CREATING CONTINOUS FLOW

Creating continuous flow

Alberto PORTIOLI STAUDACHER
Dipartimento Ing. Gestionale
Politecnico di Milano
Dep. Management, Economics and Industrial Engineering
alberto.portioli@polimi.it

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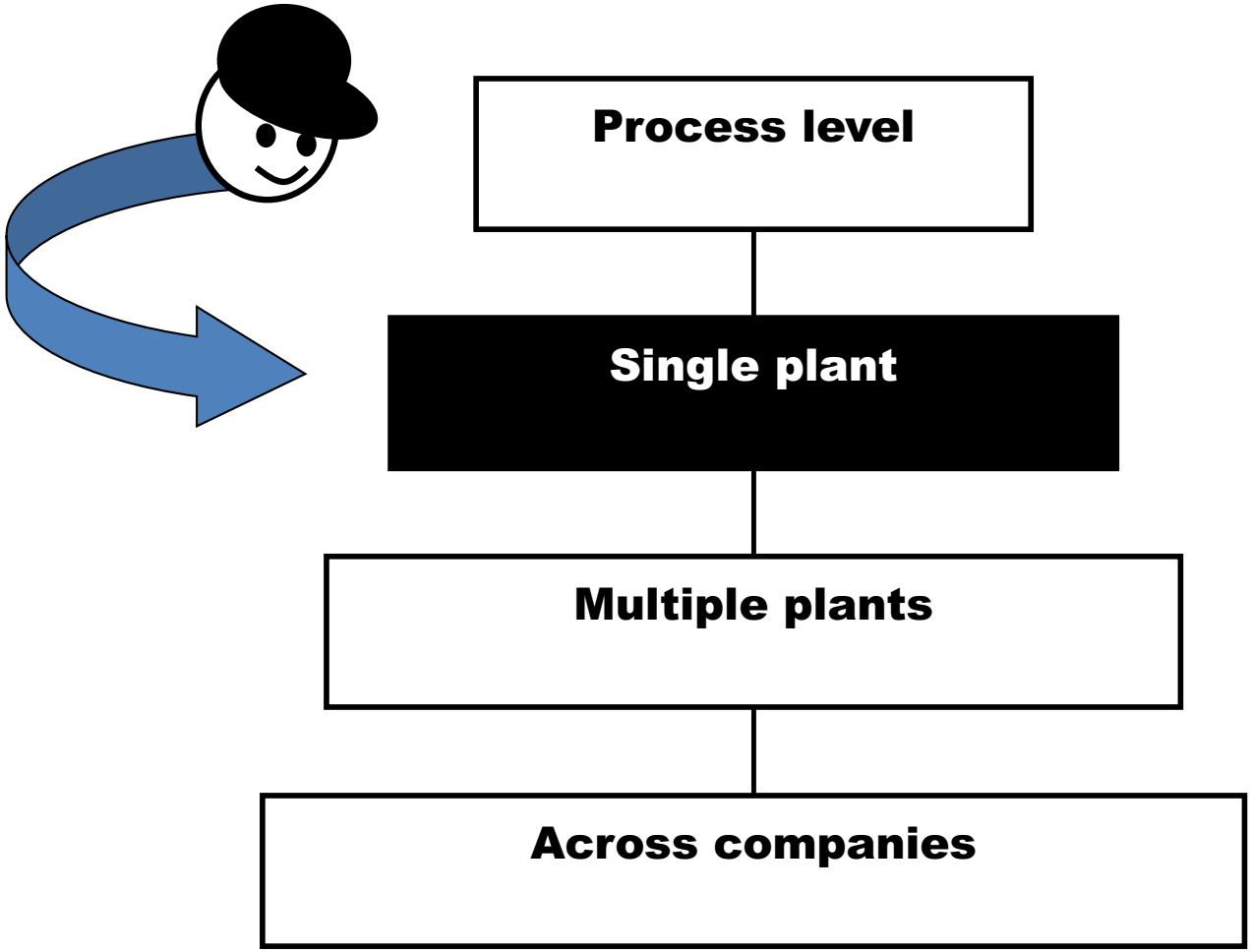
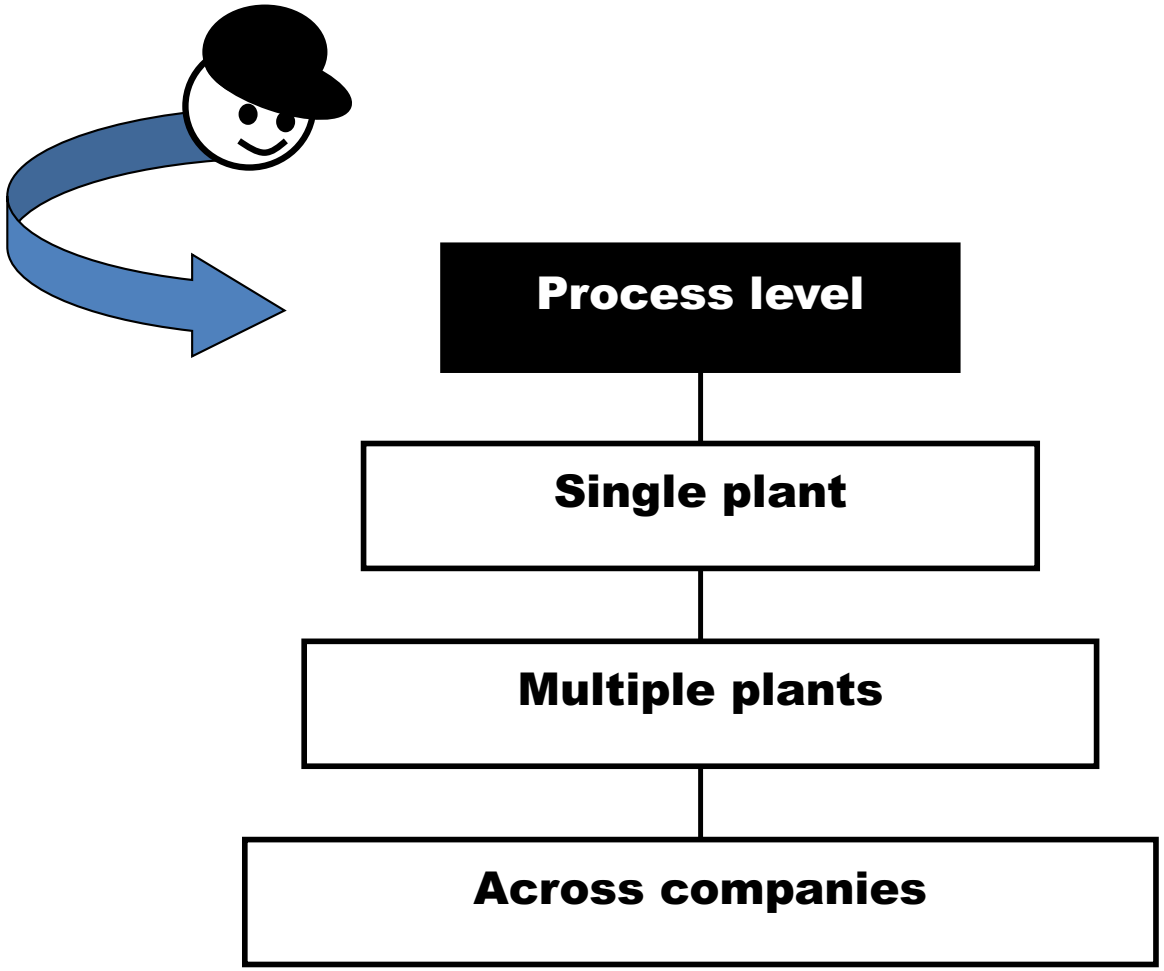
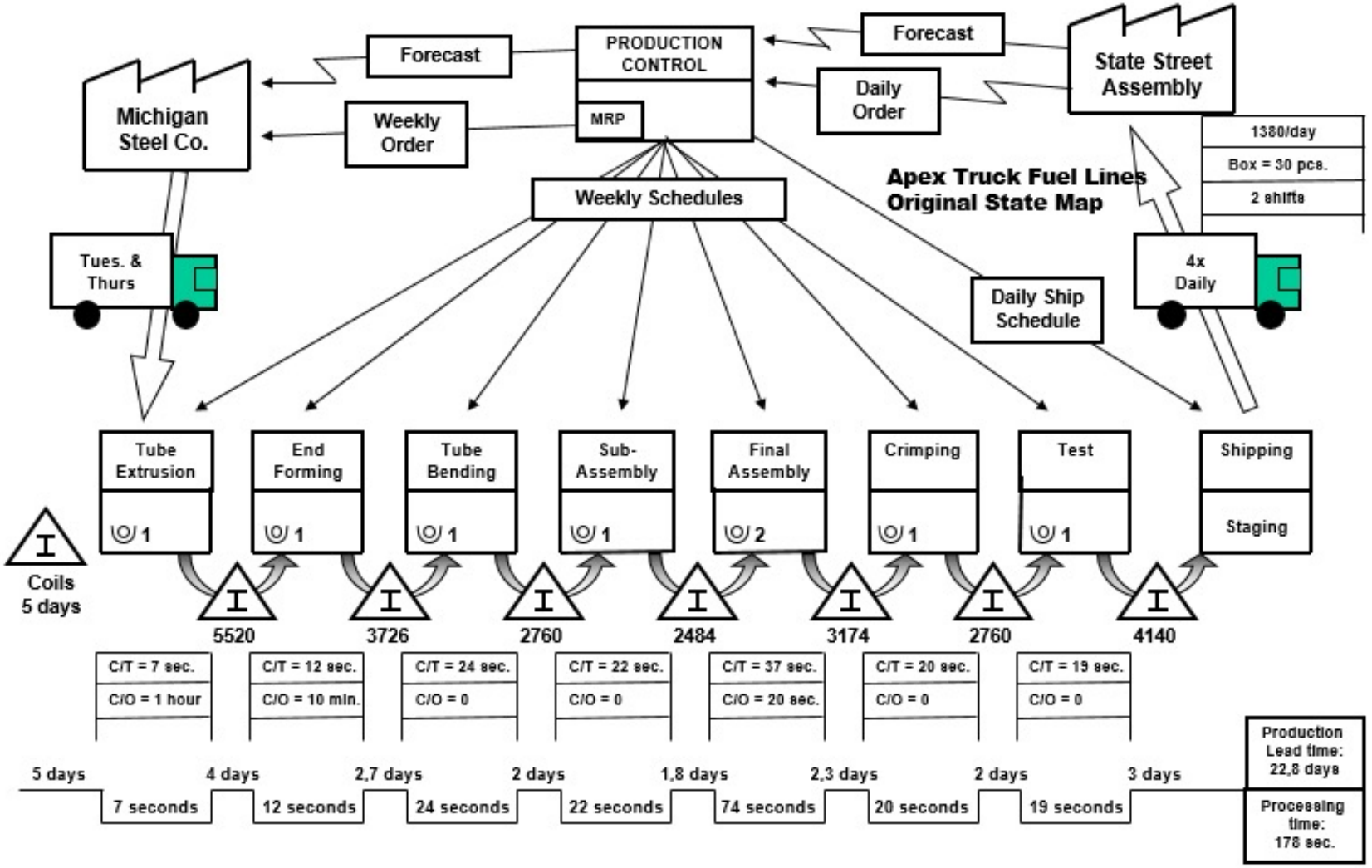

