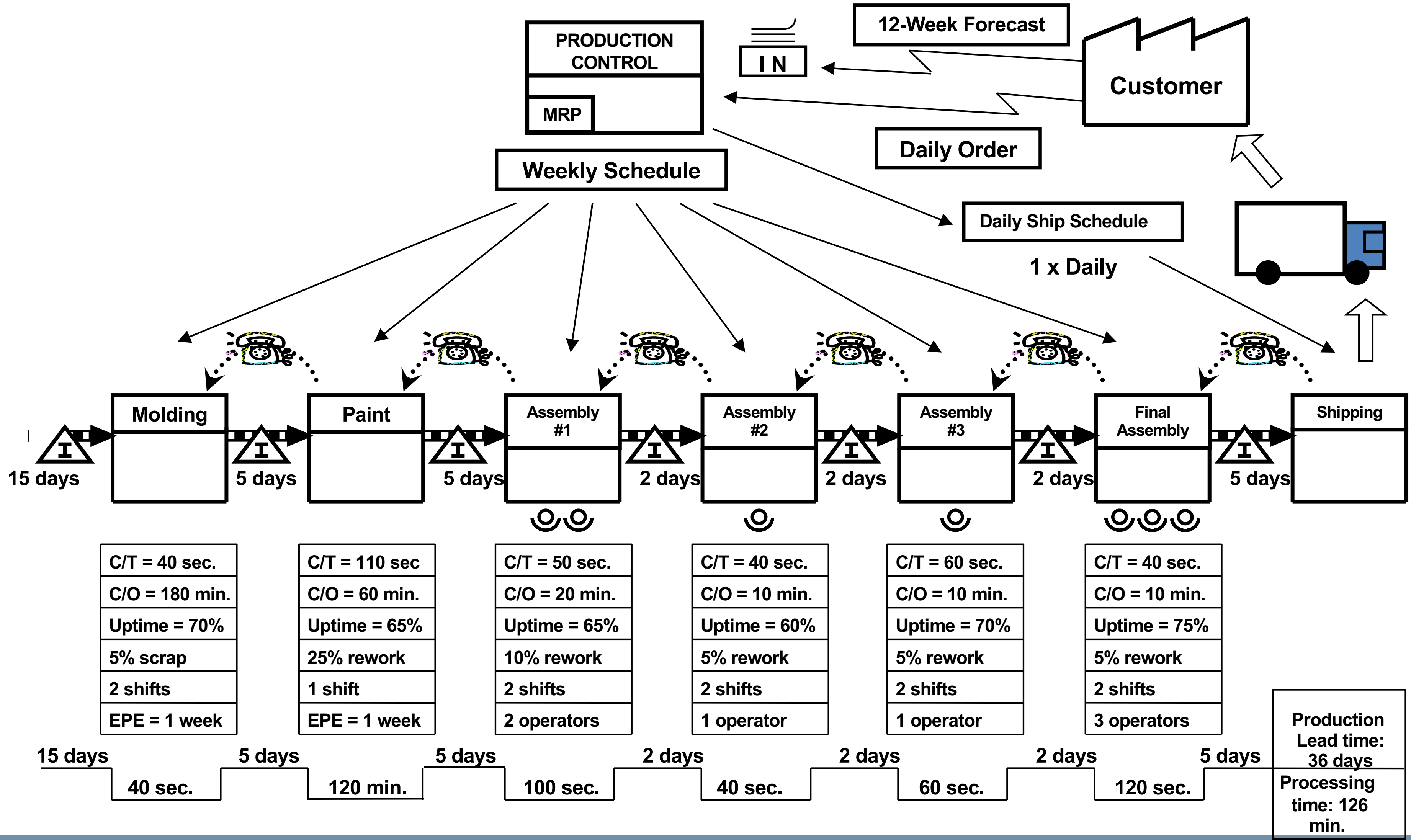
Level and Pull

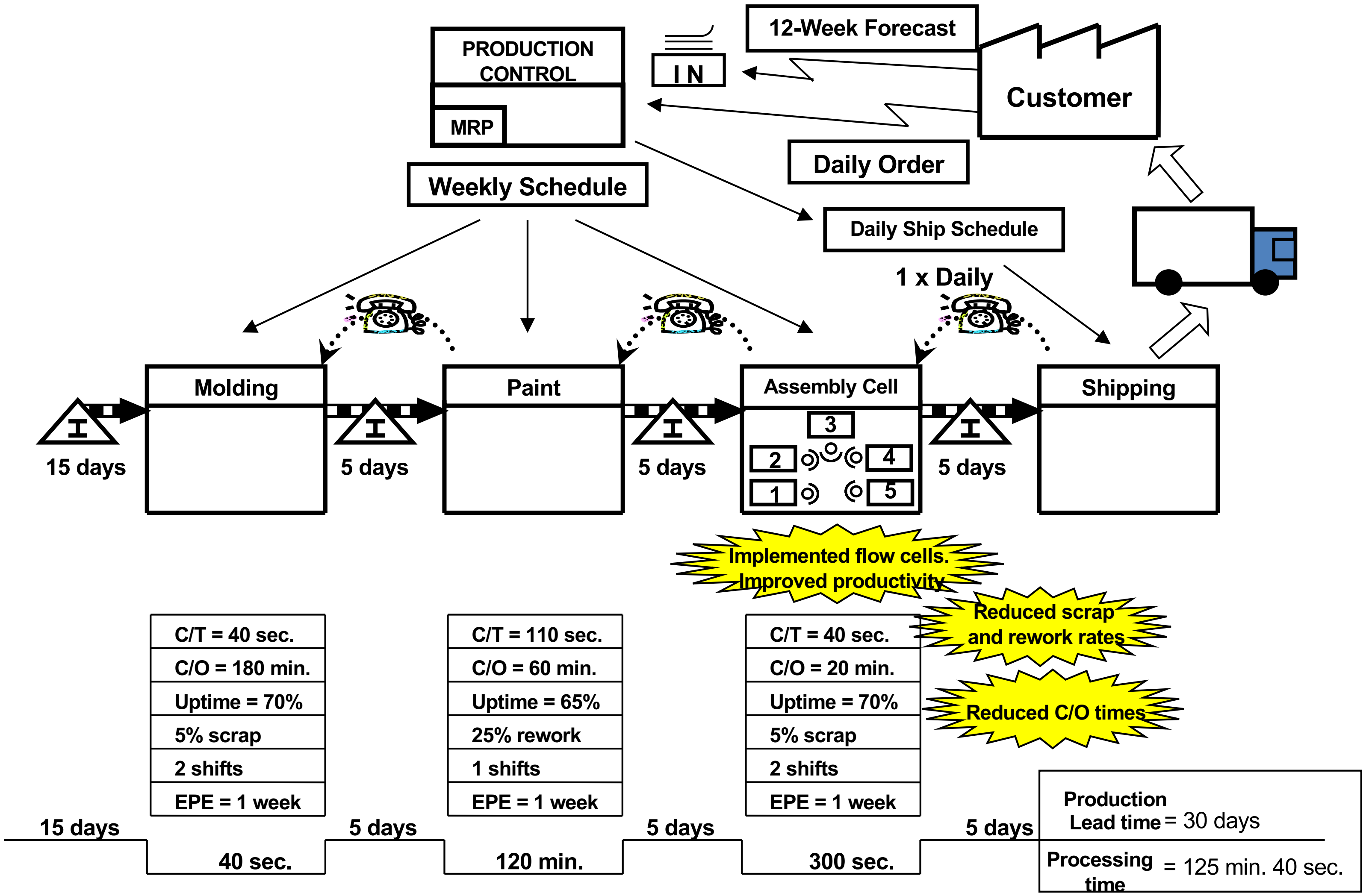
LEVEL AND PULL

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

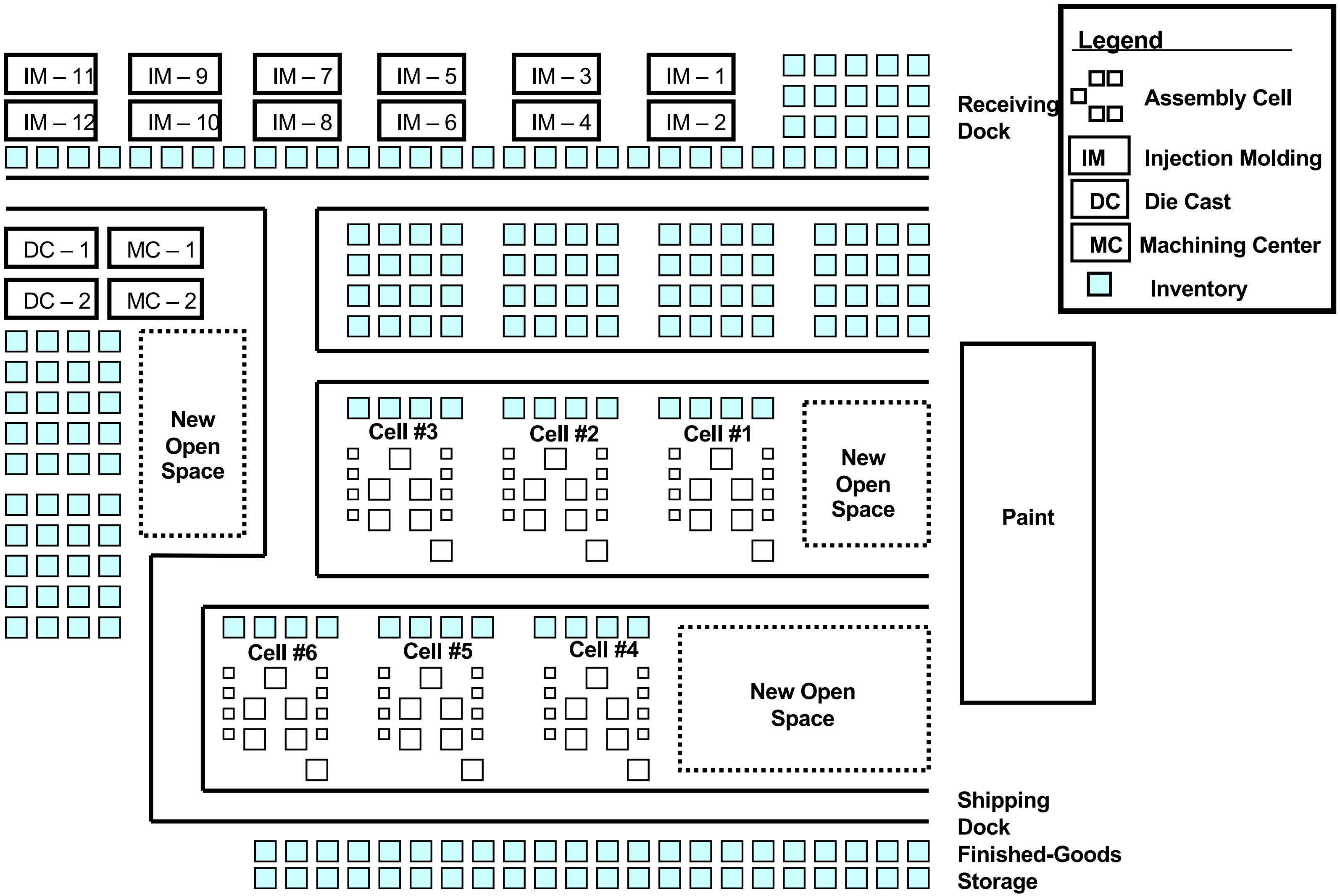
Original-State Value-Stream Map for Exterior Mirrors



Current-state Value-Stream Map for Exterior Mirrors



Apogee Overhead Layout



Box Score – Exterior-Mirror Value Stream*

	Original state	After basic stability	After cell flow kaizen	Current state
Productivity				
Direct labor (pieces per person per hr.)	9.0	10.0	11.5	**11.0**
Material handlers supporting value stream	3	3	3	**4**
Quality				
Scrap	5%	4%	3%	2%
Rework**	25%	20%	15%	15%
External (ppm)	500	250	125	105
Downtime* **				
Assembly (min. per shift)	40 min.	30 min.	10 min.	**20 min.**
Paint (min. per shift)	30 min.	20 min.	15 min.	15 min.
Molding (min. per shift)	50 min.	25 min.	25 min.	10 min.
Inventory turns				
Total	8	11	14	**12**
On-time delivery				
To assembly	65%	68%	80%	**75%**
To shipping	80%	92%	95%	**85%**
To customer	100%	100%	100%	100%
Door-to-door lead time				
Processing time (min.)	126.0	126.0	125.7	125.7
Production time (days)	36	34	28	**30**
Costs				
Overtime costs per week	$6,000	$5,000	$4,000	**$5,000**
Expedite costs per week	$2,000	$1,500	$1,500	**$2,000**

