groups (resources):**
  - MUV – mid UV photolithography (the picture)
  - DUV – deep UV photolithography (the picture)
  - ION – putting in the switches
  - ETCH – putting in the wiring
- **Feature Resource:**
  - ANT/GAZ – one or two passes of just antelope and gazelle
  - GAZ – one pass just gazelle

Traditional Capacity Information -- fixed consumption rate and capacity available							
		Resource Entity					
		shared by all part families				feature	
		MUV	DUV	ION	ETCH	ANT/GAZ	GAZ
Part Family	Antelope	5	5	6	4	2	0
	Gazelle	8	4	5	7	1	1
	Lion	6	10	10	6	0	0
CAPAVAIL		100	100	150	130	30	15

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Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools

Traditional CPE Capacity Information – resource entity level

no operations or tools – information magically provided

Fixed Consumption Rate

Traditional Capacity Information -- fixed consumption rate and capacity available							
		Resource Entity					
		shared by all part families				feature	
		MUV	DUV	ION	ETCH	ANT/GAZ	GAZ
Part Family	Antelope	5	5	6	4	2	0
	Gazelle	8	4	5	7	1	1
	Lion	6	10	10	6	0	0
CAPAVAIL		100	100	150	130	30	15

Fixed Capacity Available

into

Traditional CPE Model

Wafer Start Decision Variables

- X_A = number of wafers of Antelope
- X_G = number of wafers of Gazelle
- X_L = number of wafers of Lion

Capacity Constraint Equations – one for each resource entity

$$5X_A + 8X_G + 6X_L \leq 100 \quad MUV \quad (eq\ 1-1)$$

$$5X_A + 4X_G + 10X_L \leq 100 \quad DUV \quad (eq\ 1-2)$$

$$6X_A + 5X_G + 10X_L \leq 150 \quad ION \quad (eq\ 1-3)$$

$$4X_A + 7X_G + 6X_L \leq 130\,\mathrm{ETCH}\,(\mathrm{eq}1-4)$$

$$2X_A + 1X_G + 0X_L \leq 30\,\mathrm{ANT/GAZ}\,(\mathrm{eq}1-5)$$

$$0X_A + 1X_G + 0X_L \leq 15\,\mathrm{GAZ}\,(\mathrm{eq}1-6)$$

Where do we get the CAPREQ & CAPAVAIL values?
How does this relate to consumption of tools along the route

Traditional Capacity Information -- fixed consumption rate and capacity available							
		Resource Entity					
		shared by all part families				feature	
		MUV	DUV	ION	ETCH	ANT/GAZ	GAZ
Part Family	Antelope	5	5	6	4	2	0
	Gazelle	8	4	5	7	1	1
	Lion	6	10	10	6	0	0
CAPAVAIL		100	100	150	130	30	15

Created from
the complexity of
FAB Routes
And deployment

W ese values come from?

FAB Routes & deployment

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Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL

FAB Routes

Foc

Abbreviated Fa				
oper Seq	tool set	time	id	tools
oper 001-009	varied	100	?	??
oper 010	MUV	005	muvop01	??
oper 011				
	DUV	008	?	??
oper 016	ION	020	?	??
oper 012-015	varied	030	?	??
oper 016	DUV	008	?	??
oper 017	ION	020	?	??
oper 018-021	varied	030	?	??
oper 022	DUV	008	?	??
oper 0			?	??
oper 0			?	??
oper 032	MUV	005	muvop02	??
oper 033	ION	018	?	??
oper 034-037	varied	060	?	??
oper 038	MUV	005	muvop03	??
oper 039	ION	019	?	??
oper 106	MUV	005	muvop03	??
oper 107	ETCH	020	?	??

sequence

Tool set, rpt

iden

tools

2nd MUV operation

# passes	
	5
DUV	5
ION	6
ETCH	4

Each operation has an id
An operation can be repeated within a route for the same part; operation can be used in multiple routes (parts)

Each Operation ID has set of specific tools within the tool set that are deployed to this operation. Therefore the lot links to the tool options via the operation id

This near term “steady state” deployment. At dispatch, the tool options for the lot may be different then the deployment for manufacturing engineering reasons (temporary restriction) or business decision for flow control and allocation imposed

SHARED

tool set	# passes
MUV	5
DUV	5
ION	6
ETCH	4

Yes
We should
Use
Raw process time

Pass count
Is CAPREQ
for Antelope

Traditional Capacity Information -- fixed consumption rate and capacity available							
		Resource Entity					
		shared by all part families				feature	
		MUV	DUV	ION	ETCH	ANT/GAZ	GAZ
Part Family	Antelope	5	5	6	4	2	0
	Gazelle	8	4	5	7	1	1
	Lion	6	10	10	6	0	0
CAPAVAIL		100	100	150	130	30	15