Process level
Single plant
Multiple plants
Across companies


Process level
Single plant
Multiple plants
Across companies

Apex's Product Family Matrix

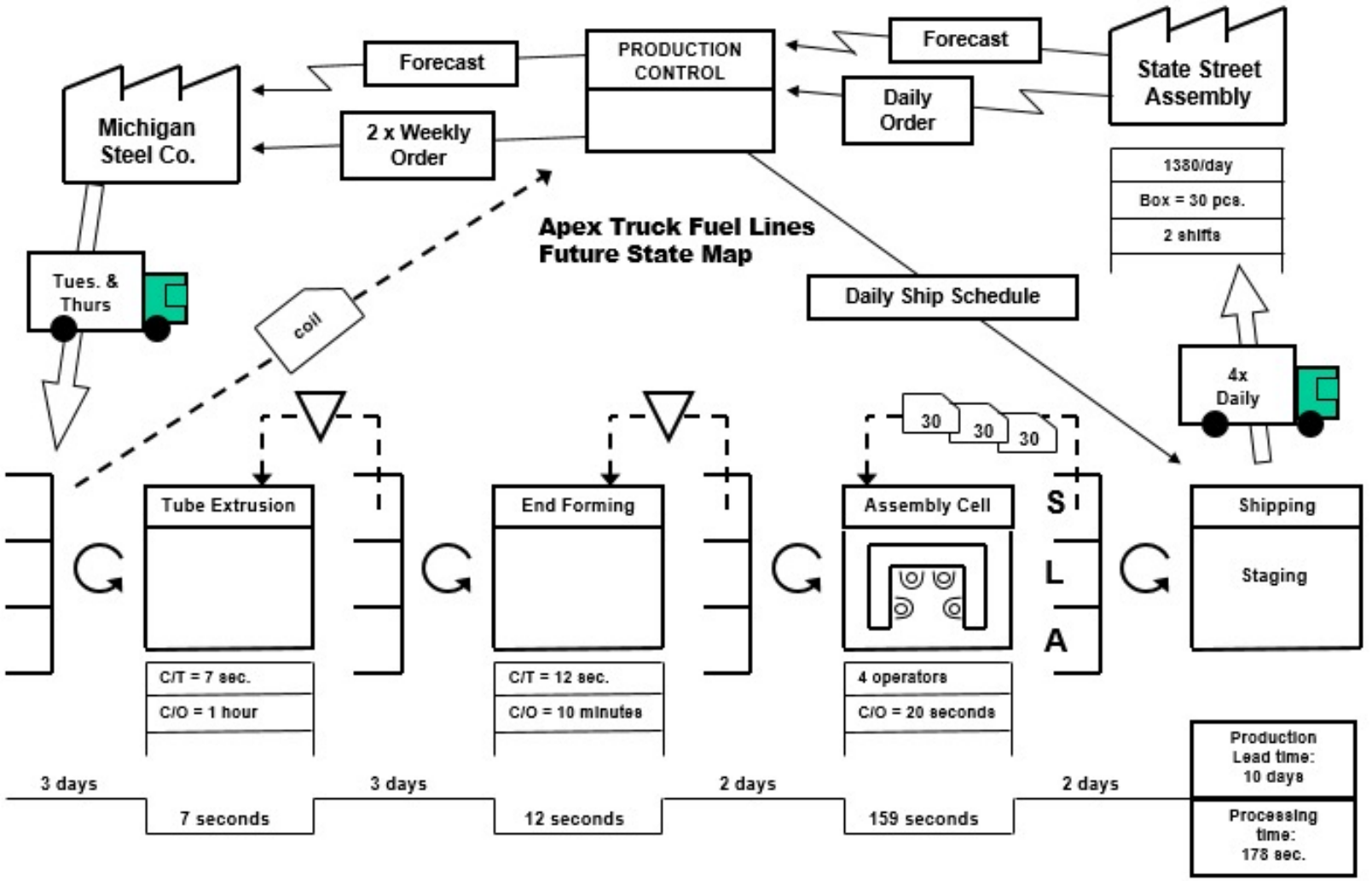
PRODUCTS	Assembly Steps and Machines							
	end form	pierce	braze	bend	sub-assembly	final assembly	crimp	test
automotive	X				X	X	X	X
truck S	X			X	X	X	X	X
truck L	X			X	X	X	X	X
truck A	X			X	X	X	X	X
heavy truck		X	X	X				X
heavy equipment	X	X	X	X		X		X


Forecast
PRODUCTION CONTROL
Forecast
State Street Assembly
Michigan Steel Co.
Weekly Order
MRP
Daily Order
1380/day
Box = 30 pcs.
2 shifts
Weekly Schedules
Apex Truck Fuel Lines
Original State Map
Tues. & Thurs
4x Daily
Daily Ship Schedule
Tube Extrusion
End Forming
Tube Bending
Sub-Assembly
Final Assembly
Crimping
Test
Shipping
Staging
1
1
1
1
2
1
1
Coils
5 days
5520
3726
2760
2484
3174
2760
4140
C/T = 7 sec.
C/O = 1 hour
C/T = 12 sec.
C/O = 10 min.
C/T = 24 sec.
C/O = 0
C/T = 22 sec.
C/O = 0
C/T = 37 sec.
C/O = 20 sec.
C/T = 20 sec.
C/O = 0
C/T = 19 sec.
C/O = 0
5 days
7 seconds
4 days
12 seconds
2,7 days
24 seconds
2 days
22 seconds
1,8 days
74 seconds
2,3 days
20 seconds
2 days
19 seconds
3 days
Production Lead time: 22,8 days
Processing time: 178 sec.

Apex future state

KEY QUESTIONS FOR FUTURE-STATE DESIGN

1. What is the takt time?
2. Will you build to a finished goods supermarket, or directly to shipping?
3. Where can you use continuous flow processing?
4. Where will you need to use supermarket pull systems to control production of upstream processes?
5. At what single point in the production chain (the “pacemaker process”) will you schedule production?
6. How will you level the production mix at the pacemaker process?
7. What increment of work will you consistently release and take away at the pacemaker process?
8. What process improvements will be necessary for the value stream to flow as your future-state design specifies?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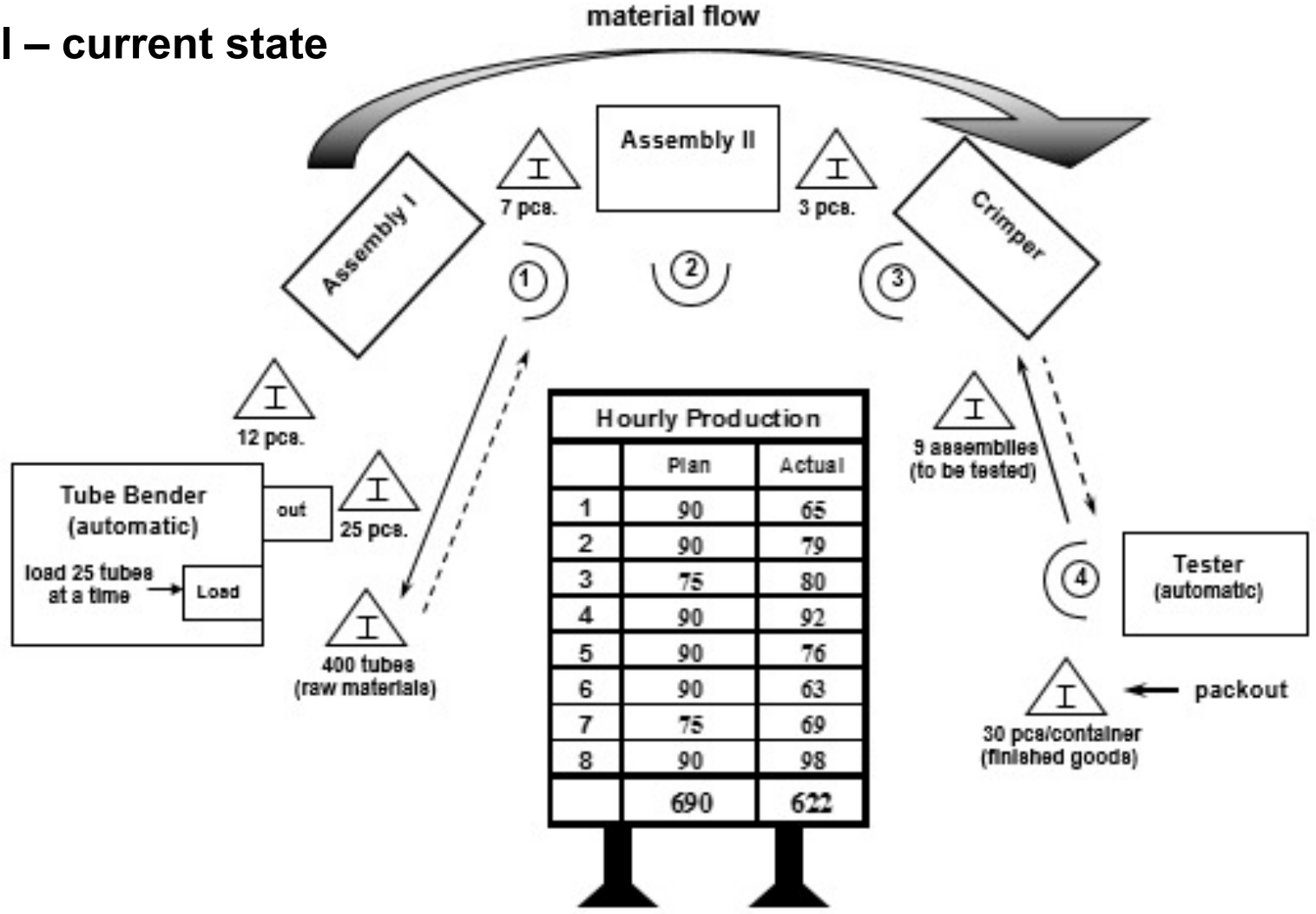
Future State Map
Tues. & Thurs
coil
Daily Ship Schedule
4x Daily
30
30
30
Tube Extrusion
End Forming
Assembly Cell
S
L
A
Shipping
Staging
C/T = 7 sec.
C/O = 1 hour
C/T = 12 sec.
C/O = 10 minutes
4 operators
C/O = 20 seconds
3 days
7 seconds
3 days
12 seconds
2 days
159 seconds
2 days
Production Lead time: 10 days
Processing time: 178 sec.