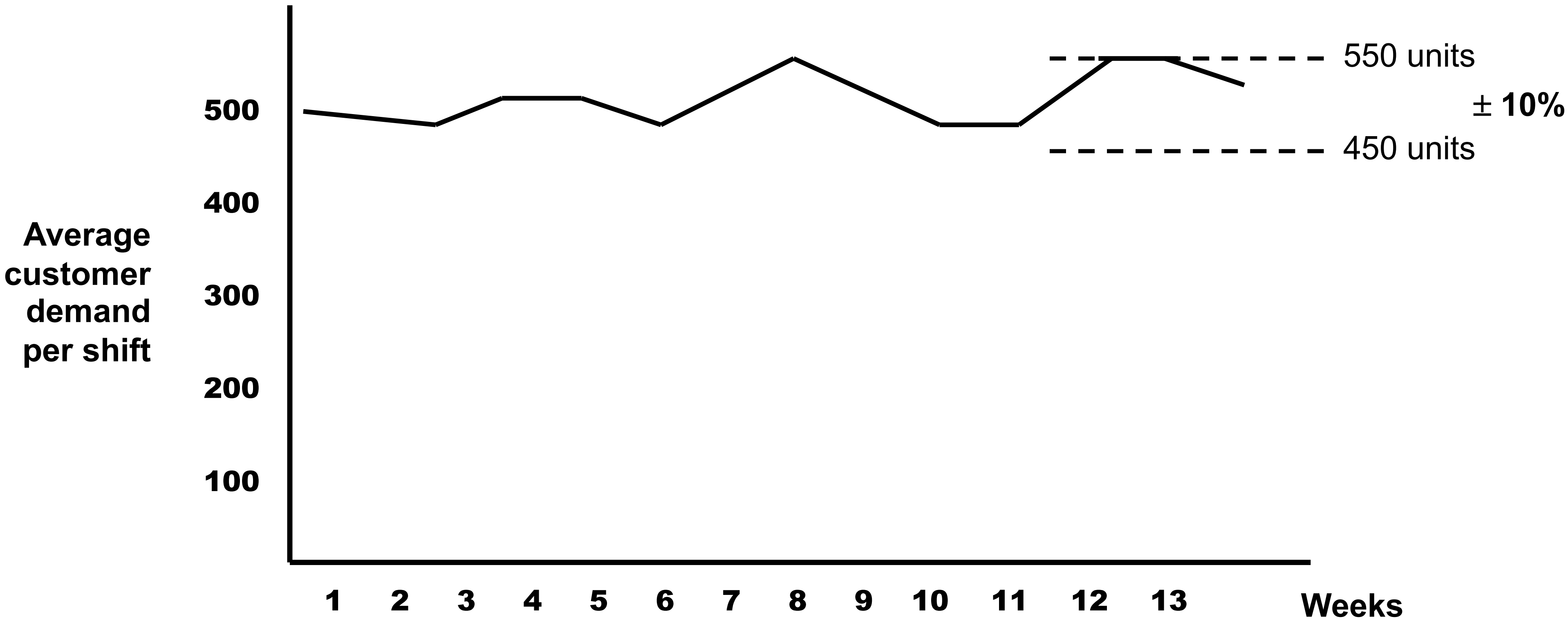
* No major change in demand or product mix over this time.

** Rework is due to persistent inclusion problems.

*** Downtime is separate from changeover time and reflects only lost time in production due to mechanical problems or material availability per shift.

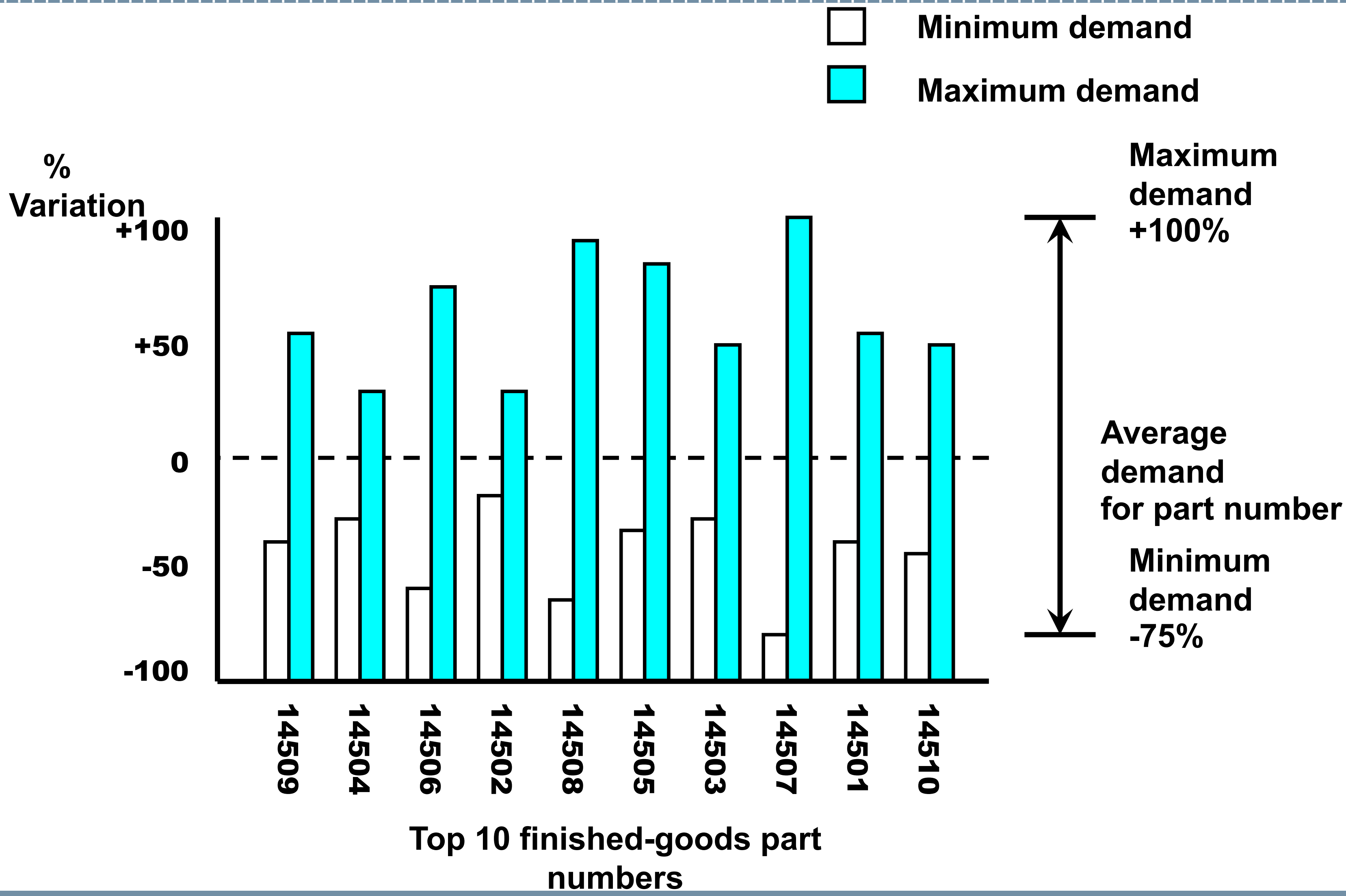
After initial improvements performance are now deteriorating