CAPAVAIL is number of passes available each time unit

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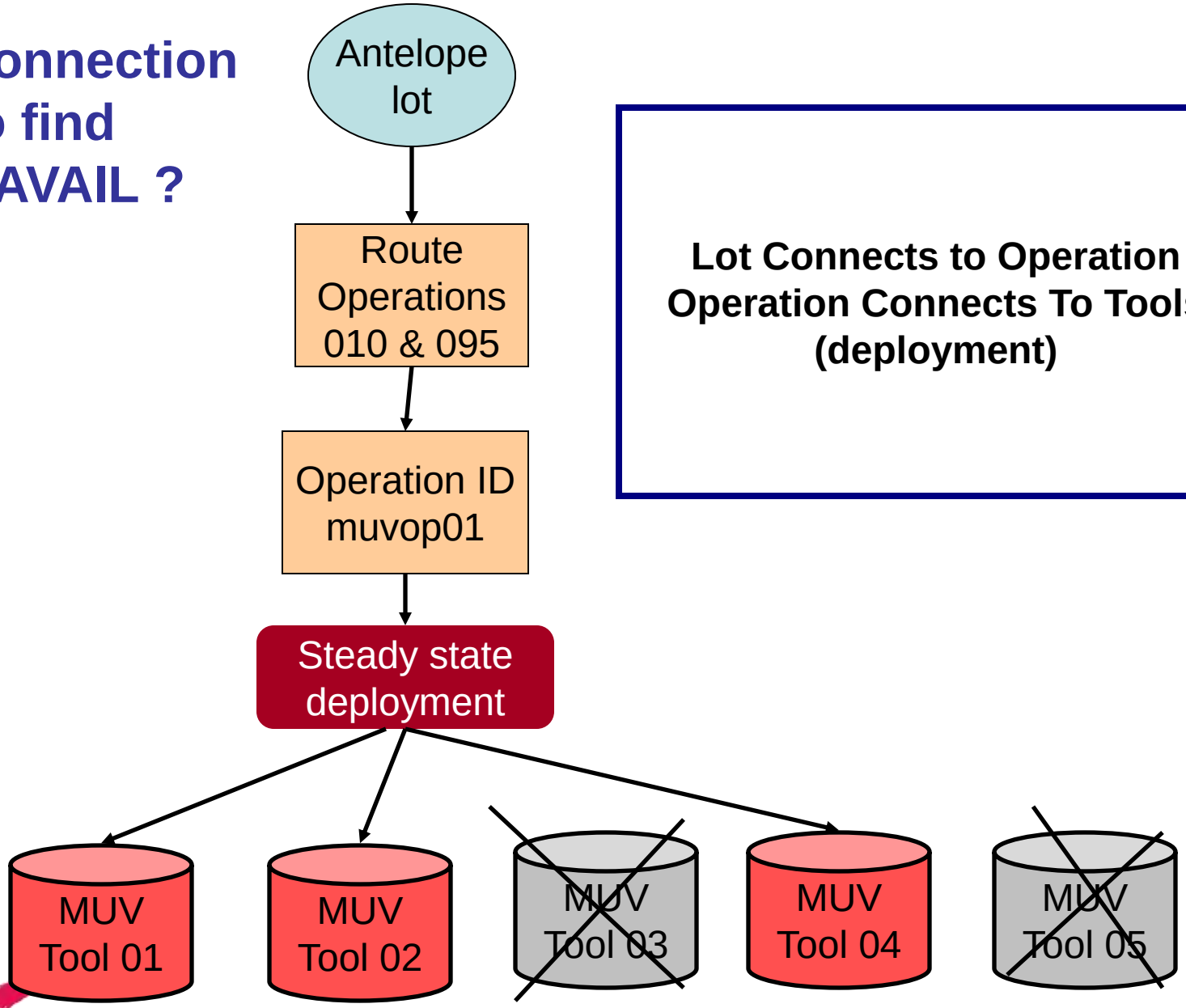
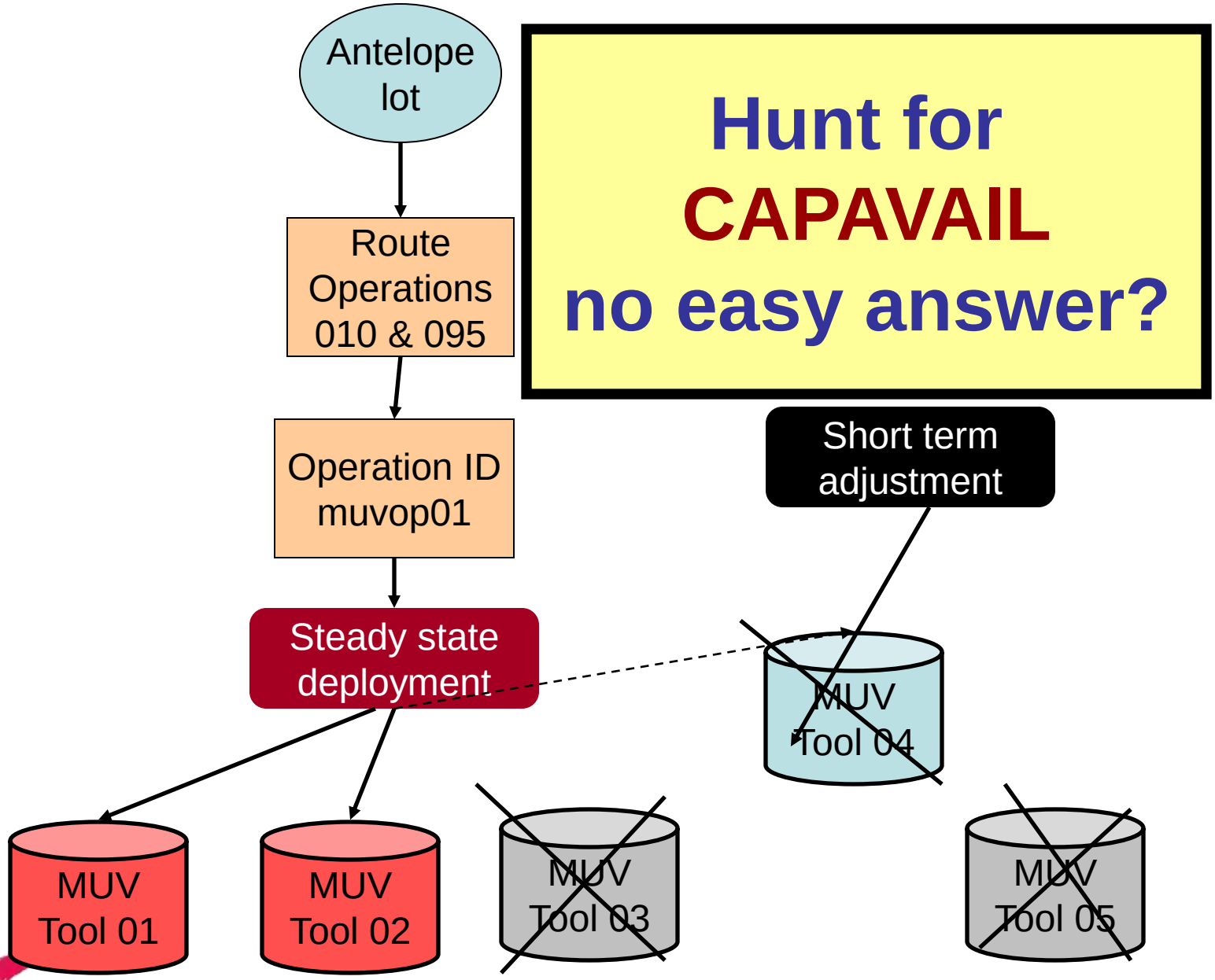
Tool Connection to find CAPAVAIL ?