This improvement is not enough

- Final results are not as good as on paper
- Redesigning the value stream is good but it is only the starting poing
- VSM is no a solution, it only highlights problems

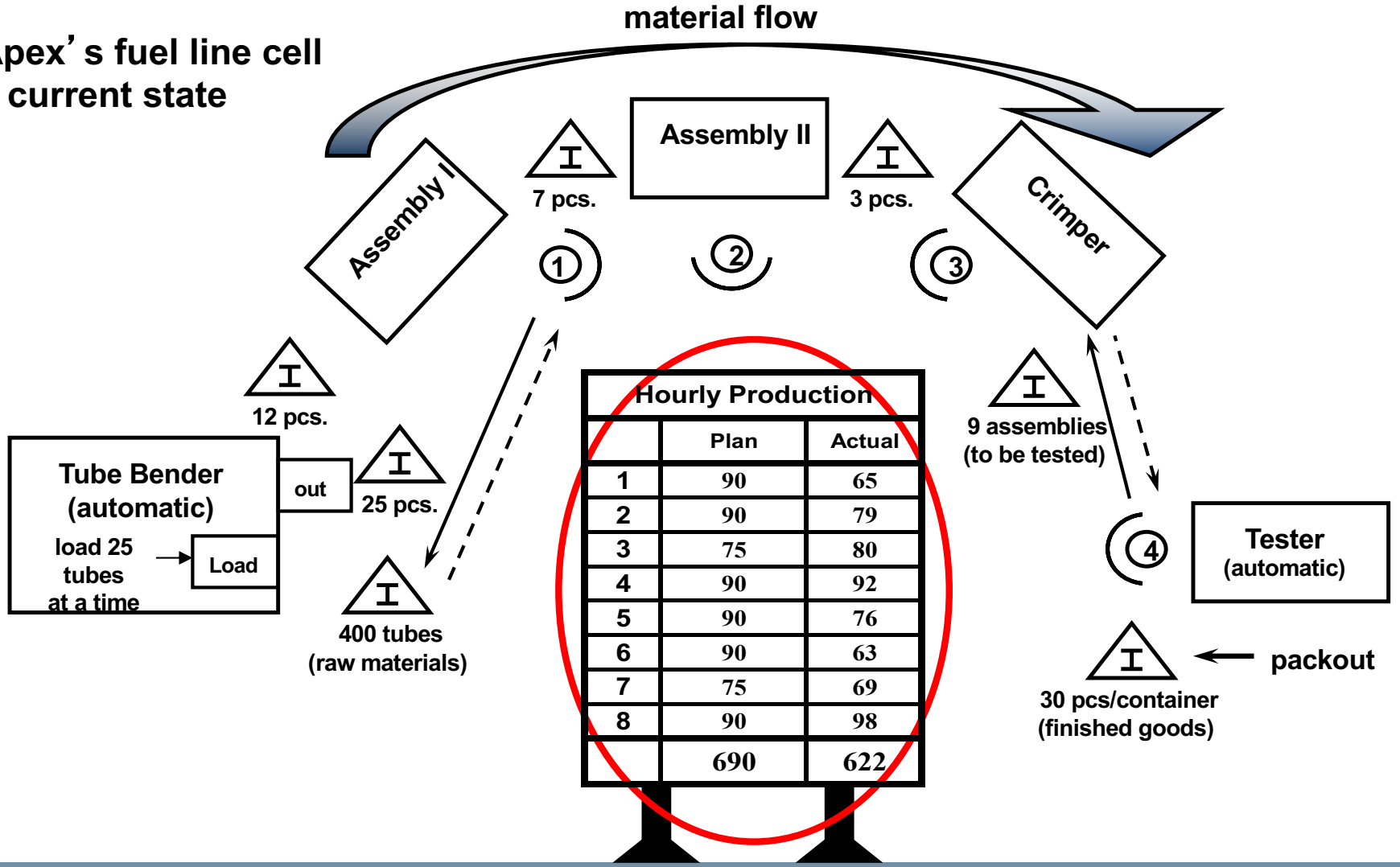
What's the problem?

Apex's fuel line cell – current state



Hourly Production		
	Plan	Actual
1	90	65
2	90	79
3	75	80
4	90	92
5	90	76
6	90	63
7	75	69
8	90	98
	690	622

Apex's fuel line cell – current state



	Plan	Actual
1	90	65
2	90	79
3	75	80
4	90	92
5	90	76
6	90	63
7	75	69
8	90	98
	690	622

Questions

Causes: Why there is so much variation?

- Is the machine not capable (scrap/rework)?
- Is the machine not always running?
- Are parts missing?
- Is the supplier shipping defective parts?
- …

Actions: Who reacts when these problems occur?

Signals

- First operator leaves his/her area every 25 pieces (flow stops)
- Inventories between operations
- Production operators are anchored to their machine
- Very wide U

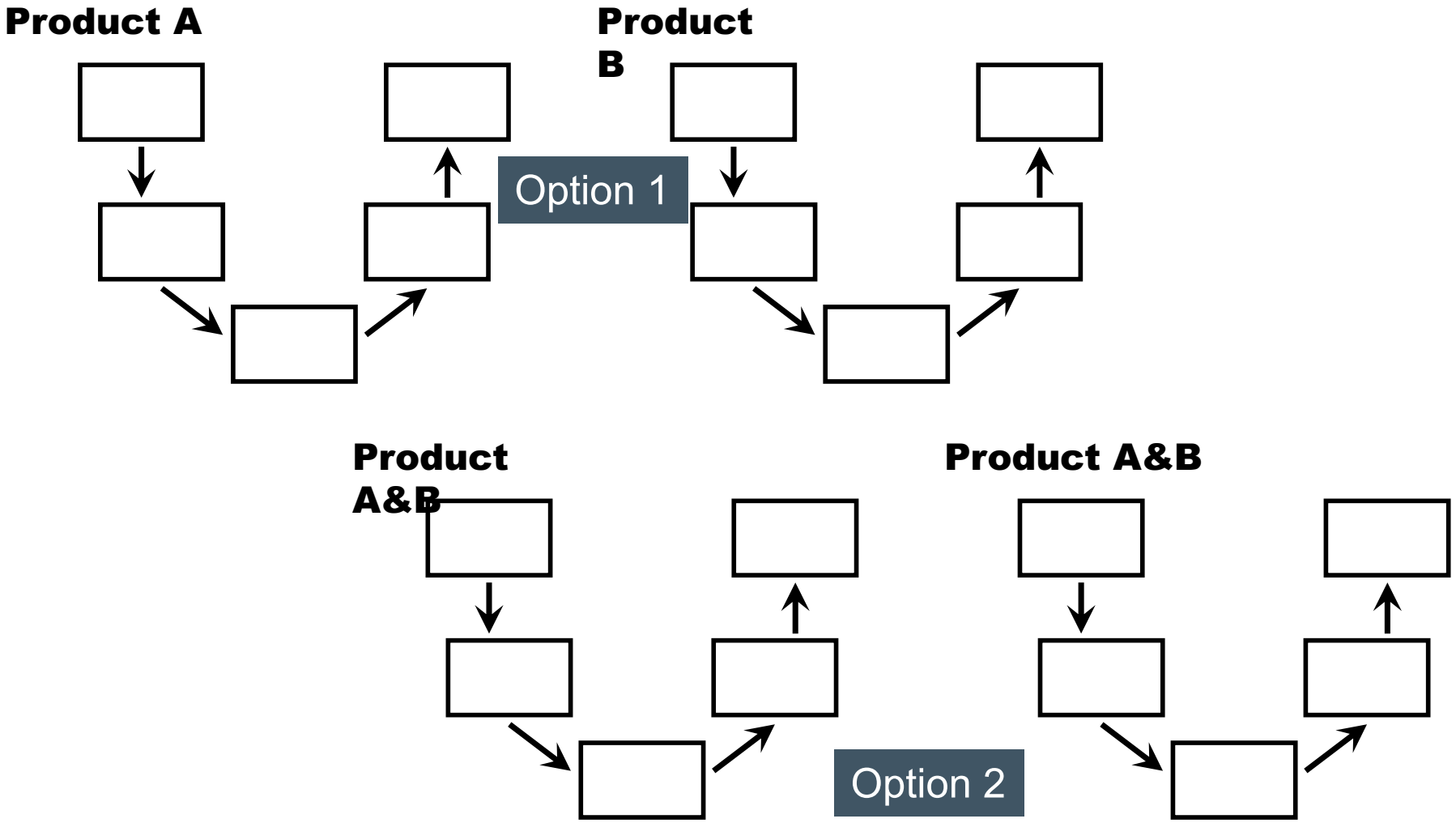
Apex's Progress with Continuous Flow

	Original State	Current State
Continuous Flow	No	No
Production per Shift (actual/target)	unstable ≈ 622 / 690	unstable ≈ 622 / 690
Space (sq. feet)	1130	580
Assembly Lead Time (WIP x Takt)	11 days	37 min.
Number of Operators	6	4
Productivity (pieces/associate/hr)	13.05	20
Functions Effectively as Pacemaker	No	No

Targets for Apex's Fuel Line Cell

	Original State	Current State	Target
Continuous Flow	No	No	Yes
Production per Shift (actual/target)	unstable ≈ 622 / 690	unstable ≈ 622 / 690	690 / 690
Space (sq. feet)	1130	580	252
Assembly Lead Time (WIP x Takt)	11 days	37 min.	200 sec.
Number of Operators	6	4	2
Productivity (pieces/associate/hr)	13.05	20	40
Functions Effectively as Pacemaker	No	No	Yes

Do you have the right items?



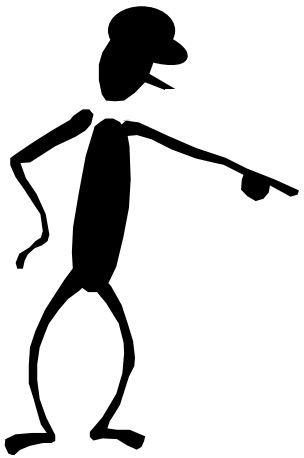
How to chose what items in the cell

- Flexibility
- Variation in total work content
- Similarity in processing steps and equipment
- Takt Time
- Customer demand
- Customer Location

What is the takt time?

takt time

Used to help synchronize pace of production with the pace of sales



$$\text{takt time} = \frac{\text{your available work time per shift}}{\text{customer demand per shift}}$$

$$\text{example: } \frac{27{,}600 \text{ seconds}}{690 \text{ pieces}} = 40 \text{ seconds}$$

this means: The customer is buying this product at a rate of one every 40 seconds.

Because Takt Time represents the demand rate, do not subtract time for changeover, downtime, and other internal problems

Setting the pace

TT is based on customer's demand (which you cannot change) and available production time (which you can change).

Your levers:

- Number and type of items in a cell
- Available production time
- Number of cells making a specific item

What if the demand rate changes?

Takt Time refers to average demand. Changing TT frequently causes inefficiency

- In MTS use **Buffer Stock** to protect the production system
- In MTO use **Backlog** to protect the production system