Apogee Demand Variation for Exterior Mirrors

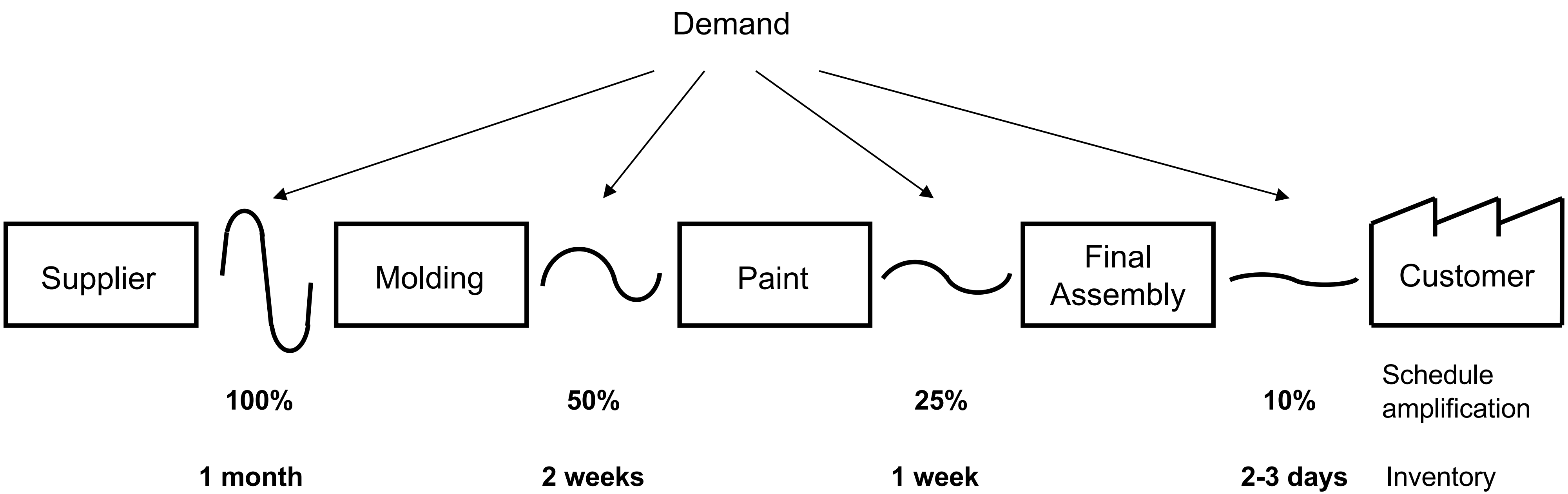


Overall demand variation is low

Apogee demand and mix variation



Moving upstream variations increase

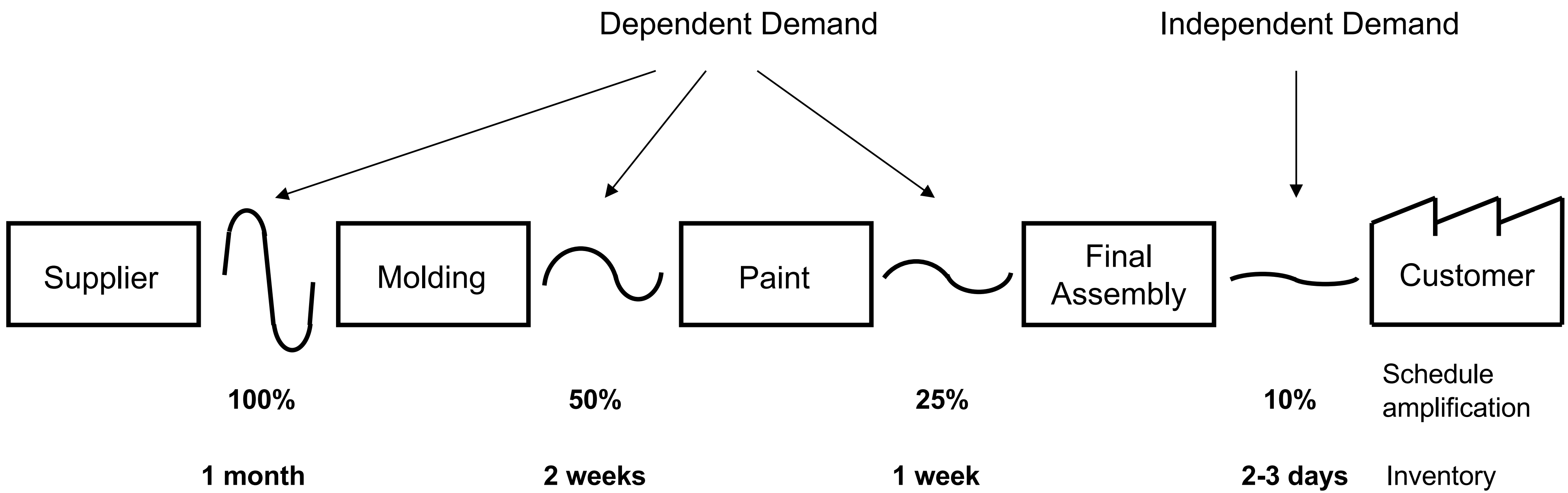