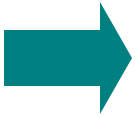


Lot Connects to Operation
Operation Connects To Tools (deployment)


Antelope lot
Route Operations 010 & 095
Operation ID muvop01
Steady state deployment
Hunt for CAPAVAIL no easy answer?
Short term adjustment
MUV Tool 01
MUV Tool 02
MUV Tool 03
MUV Tool 04
MUV Tool 05

Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL
3) Focus on MUV resource entity incorporating tools and operations
   a) Creating capacity constraints for each MUV operation instead of one constraint for the MUV resource entity
   b) Determining CAPREQ with pass count at each unique MUV operation



Abbreviated Route for Antelope Highlight MUV

Abbreviated Fabrication Route for Anteloppe				
oper Seq	tool set	raw process time	operation id	specific tools
oper 001-009	varied	100	?	??
oper 010	MUV	005	muvop01	??
oper 011	ION	020	?	??
oper 011-014	varied	030	?	??
oper 015	DUV	008	?	??
oper 016	ION	020	?	??
oper 012-015	varied	030	?	??
oper 016	DUV	008	?	??
oper 017	ION	020	?	??
oper 018-021	varied	030	?	??
oper 022	DUV	008	?	??
oper 023	ION	020	?	??
oper 024-031	varied	060	?	??
oper 032	MUV	005	muvop02	??
oper 033	ION	018	?	??
oper 034-037	varied	060	?	??
oper 038	MUV	005	muvop03	??
oper 039	ION	019	?	??
oper 040-060	varied	110	?	??
oper 061	DUV	007	?	??
oper 062	ETCH	030	?	??
oper 063-083	varied	110	?	??
oper 084	DUV	007	?	??
oper 085	ETCH	030	?	??
oper 086-094	varied	110	?	??
oper 095	MUV	005	muvop01	??
oper 096	ETCH	020	?	??
oper 097-105	varied	110	?	??
oper 106	MUV	005	muvop05	??
oper 107	ETCH	020	?	??

Sequence is

MUVOP01
MUVOP02
MUVOP03
MUVOP01
MUVOPO5

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Focus on MUV Operations in Route

Detailed Flow Sequence of Each Part through MUV unconcerned with time interval between passes

pass	Part Family		
	Antelope(5)	**Gazelle(8)**	**Lion(6)**
pass 1	muvop01	muvop01	muvop01
pass 2	muvop02	muvop02	muvop02
pass 3	muvop03	muvop03	muvop06
pass 4	muvop01	muvop01	muvop06
pass 5	muvop05	muvop04	muvop07
pass 6	na	muvop04	muvop05
pass 7	na	muvop05	na
pass 8	na	muvop05	na

Antelope & MUV

op01 -> op02 -> op03 -> op01 -> op05

Convert from Sequence to Count (passes)

number times Part Family invokes a specific MUV operation unconcerned with sequence

operation	Part Family			
	Antelope(5)	**Gazelle(8)**	**Lion(6)**	**row sum**
muvop01	2	2	1	5
muvop02	1	1	1	3
muvop03	1	1	0	2
muvop04	0	2	0	2
muvop05	1	2	1	4
muvop06	0	0	2	2
muvop07	0	0	1	1
col sum	5	8	6	19

Extending Capacity Required to All Unique MUV Operations

Traditional Capacity Information -- fixed consumption rate and capacity available							
		Resource Entity					
		shared by all part families				feature	
		MUV	DUV	ION	ETCH	ANT/GAZ	GAZ
Part Family	Antelope	5	5	6	4	2	0
	Gazelle	8	4	5	7	1	1
	Lion	6	10	10	6	0	0
CAPAVAIL		100	100	150	130	30	15

CAPREQ (raditional CPE) for MUV Resource expanded to granular level of MUV Operations										
		MUV	→	muvop01	muvop02	muvop03	muvop04	muvop05	muvop06	muvop07
Part Family	Antelope	5	→	2	1	1	0	1	0	0
	Gazelle	8	→	2	1	1	2	2	0	0
	L									1
CAPA										ap07?

5 MUV passes for Antelope are split across 7 MUV operations
2 – 1 – 1 – 0 – 1 - 0 - 0

From one MUV constraints to 7 – one for each unique MUV operation

The Path From Route to CAPREQ for each MUV Operation

Sequence

Table 4: Detailed Flow Sequence of Each Part through MUV

pass	Part Family		
	Antelope(5)	**Gazelle(8)**	**Lion(6)**
pass 1	muvop01	muvop01	muvop01
pass 2	muvop02	muvop02	muvop02
pass 3	muvop03	muvop03	muvop06
pass 4	muvop01	muvop01	muvop06
pass 5	muvop05	muvop04	muvop07
pass 6	na	muvop04	muvop05
pass 7	na	muvop05	na
pass 8	na	muvop05	na

Count

Table 5: number times Part Family invokes a specific MUV operation

operation	Part Family		
	Antelope(5)	**Gazelle(8)**	**Lion(6)**
muvop01	2	2	1
muvop02	1	1	1
muvop03	1	1	0
muvop04	0	2	0
muvop05	1	2	1
muvop06	0	0	2
muvop07	0	0	1

Table 6: CAPREQ from Table 1 for MUV Resource expanded to granular level of MUV Operations

		MUV	→	muvop01	muvop02	muvop03	muvop04	muvop05	muvop06	muvop07
Part Family	**Antelope**	5	→	2	1	1	0	1	0	0
	Gazelle	8	→	2	1	1	2	2	0	0
	Lion	6	→	1	1	0	0	1	2	1
CAPAVAIL		100	→	cap01?	cap02?	cap03?	cap04?	cap05?	cap06?	cap07?