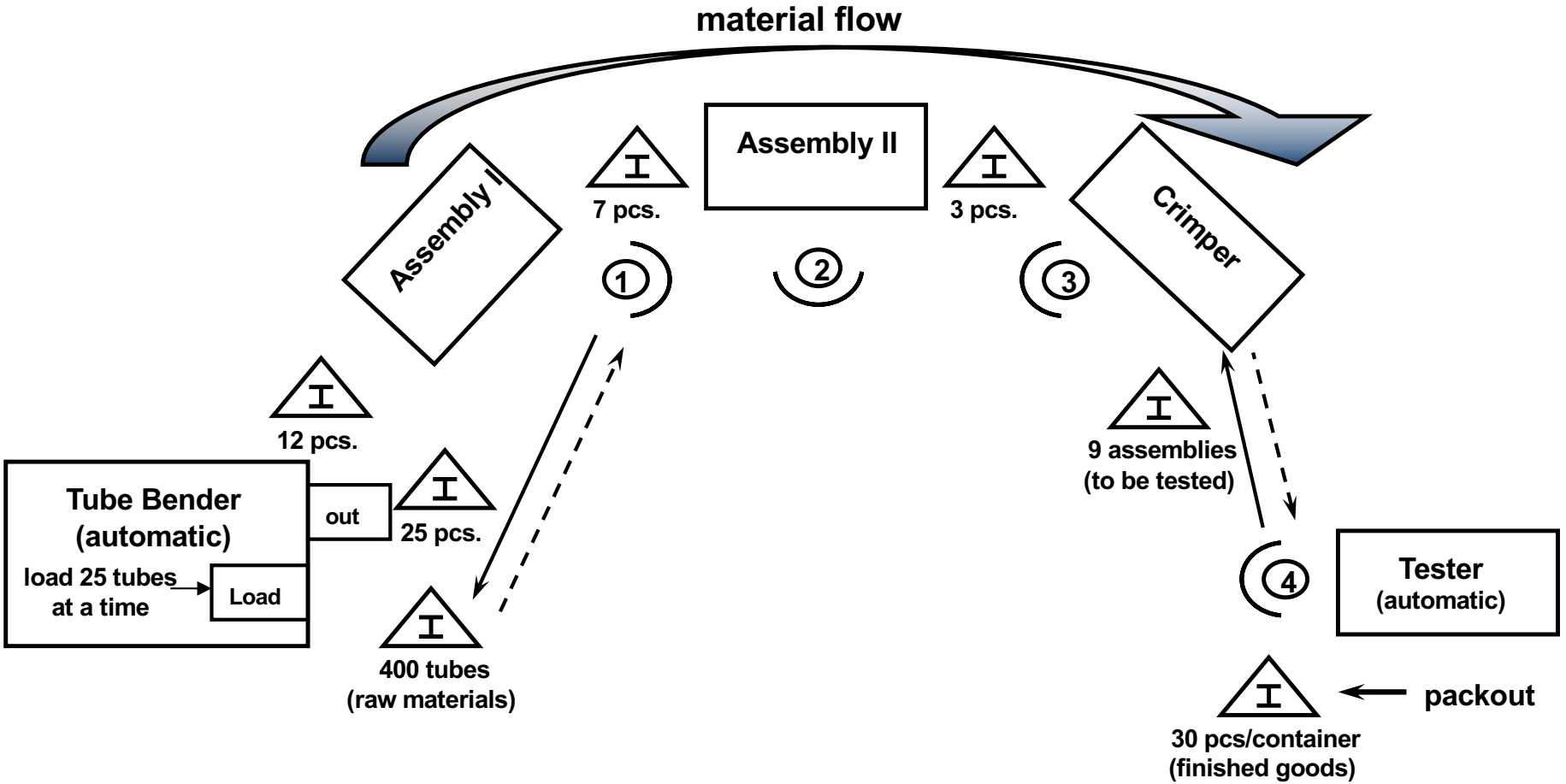
Cycling much faster than TT

- May require more people
- Increases the chances of overproducing
- May conceals production problems
- Eases tension to improve

Timing tips

- Collect real time of the processes (do not rely on standard time)
- Position yourself where you can see the operator's hand motions
- Time each work element separately
- Time several cycles of each work element
- Observe an operator who is qualified to perform the job
- Always separate operator time and machine time
- Select the lowest repeatable time for each element
- Remember shop floor courtesy

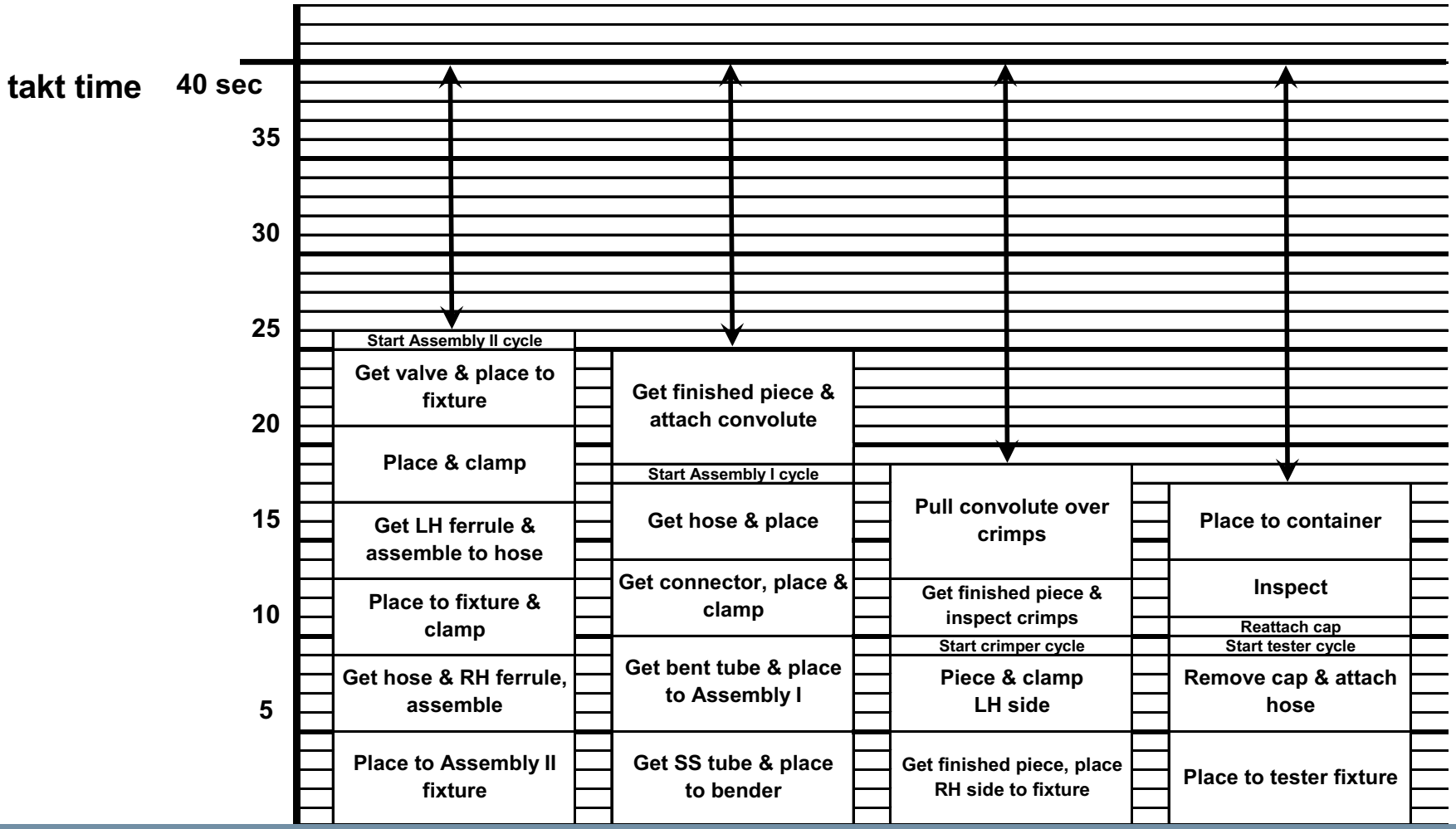
Apex's fuel line cell – work element times



APEX paper kaizen

Bender		Assembly I		Assembly II		Crimper		Tester	
Work Elements	Time	Work Elements	Time	Work Elements	Time	Work Elements	Time	Work Elements	Time
Before Kaizen:		Get bent tube, place	5	Get tube & place	5	Get assembly & place RH side to fixture	5	Get assembly & place to fixture	5
Load auto feeder (batch 25 pcs)	3 min.	Get connector, place & clamp	4	Get teflon hose & right ferrule to hose	4	Place & clamp LH side	4	Remove hose cap & attach hose to fixture	4
Cycle	16 sec.	Get hose & place	4	Place to fixture & clamp	4	Start cycle	1	Start cycle	1
Auto eject		Start cycle	1	Get left ferrule & assemble to hose	4	Cycle (wait)	5	Cycle (wait)	5
		Cycle (wait)	4	Place & clamp	4	Unclamp & remove	3	Remove	4
		Unclamp & remove	2	Get valve & place to fixture	4	Inspect crimps	3	Re-attach cap	1
		Attach convolute	6	Start cycle	1	Pull convolute over crimps	6	Inspect	3
		Aside		Cycle (wait)	7	Aside		Place to shipping container	4
				Unclamp & remove	4				
				Aside					
Machine Cycle = 16 sec.		Machine Cycle = 4 sec.		Machine Cycle = 7 sec.		Machine Cycle = 5 sec.		Machine Cycle = 5 sec.	

APEX's operator balance chart (OBC)
Current situation



OBC is summarising human work, not machine work

How much automation?

Set the new workpiece aside.

Remove the finished workpiece from the machine.

Set the finished workpiece aside.

Pick up the new workpiece.

Place the new workpiece in the machine.

Start the machine, which then cycles unattended.

Pick up the finished work piece.

Bring the finished piece to the next machine, and repeat these steps.

How much automation?

Levels of automation

One touch automation

LEVEL

	Load Machine	Machine Cycle	Unload Machine	Transfer Part
1				
2		Auto		
3		Auto	Auto	
The Great Divide				
4	Auto	Auto	Auto	
5	Auto	Auto	Auto	Auto

Easy to achieve
Inexpensive

May be too much

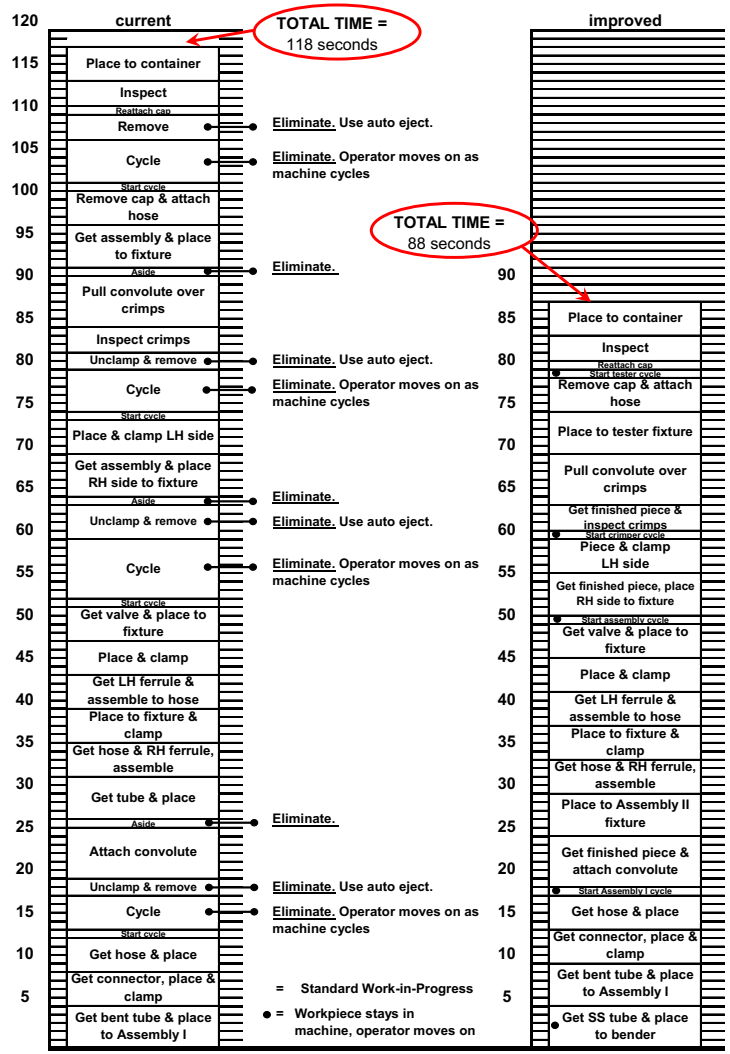
Double handling means that pacemaker process needs Level 3 Automation