Demand transmission and amplification

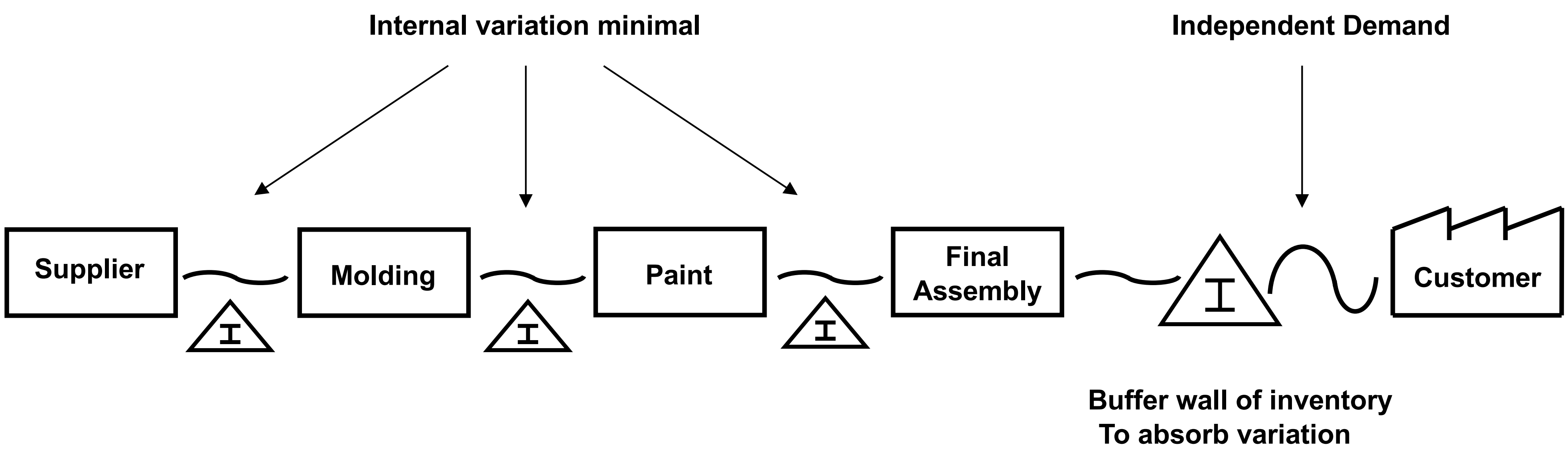
Forrester effect (Bullwhip effect)

- Lead time
- Batch size
- Unpredictability (Scrap, downtine, …)
- Wrong expectations, fears,…