CAPREQ each unique MUV operation

Where CAPREQ is pass count at each MUV operation

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Extending MUV Resource Entity Capacity Equation To one equation for each unique MUV Operation

$$5X_A + 8X_G + 6X_L \leq 100\,\text{MUV}\ (\text{eq}1-1)$$

Eq (1-1) original model is replaced by Equation Set 1

Equation Set 1

One Equation for each of Seven MUV Operations

$$2X_A + 2X_G + 1X_L \leq cap01?\ \text{muvop01}\ (\text{eq}1-1-1)$$

$$1X_L \leq cap02?\ \text{muvop02}$$

$$0X_L \leq cap03?\ \text{muvop03}$$

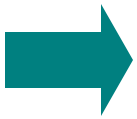
How do We Determine cap0X?

Link tools to operations

Hunt for CAPAVAIL

Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL
3) Focus on MUV resource entity incorporating tools and operations
   a) Creating capacity constraints for each MUV operation instead of one constraint for the MUV resource entity
   b) Determining CAPREQ with pass count at each unique MUV operation
   c) Hunt for CAPAVAIL



Linking MUV Operations to MUV Tools - Deployment

MUV Deployment Table Core Structure link 7 MUV operations with 5 MUV tools						
		MUV Tools				
		MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
MUV Operations	muvop01	?	?	?	?	?
	muvop02	?	?	?	?	?
	muvop03	?	?	?	?	?
	muvop04	?	?	?	?	?
	muvop05	?	?	?	?	?
	muvop06	?	?	?	?	?
	muvop07	?	?	?	?	?
Capacity Avail		???	???	???	???	???

"?" is 0 if tool can not service operation, 1 if it can
more advanced version value is between 0 and 1 inclusive

Linking MUV Operations to MUV Tools

MUV Deployment Table Core Structure link 7 MUV operations with 5 MUV tools						
		MUV Tools				
		MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
MUV Operations	muvop01	?	?	?	?	?
	muvop02	?	?	?	?	?
	muvop03	?	?	?	?	?
	muvop04	?	?	?	?	?
	muvop05	?	?	?	?	?
	muvop06	?	?	?	?	?
	muvop07	?	?	?	?	?
Capacity Avail		???	???	???	???	???

"???" raw capacity available for tool after accounting various factors

Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL
3) Focus on MUV resource entity incorporating tools and operations
   a) Creating capacity constraints for each MUV operation instead of one constraint for the MUV resource entity
   b) Determining CAPREQ with pass count at each unique MUV operation
   c) Hunt for CAPAVAIL

4) Cases / Options to find CAPAVAIL

a) Case 1: simplest, all tools can service all operations

Linking MUV Operations to MUV Tools – case 1

Simplest Case – All Tools Can Handle All operations

MUV Deployment Case - all tools handle all operations						
		MUV Tools				
		MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
MUV Operations	muvop01	1	1	1	1	1
	muvop02	1	1	1	1	1
	muvop03	1	1	1	1	1
	muvop04	1	1	1	1	1
	muvop05	1	1	1	1	1
	muvop06	1	1	1	1	1
	muvop07	1	1	1	1	1
Capacity Avail		20	20	20	20	20

Assume CAPAVAIL each tool is 20

Single MUV Equation Works Fine

Equation Set 1
1 equation each MUV Operation

replace with this equation
When all tools handle all operations

$$5X_A + 8X_G + 6X_L \leq 100 \quad MUV \quad (eq\ 1-1)$$

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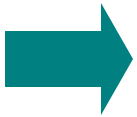
Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL
3) Focus on MUV resource entity incorporating tools and operations
   a) Creating capacity constraints for each MUV operation instead of one constraint for the MUV resource entity
   b) Determining CAPREQ with pass count at each unique MUV operation
   c) Hunt for CAPAVAIL
4) **Cases / Options to find CAPAVAIL**
   a) Case 1: simplest, all tools can service all operations
   b) Case 2: two independent groups



Linking MUV Operations to MUV Tools – Case 2

Case – Two Independent Groups

Two Complete Independent Groups						
		MUV Tools				
		MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
MUV Operations	muvop01	1	1	1	0	0
	muvop02	1	1	1	0	0
	muvop03	1	1	1	0	0
	muvop04	0	0	0	1	1
	muvop05	0	0	0	1	1
	muvop06	0	0	0	1	1
	muvop07	0	0	0	1	1
Capacity Avail		20	20	20	20	20

MUV can be divided into two independent Resource Entities

MUV Resource Entity 1 (MUVRE1)
- tools 1, 2, and 3
- servicing operations 1, 2, and 3

MUV Resource Entity 2 (MUVRE2)
- tools 4 and 5
- servicing operations 4, 5, 6, and 7