APEX paper kaizen

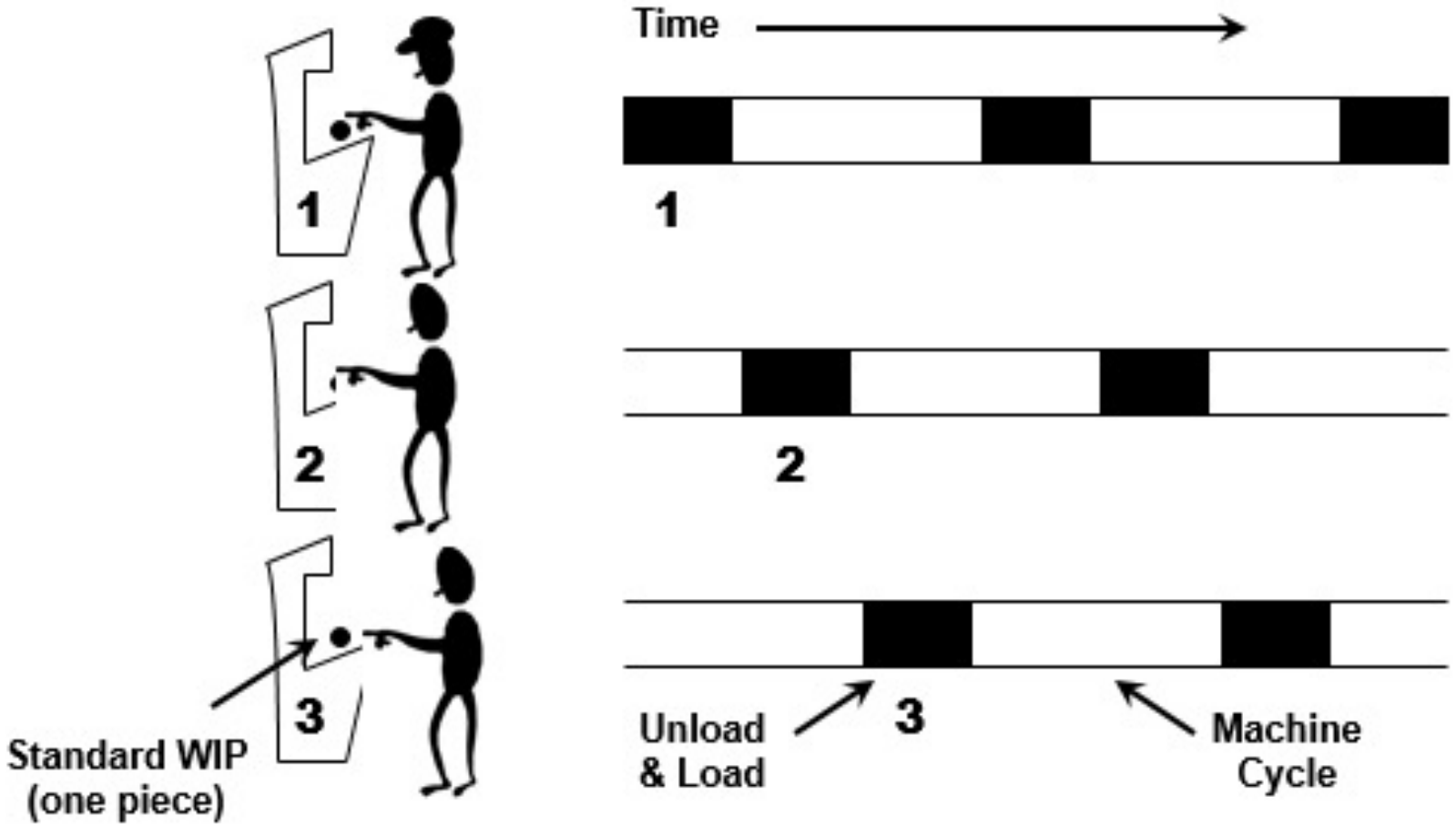
- Eliminate wait while machine cycles (Operators wait for machine to cycle 21 s)
- Introduce auto-eject at Ass I, Ass II, Crimper, Tester (unclamp, remove, set aside)
- Convert out-of-cycle work (loading the bender with a batch of 25 tubes) to in-cycle-work of loading one tube every cycle

Bender		Assembly I		Assembly II		Crimper		Tester	
Work Elements	**Time**	**Work Elements**	**Time**	**Work Elements**	**Time**	**Work Elements**	**Time**	**Work Elements**	**Time**
Before Kaizen:		Get bent tube, place	5	Get tube & place	5	Get assembly & place RH side to fixture	5	Get assembly & place to fixture	5
Load auto feeder ~~(batch 25 pcs)~~	3 min.	Get connector, place & clamp	4	Get teflon hose & right ferrule to hose	4	Place & clamp LH side	4	Remove hose cap & attach hose to fixture	4
Cycle	16 sec.	Get hose & place	4	Place to fixture & clamp	4	Start cycle	1	Start cycle	1
Auto eject		Start cycle	1	Get left ferrule & assemble to hose	4	~~Cycle (wait)~~		~~Cycle (wait)~~	
After Kaizen:		~~Cycle (wait)~~		Place & clamp	4	~~Unclamp & remove~~		~~Remove~~	
Get SS tube & place to bender	5	~~Unclamp & remove~~		Get valve & place to fixture	4	Inspect crimps	3	Re-attach cap	1
~~Cycle~~	~~16~~	Attach convolute	6	Start cycle	1	Pull convolute over crimps	6	Inspect	3
~~Auto eject~~	~~1~~	Aside		~~Cycle (wait)~~		Aside		Place to shipping container	4
				~~Unclamp & remove~~					
				Aside					
Machine Cycle = 17 sec.		Machine Cycle = 4 sec.		Machine Cycle = 7 sec.		Machine Cycle = 5 sec.		Machine Cycle = 5 sec.	

Paper kaizen for Apex fuel line work content

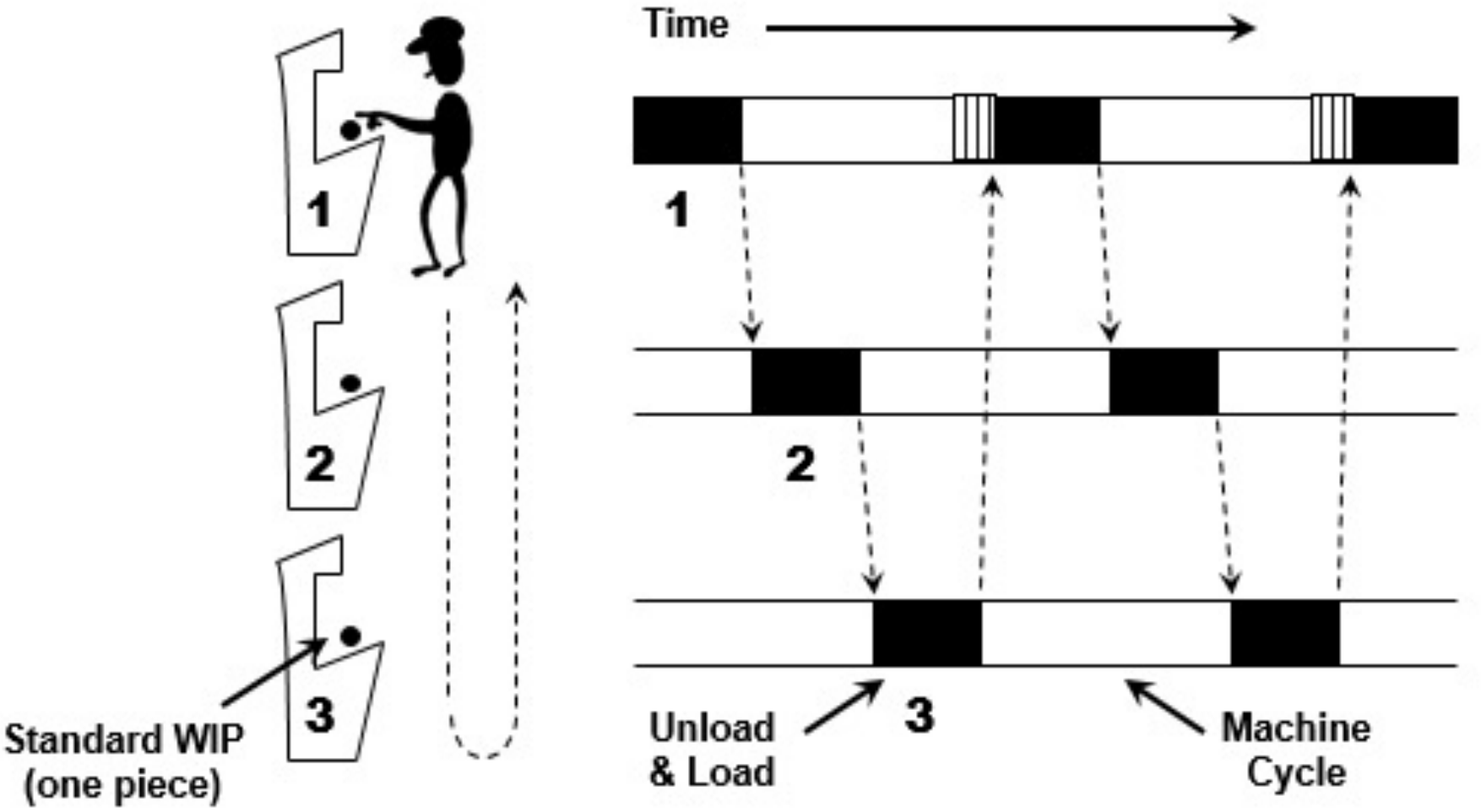


Traditional approach



Operator works for the machine

Multi process handling instead of waiting



Machine can run idle (look at the flow)

Can your equipment meet TT?

Effective Cycle Times of machines in Apex's cell

Machine	Machine Cycle	Load, Start & Unload Time	c/o Time/ Batch Size	Effective Machine Cycle
Bender	16 sec	5 sec	0	21 sec
Assembly I	4 sec	16 sec	0	20 sec
Assembly II	7 sec	28 sec	1*	36 sec
Crimper	5 sec	12 sec	0	17 sec
Tester	5 sec	12 sec	0	17 sec

* Time is actually 0,67 second with a minimum batch size of 30 (based on packaging the customer requires as explained later). With a 20-second changeover time, the changeovers on this machine consume just under one second per cycle when averaged over the smallest run

In a world where machine are not completely capable, or completely available, Effective TT <= 0,8*minTT

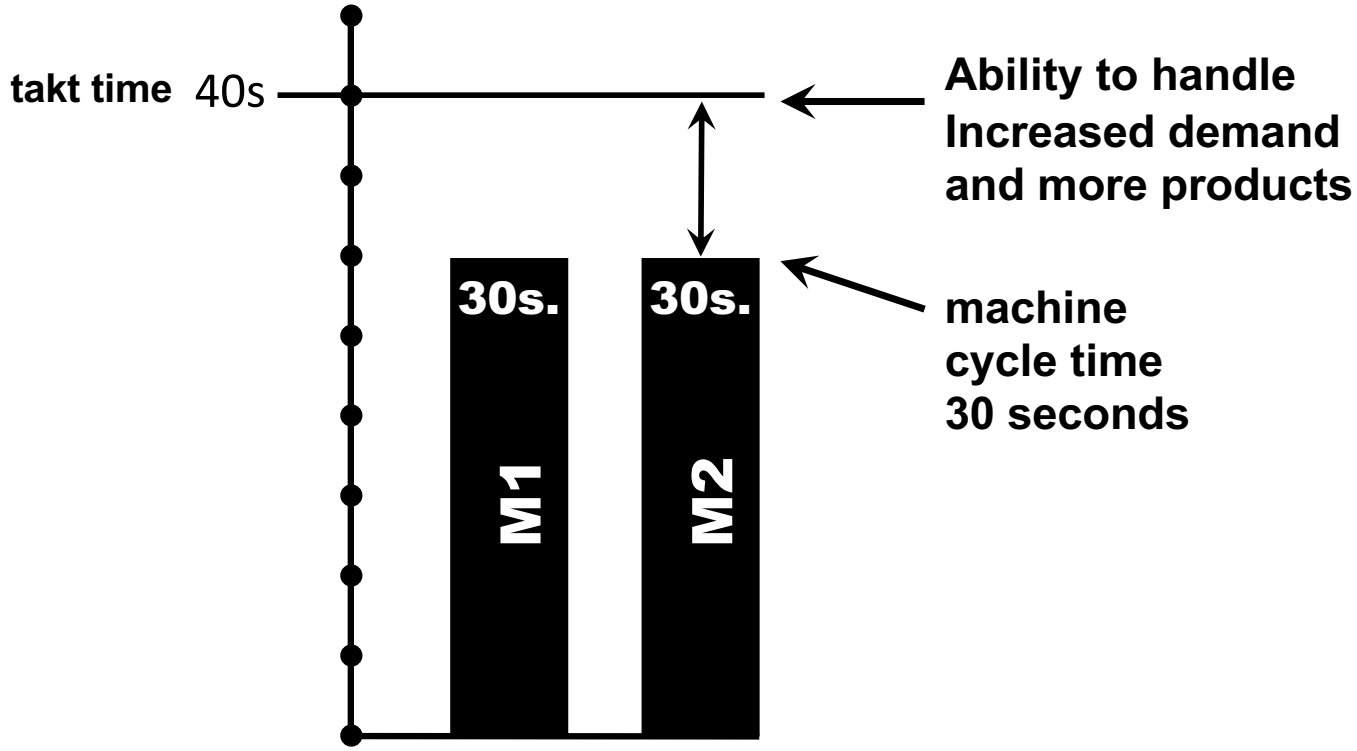
If not meeting TT

- Reduce setup time
- Increase availability
- Kaizen the load, start, unload process
- Eliminate waste in the machine cycle itself
- Split apart some of the tasks a bottleneck machine is performing and use more than one machine (select simpler machines)
- Install 2 machines of the same type in parallel
- Create 2 cells instead of one