Level and pull to smooth demand amplification



Level and pull to smooth demand amplification



We will address location and size of buffer stock between departments

Box score
All value stream

	Original state	Current state	Target state
Productivity			
Direct labor (pieces per person per hr.)	*7.8*	*10.2*	*12.5*
Material handlers per shift	*24*	*25*	*15*
Quality*			
Scrap	*5%*	*2%*	*<1%*
Rework	*25%*	*15%*	*<5%*
External (ppm)	*500*	*105*	*<50*
Downtime			
Assembly (min. per shift)	*40*	*30*	*<5*
Paint (min. per shift)	*30*	*15*	*<10*
Molding (min. per shift)	*20*	*20*	*<10*
Inventory turns			
Total	*8*	*10*	*30*
On-time delivery			
To assembly	*60%*	*75%*	*98%*
To shipping	*85%*	*85%*	*100%*
To customer	*100%*	*100%*	*100%*
Door-to-door lead time			
Processing time (min.)	*126.0*	*125.7*	*125.7*
Production time (days)	*36*	*30*	*12*
Costs			
Overtime costs per week	*$30,000*	*$25,000*	*$0*
Expedite costs per week	*$12,000*	*$9,000*	*$0*

* Quality issues will not be directly addressed in this implementation effort. These targets represent long-term goals for the value stream.

Start with a small pilot

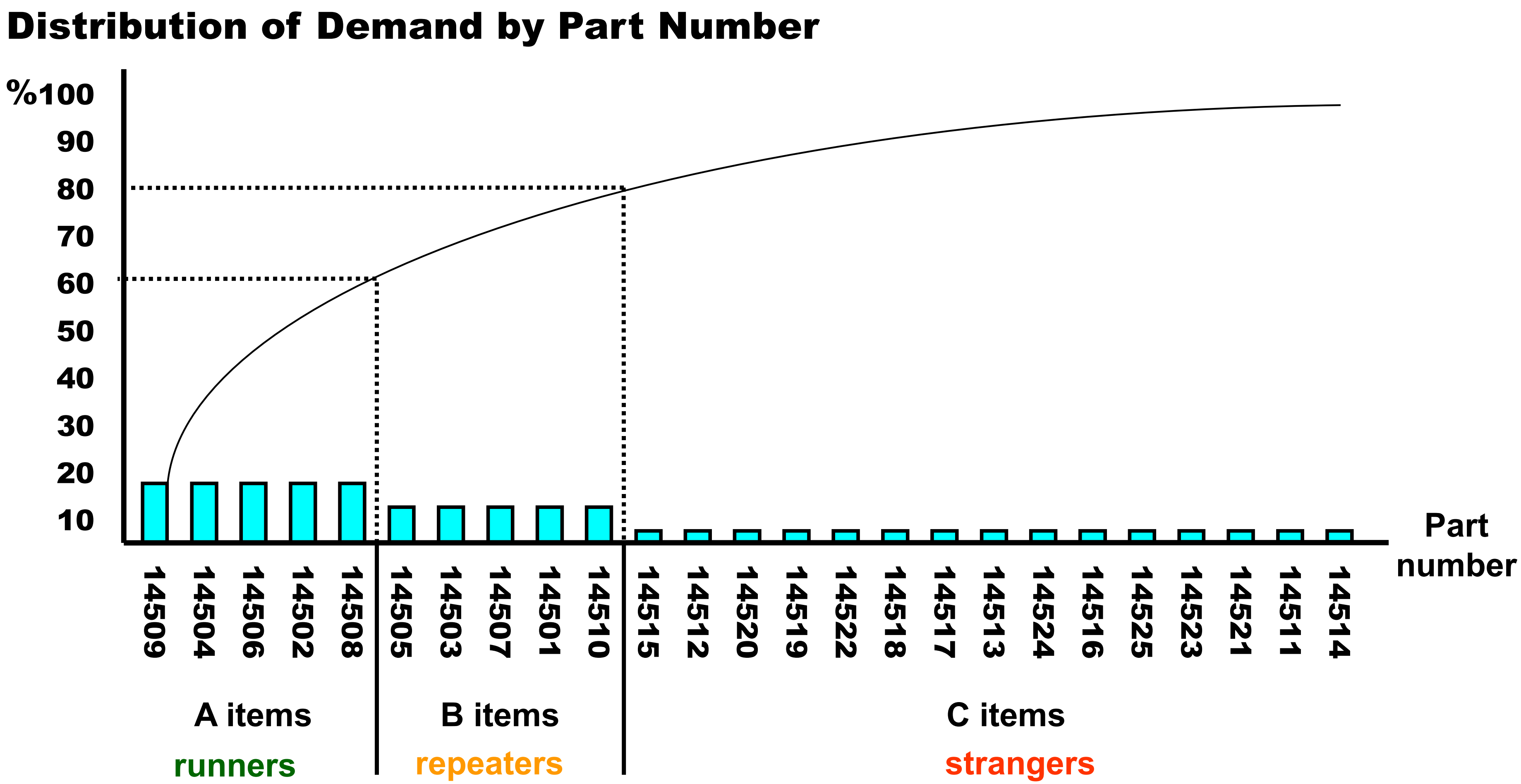
Matching capacity to demand

1. What production strategy for each product (MTS,ATO,MTO)?
2. How much inventory for each MTS product?
3. How should you organise and control the finished goods store?