Divide Equation Set into two groups

$$2X_A + 2X_G + 1X_L \le cap01?\ \ muvop01\ \ (eq\ \ 1-1-1)$$
$$1X_A + 1X_G + 1X_L \le cap02?\ \ muvop02\ \ (eq\ \ 1-1-2)$$
$$1X_A + 1X_G + 0X_L \le cap03?\ \ muvop03\ \ (eq\ \ 1-1-3)$$

Equation Set MUV-RE1

$$0X_A + 2X_G + 0X_L \le cap04?\ \ muvop04\ \ (eq\ \ 1-1-4)$$
$$1X_A + 2X_G + 1X_L \le cap05?\ \ muvop05\ \ (eq\ \ 1-1-5)$$
$$0X_A + 0X_G + 2X_L \le cap06?\ \ muvop06\ \ (eq\ \ 1-1-6)$$
$$0X_A + 0X_G + 1X_L \le cap07?\ \ muvop07\ \ (eq\ \ 1-1-7)$$

Equation Set MUV-RE2

Equation Set MUV – the 7 MUV Operations split into two Equation Sets (MUV-RE1 and MUV-RE2)

When MUV can be split into two independent components
Capacity Consumption for MUV can be represented with two equations

Two Complete Independent Groups						
		MUV Tools				
		MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
MUV Operations	muvop01	1	1	1	0	0
	muvop02	1	1	1	0	0
	muvop03	1	1	1	0	0
	muvop04	0	0	0	1	1
	muvop05	0	0	0	1	1
	muvop06	0	0	0	1	1
	muvop07	0	0	0	1	1
Capacity Avail		20	20	20	20	20

Equation Set 1
Is split into Equation Set 2 and Set 3

$$2X_A + 2X_G + 1X_L \le cap01?\ \ muvop01\ \ (eq\ \ 1-1-1)$$
$$1X_A + 1X_G + 1X_L \le cap02?\ \ muvop02\ \ (eq\ \ 1-1-2)$$
$$1X_A + 1X_G + 0X_L \le cap03?\ \ muvop03\ \ (eq\ \ 1-1-3)$$

Equation Set 2
Operation 1, 2, 3 and tools 1,2, 3

$$0X_A + 2X_G + 0X_L \le cap04?\ \ muvop04\ \ (eq\ \ 1-1-4)$$
$$1X_A + 2X_G + 1X_L \le cap05?\ \ muvop05\ \ (eq\ \ 1-1-5)$$
$$0X_A + 0X_G + 2X_L \le cap06?\ \ muvop06\ \ (eq\ \ 1-1-6)$$
$$0X_A + 0X_G + 1X_L \le cap07?\ \ muvop07\ \ (eq\ \ 1-1-7)$$

Equation Set 3
Operation 4, 5, 6, 7 and tools 4, 5

Equation Set 2 and 3
each can be replaced with single equation
When all tools handle all operations within
A specific group of tools and operations

$$4X_A + 4X_G + 2X_L \le 60 \ \Rightarrow MUVRE1\ \ (eq\ \ 5-3)$$

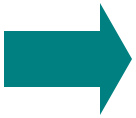
Replaces Equation Set 2

$$1X_A + 4X_G + 4X_L \le 40 \ \Rightarrow MUVRE2\ \ (eq\ \ 5-5)$$

Replaces Equation Set 3

Example Steps

1) Traditional CPE - capacity constraints at resource entity level
   a) No details on operations and tools
2) FAB Routes – sequence, pass count
   a) Using pass counts to create CAPREQ for each resource entity
   b) Preliminary search for CAPAVAIL
3) Focus on MUV resource entity incorporating tools and operations
   a) Creating capacity constraints for each MUV operation instead of one constraint for the MUV resource entity
   b) Determining CAPREQ with pass count at each unique MUV operation
   c) Hunt for CAPAVAIL
4) **Cases / Options to find CAPAVAIL**
   a) Case 1: simplest, all tools can service all operations
   b) Case 2: two independent groups
   c) **Case 3: asymmetric deployment – life gets complicated**
      – **Six options**