Finally, if anything else fails:

- Remove the bottleneck equipment from the cell, decouple it and operate in batch.

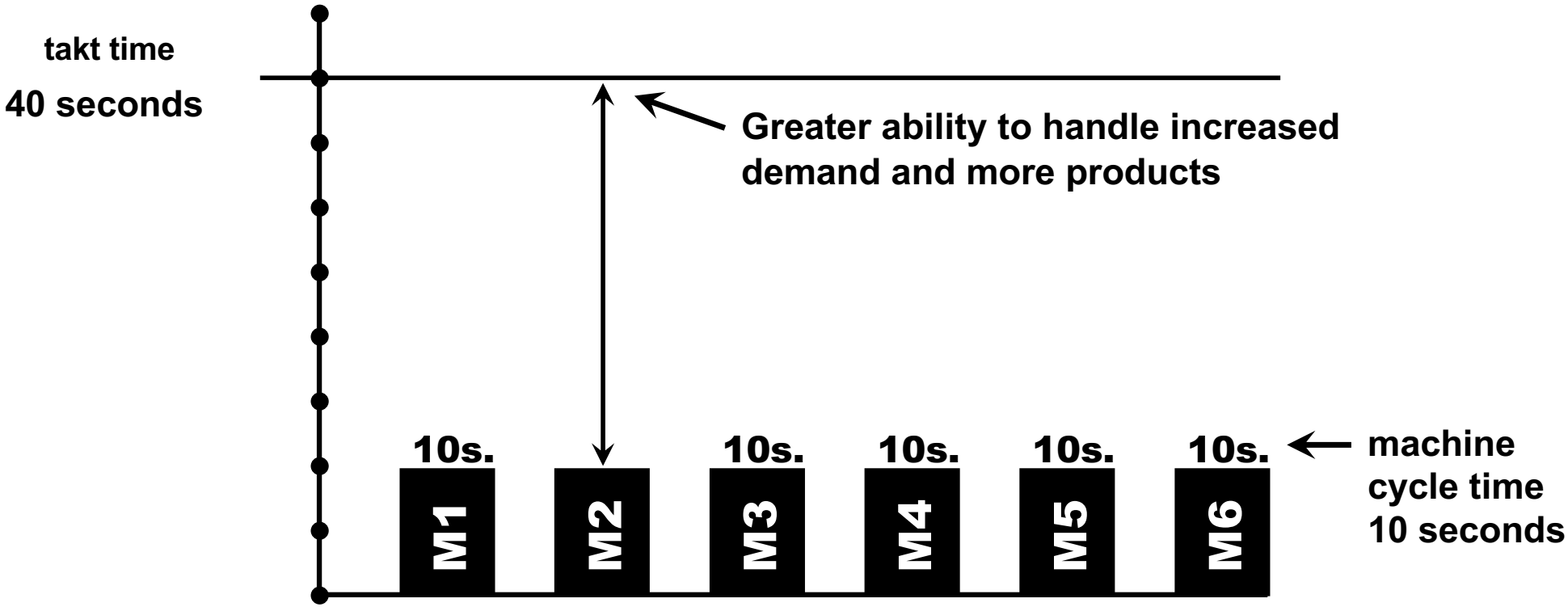
What kind of machines?
Few large/multi function machines



machine balance chart

What kind of machines?
Few large/multi function machines

Greater flexibility of simple machines



Large vs small machines

Large

Economy of scale

Utilisation is critical

Small

Reliability

Volume flexibility

Mix flexibility

Trade-off between Machine utilisation, Material utilisation, Man utilisation

Human are the most flexible

Guidelines for machines

- ❑ **Use small equipment dedicated to a single task rather than large, multi-task equipment.**
- ❑ **Introduce auto-eject (Level 3 Automation) whenever operators must use both hands to handle the part.**
- ❑ **Install one-touch automation where possible.**
- ❑ **Avoid batching.**
- ❑ **Incorporate sensors to signal abnormal conditions and even automatically stop machines if necessary, so operators do not need to watch machines during their cycle.**
- ❑ **Design in maintainability.**
- ❑ **At the pacemaker process, strive to device machine changeovers between different end items that take less than one takt time cycle.**

Cell layout

Arrange machines, workstations, and material presentation devices as if only one operator makes the product from beginning to end.

Guidelines for cell layout

- ❑ Place machines and workstations close together to minimize walking distance.
- ❑ Remove obstacles from the efficient operator walking path.
- ❑ Try to keep the inside width of a cell at around five feet to allow flexibility in reallocating work elements among team members.
- ❑ Eliminate spaces and surfaces where work-in-process inventory can be accumulated.
- ❑ Maintain consistent heights for work surfaces and points of use.
- ❑ Locate the leadoff and final processes near one to another.
- ❑ Avoid up-and-down and front-to-back transfers of the workpiece.
- ❑ Use gravity to assist operators in placing parts and moving materials whenever possible.
- ❑ Install flexible utility drops from the ceiling to make layout adjustments easier.
- ❑ Keep hand tools as close as possible to the point of use and orient them in the direction that they are used by operators.
- ❑ Use dedicated hand tools instead of tools that require bit changes, and combine two or more tools wherever possible.

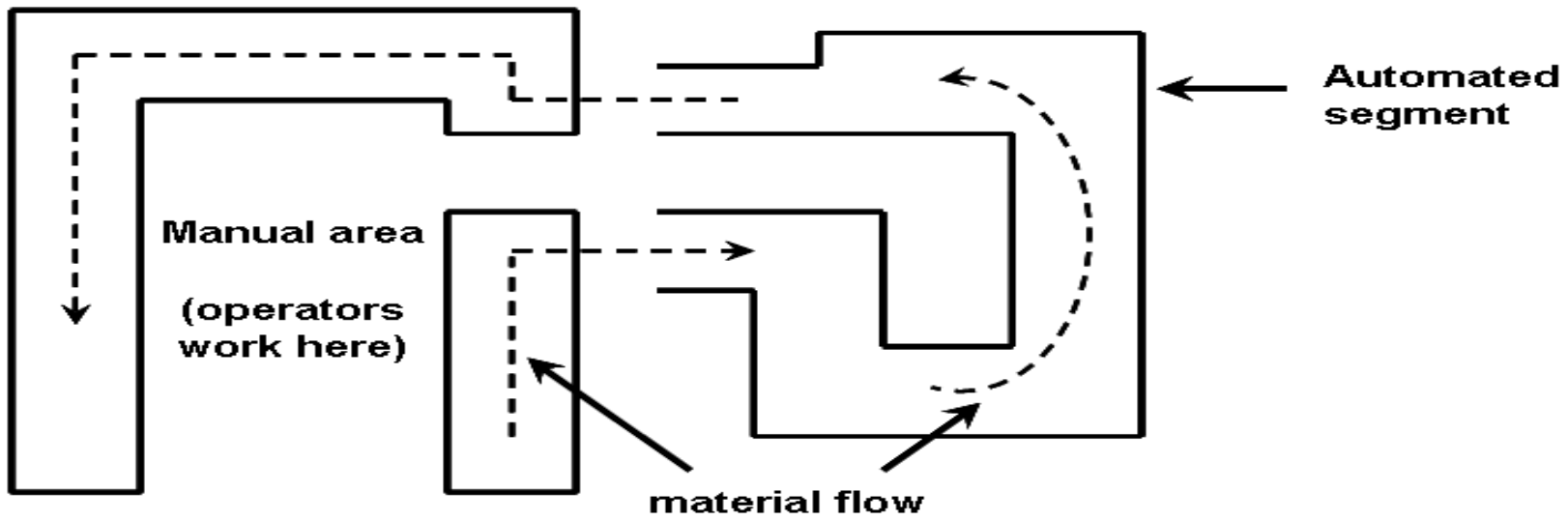
Guidelines for cell layout

- ❑ **Absolutely ensure safety and good ergonomics.**

- ❑ **Keep manual, operator-based work steps close togheter to allow flexible work element distribution and value-added operator work.**

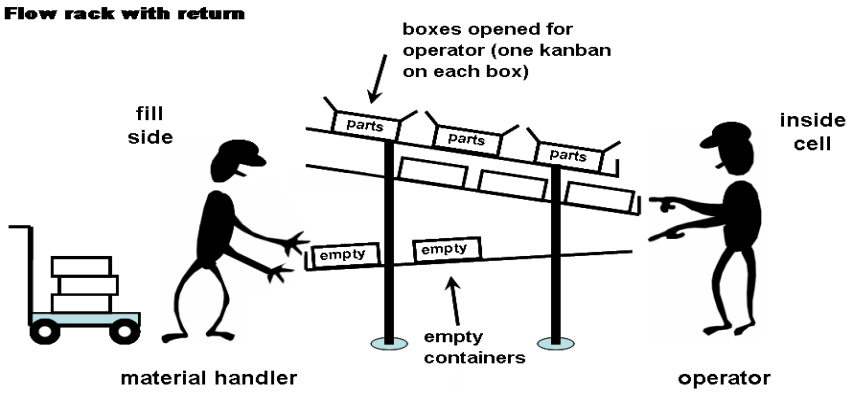
- ❑ **Segregate Level 5 automation and continuous-cycle operations (like ovens) from manual operators or operator-based work flow, as shown in the diagram below.**

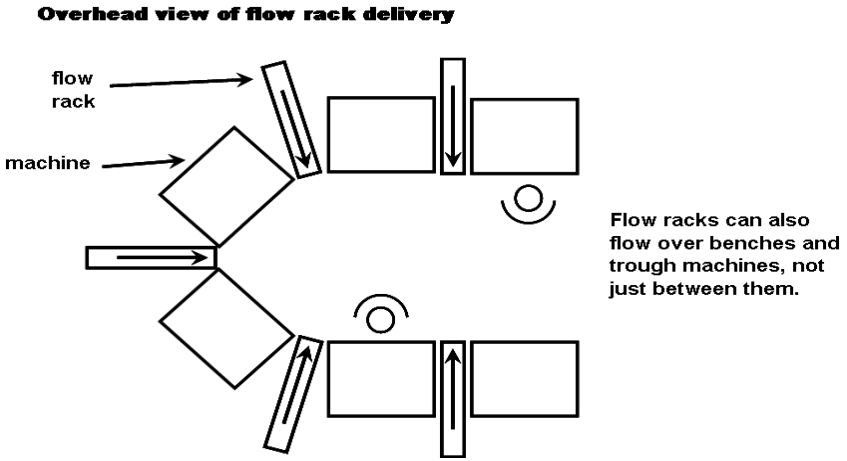
Incorporating automated segments into cells



Guidelines for material management

- **Do not interrupt work cycles to replenish parts.**



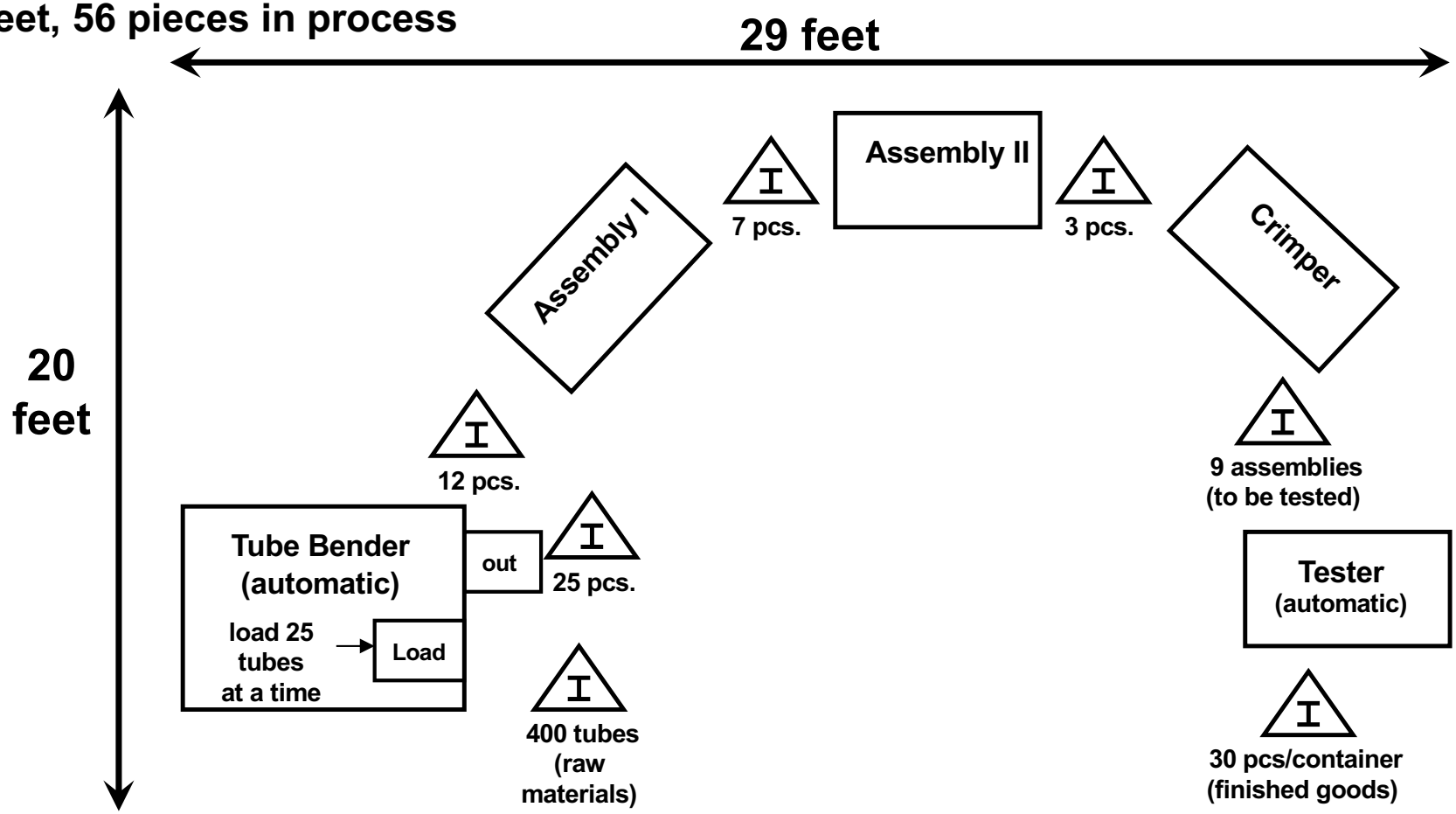


Guidelines for material management

- ❑ **Present parts as close as possible to the point of use, but not in the walking path of the operator.**
- ❑ **Display parts in order to make operators able to use both hands simultaneously.**
- ❑ **Try to keep all part variations at the operators' fingertips at all times to eliminate changeover time.**
- ❑ **Do not have operators get or restock their own parts.**
- ❑ **Keep no more than two hours of materials at the point of use.**
- ❑ **Do not put additional parts storage in or near the process because this makes the operation of the cell or line harder to understand and encourages operators to get their own parts.**
- ❑ **Utilize kanban to regulate parts replenishment.**
- ❑ **Size parts containers in the operators' interest or as a multiple of finished-goods packout quantity. Not do it in the material handler's interest or in the one of the supplying process.**

Current Apex fuel line module layout

580 square feet, 56 pieces in process

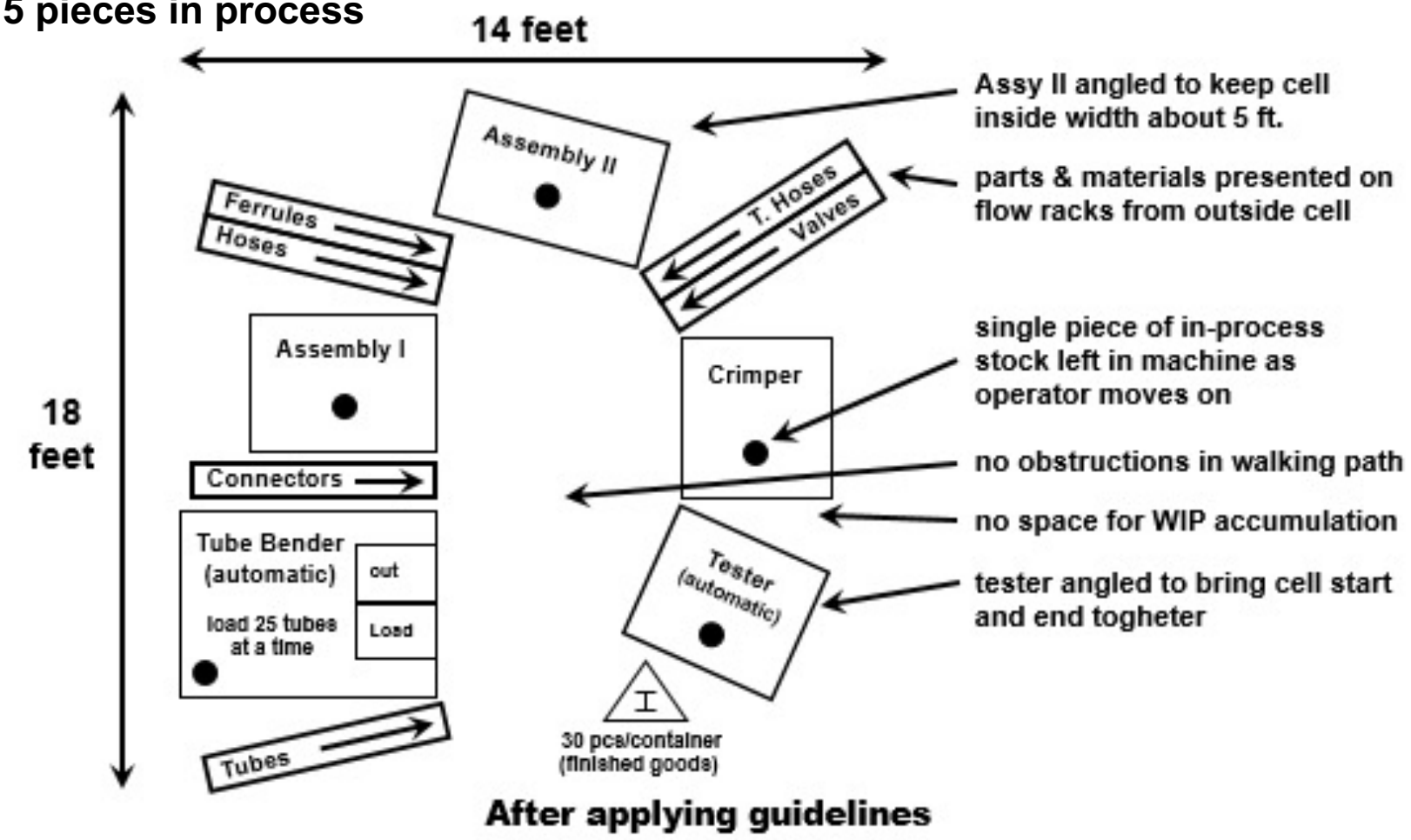


Before applying guidelines

Applying the guidelines to the APEX cell

- Too much walking distance from beginning to end
- The inside of the cell is too wide
- The leadoff and final operations are far apart
- There is broad space for WIP accumulation between machines
- The tube bender needs modifications to load one tube at a time
- The out tray for the bender obstructs the operator walking path

Example layout for efficient one-operator, one-piece flow
252 square feet, 5 pieces in process



After applying guidelines

Dealing with batch-oriented equipment

- Separate batch process from continuous flow with a supermarket or a FIFO lane
- Keep in the continuous flow if equipment is moving-conveyor type (and operator can drop a single piece at start, and pick up one at end within TT)
- Ignore equipment batch capability and use it single piece
- Transform equipment from batch to single
- Replace batch equipment with one or more single piece inexpensive equipment

Distributing the work
How many operators?