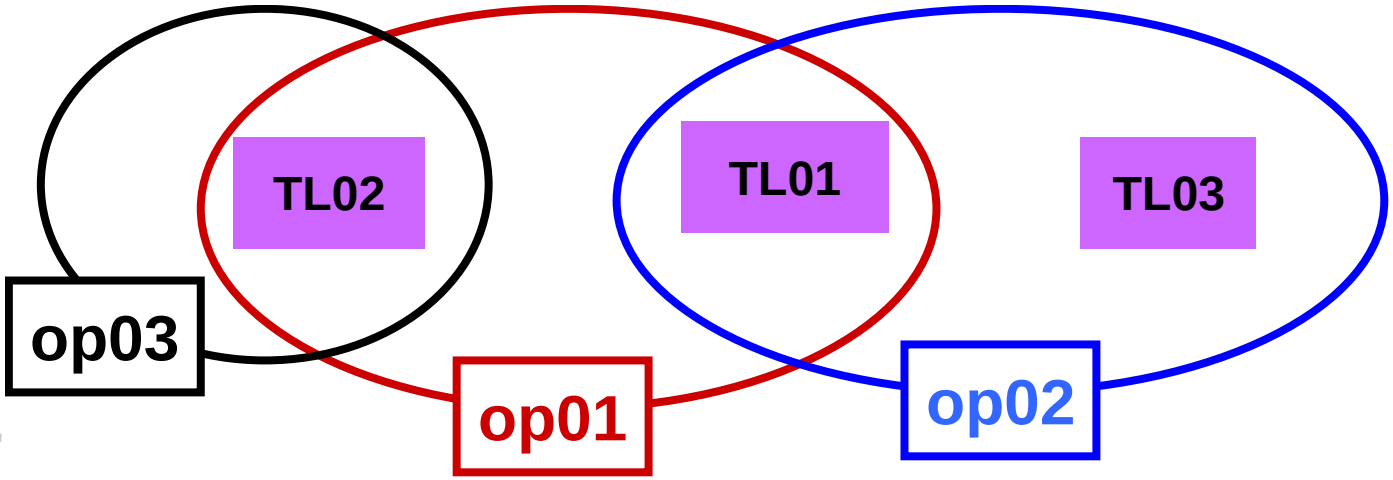
Linking MUV Operations to MUV Tools
Real world complexity non-uniform deployment

Complicated MUVRE1 non-uniform coverage

MUV Operations	MUV Tools				
	MUVTL01	MUVTL02	MUVTL03	MUVTL04	MUVTL05
muvop01	1	1	0	0	0
muvop02	1	0	1		
muvop03	0	1	0		
muvop04	0	0	0		
muvop05	0	0	0		
				1	1
				1	1
				20	20

MUVRE1
all tools do not
handle all operations

op01 serviced by TL01 & TL02
op02 serviced by TL01 & TL03
op03 serviced by TL02



The Critical Question

How does non-uniform deployment
Impact our ability to estimate cap01, cap02, and cap03

$$2X_A + 2X_G + 1X_L \le cap01?\ \ muvop01\ \ (eq\ \ 1-1-1)$$
$$1X_A + 1X_G + 1X_L \le cap02?\ \ muvop02\ \ (eq\ \ 1-1-2)$$
$$1X_A + 1X_G + 0X_L \le cap03?\ \ muvop03\ \ (eq\ \ 1-1-3)$$

Equation Set MUV-RE1

It creates a situation that requires a careful balance between solution accuracy, model complexity, model performance, and stressing the social order

Six Options

1. Maximize Capacity Flexibility
2. Minimize Capacity Flexibility
3. projected wafer start profile
4. modify traditional method for capacity to handle or conditions
5. Capacity Allocation Decision Variable
6. Combination of options using heuristics to create resource entity

Traditional way to handle capacity in CPEs For FABS

Typically Historically
Central Planning Engines
Handle FAB Capacity

with Nested Wafer Starts (Exits)
Separate from cycle time

CAPAVAIL stated as maximum
Number of wafer starts allowed per day
For various groupings of parts

Wafer Start Equivalents – evolved to nested set of limits

Table 14: Stating FAB Capacity Limits as a Nested Set of Start Limits				
row number	**Group**	**Time frame 1**	**Time frame 2**	**Time frame 3**
001	Wiring Group 1	600	675	675
002	Technology Group A	400	425	450
003	Technology Group B	300	325	350
004	Option set W	100	100	100
005	Option set X	210	300	300
006	Wiring Group 2	500	525	550
007	Technology Group D	350	350	375
008	Technology Group E	250	275	275
009	Option set Y	100	100	100
010	Option set Z	200	200	200
011	Total Fab Limit	1000	1100	1150

- The overall FAB limit is stated in terms of wafers per day and that each product is mapped to one or more limit. The current methodology allows the CPE to start up to, but not over any limit to which products are mapped.