In APEX example

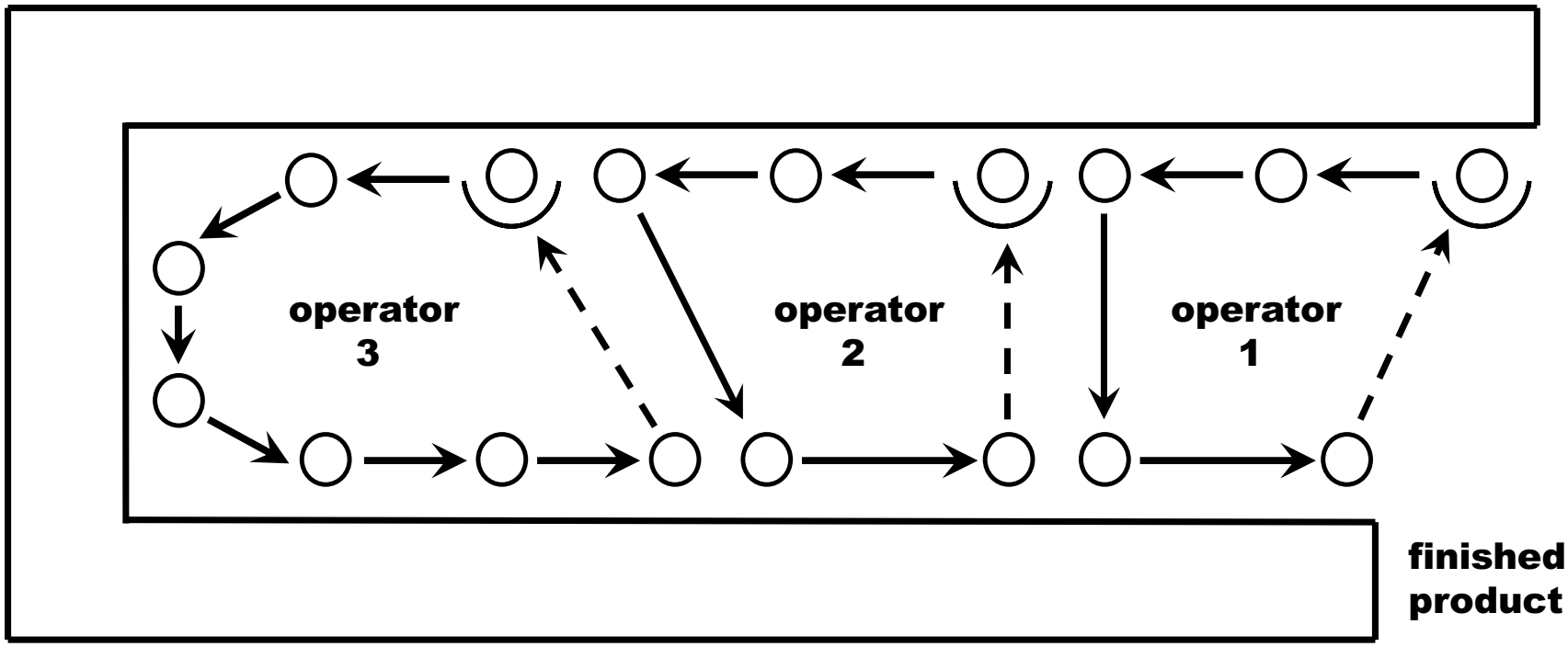
88/ 40 = 2.2 operators

Guidelines for determining the number of operators in a cell

Remainder in # of operators calculation (after paper kaizen)	Guideline / Target
< .3	Do not add an extra operator. Further reduce waste & incidental work.
.3 - .5	Do not add an extra operator yet. After two weeks of cell operation & kaizen, carefully evaluate if enough waste & incidental work can be taken out.
> .5	Add an extra operator if necessary and keep reducing waste & incidental work to eventually eliminate the need for that operator in the cell.

Work distribution among operators
Split the work

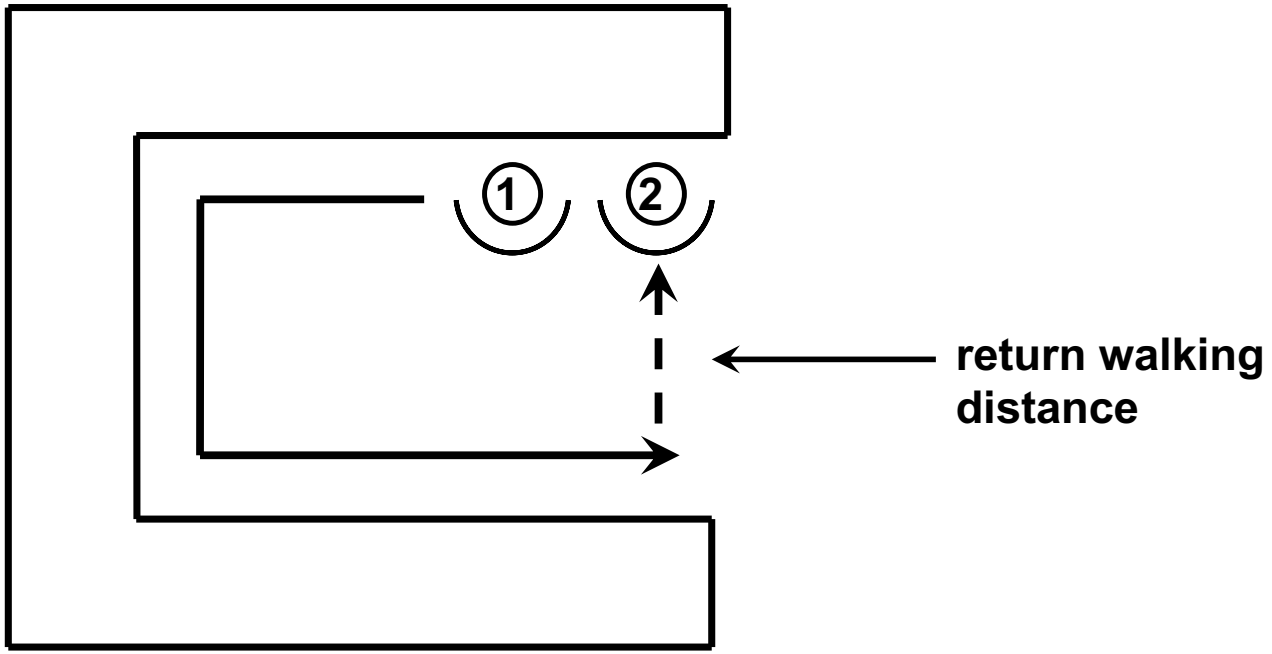
Splitting the work means that each operator is given one portion of the total work content.



Assign first and last work element in the material flow to the same operator

Work distribution among operators
The circuit

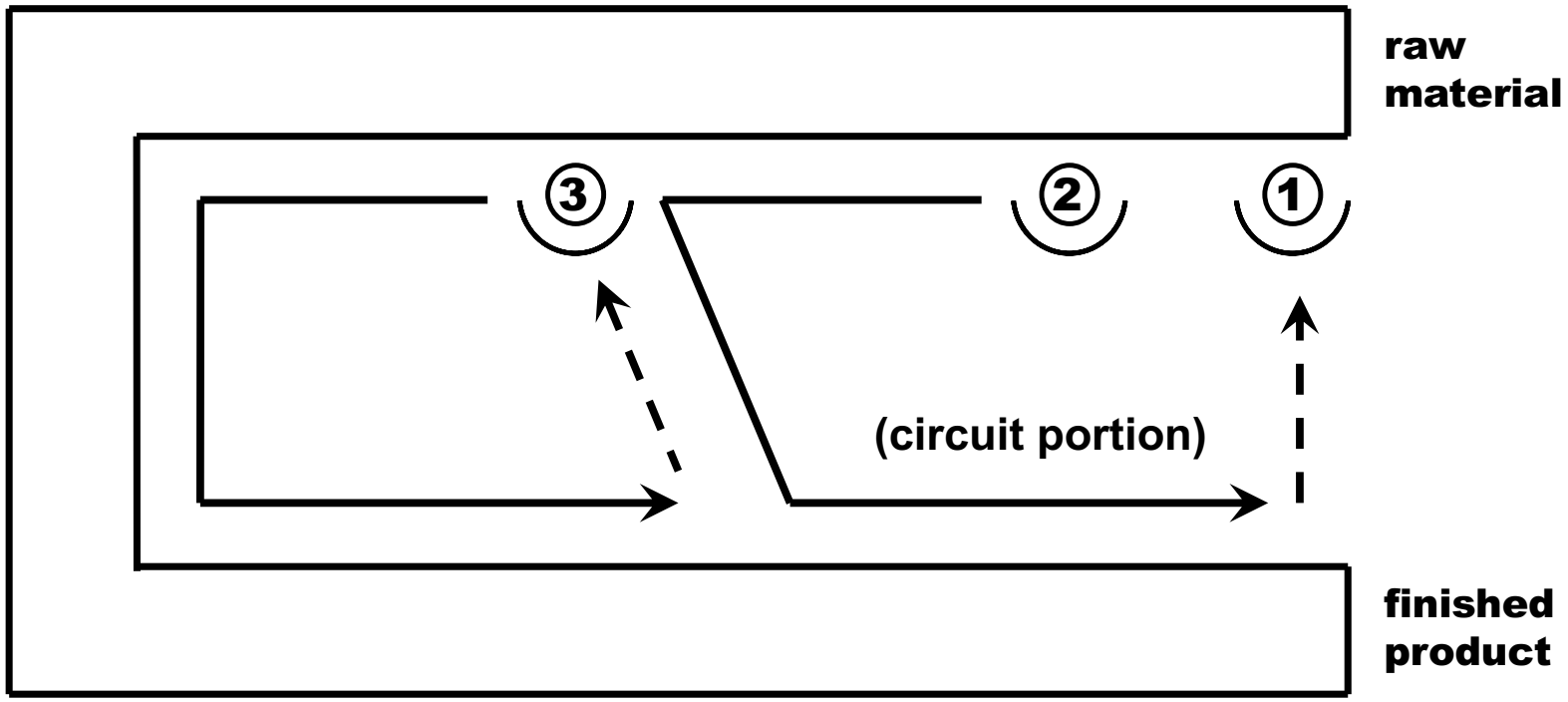
Each operator performs all the work elements.



- Generally limited to 1-2 operators
- Does not work if a single operations has more than 40% of TWC
- Require skilled operators

Work distribution among operators
Combination

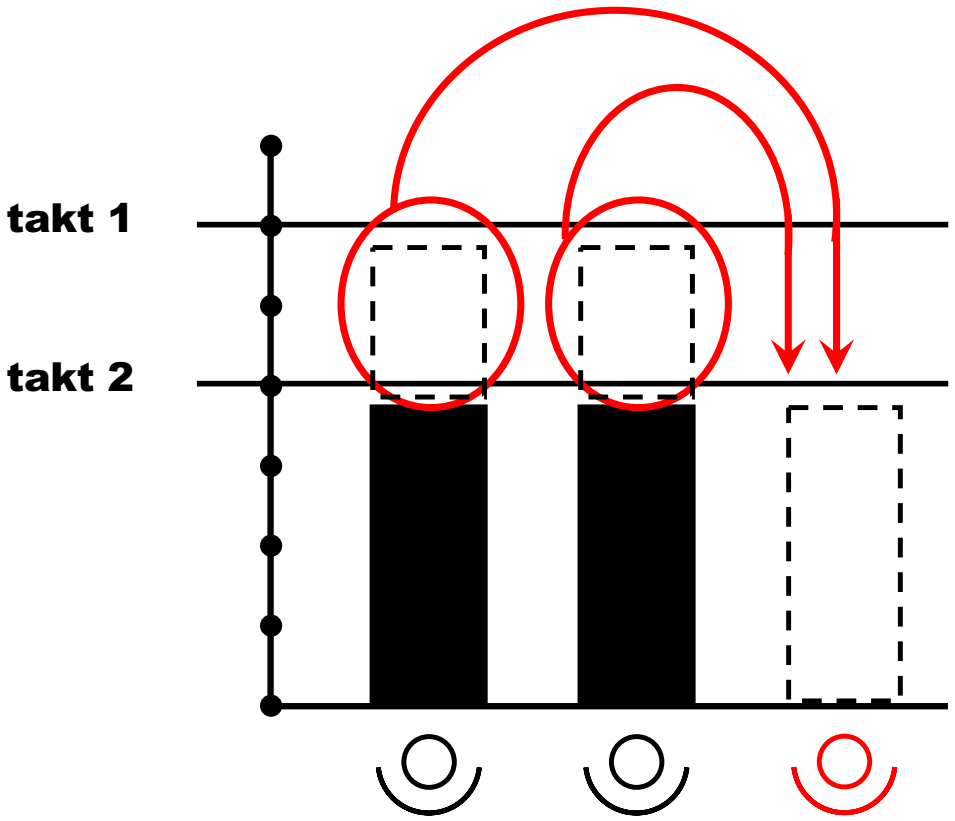
Combination work distribution



How will the pacemaker react to changes in customer demand?

When designing cells, engineers should prepare one-up and one-down scenarios for responding to volume changes

Responding to an increase in demand



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