History – evolved nested set of limits

- In this example a part that maps to option set W also maps to Technology Group B, then Wiring Group 1, and finally “Total FAB”. A part consuming some of the 100 units of Option set W capacity (capacity is stated in wafer starts) simultaneously consumes some of the 300 units of Technology Group B, 600 units of Wiring Group 1, and 1000 units of “Total” FAB. The same applies to Option set X. Similarly a part that maps to Option set Y or Z also maps to Technology Group E, Wiring Group 2, and “Total FAB”. A part might belong to Technology Group B and neither Option Set W or X. Some parts will belong to Technology Group A which has no “option” sets in this statement of capacity. A part can belong to at most one option set, at most one technology group, and at most one wiring group. All parts belong to “Total FAB limit.”

Example nested set of limits

Table 14: Stating FAB Capacity Limits as a Nested Set of Start Limits				
row number	**Group**	**Time frame 1**	**Time frame 2**	**Time frame 3**
001	Wiring Group 1	600	340(=600-260) available	
002	Technology Group A	400	340(=min(340,400) available	
		300	40 available (300-260)	
004	Option set W	100	100	100
005	Option set X	210		300
006	Wiring Group 2	500	525	550
007	Technology Group D	350	350	375
008	Technology Group E	250	275	275
009	Option set Y	100	100	100
010	Option set Z	200	200	200
011	Total Fab Limit	1000	1100	1150

260(180+60+20) allocated

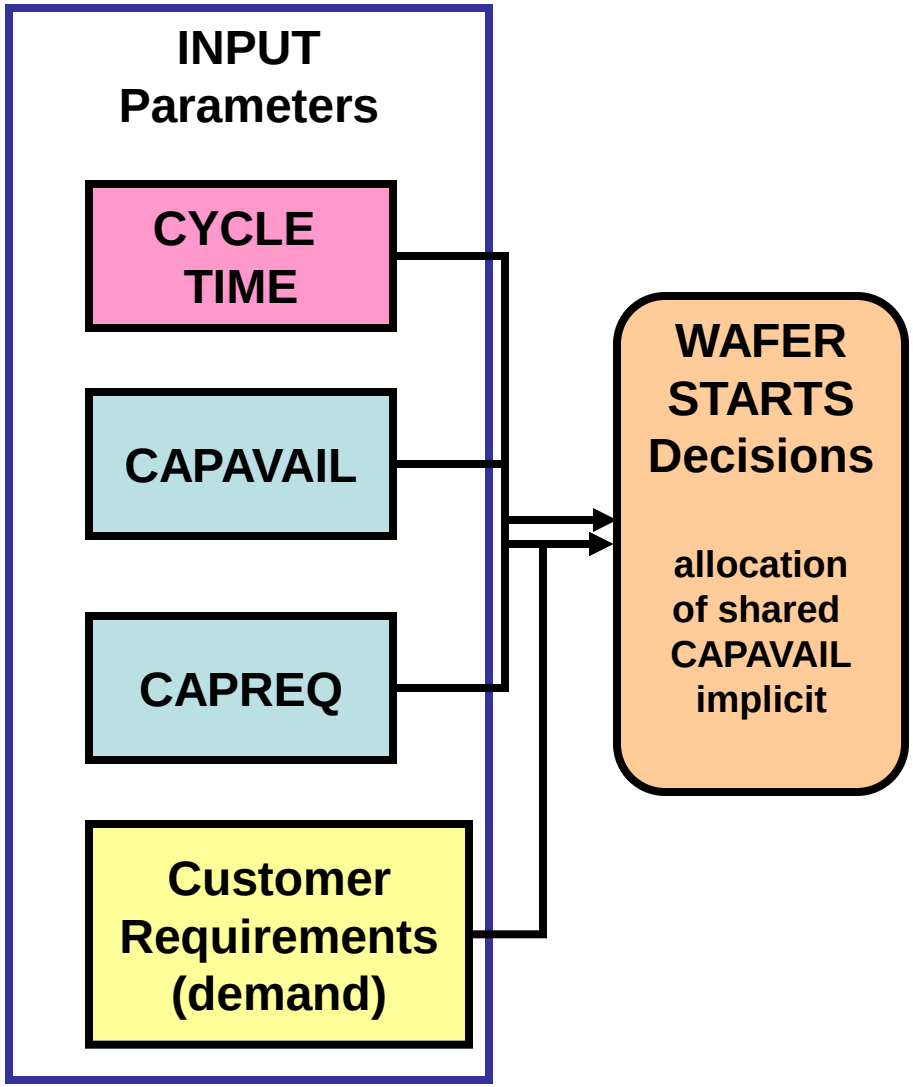
20 selected

60 selected

180 selected

- The overall FAB limit is stated in terms of wafers per day and that each product is mapped to one or more limit. The current methodology allows the CPE to start up to, but not over any limit to which products are mapped.

Traditional CPE



Behind the Drapes of a Traditional CPE