1. What production strategy?

Apogee piled up finished goods stock for every product it could not deliver fast enough

1. What production strategy?



The bars in the diagram show the fraction of total demand accounted for by each part number. The curved line running from left to right stacks the orders to show the fraction of total demand accounted for by any given number of products.
For example, the first five part numbers account for 60% of total demand and the first 10 account for 80%.

- **Runners**: ordered every day, large overall quantities, small percentage variations in volume

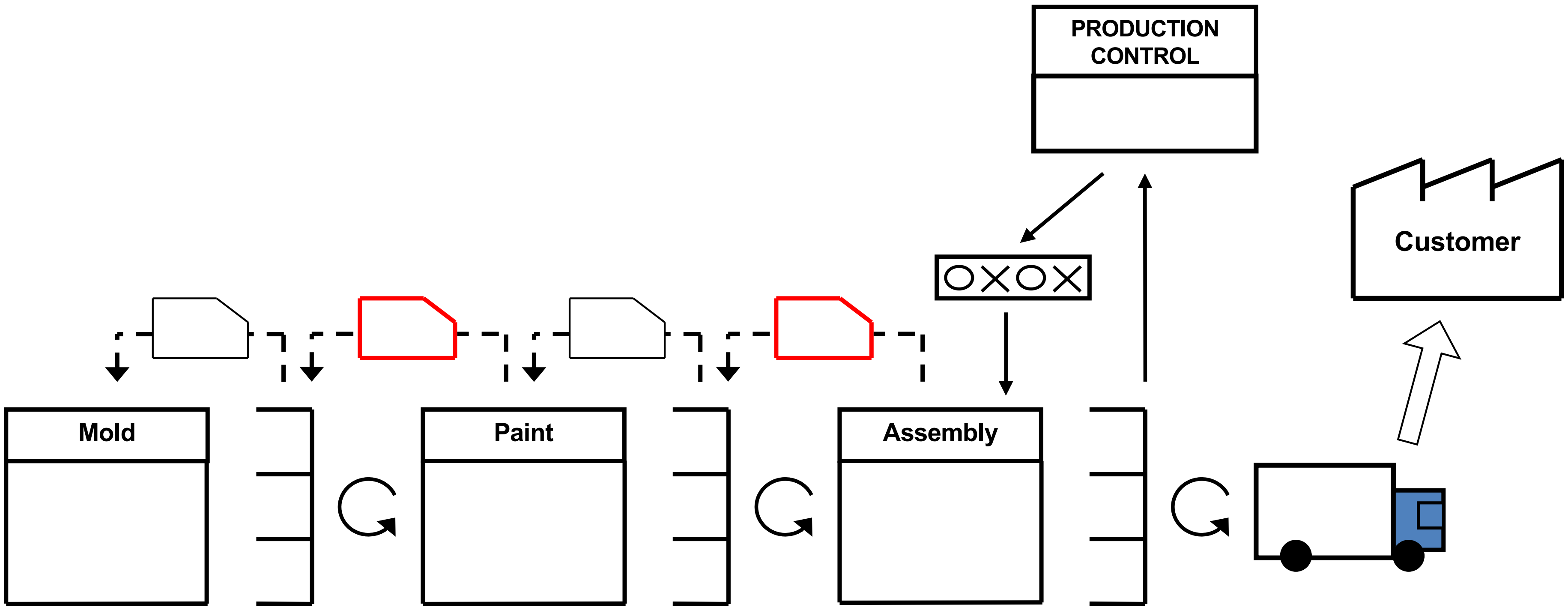
- **Repeaters**: ordered frequently (not every day), medium overall quantities

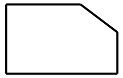
- **Strangers**: ordered from time to time, small overall quantities, very large percentage variation in volume

Options for finished goods vs Make to order

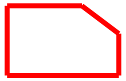
Options	Pros	Cons	Apogee situation	Apogee decision
1. Hold finished-goods inventory of all products (As, Bs, and Cs) and make all to stock–**replenishment pull system.**	Ready to ship all items on short notice	Requires inventory for each part number and much space	Finished-goods stores and shipping unable to hold all items	Not practical due to physical layout constraints and number of end items
2. Hold no finished-goods inventory and make all products to order–**sequential pull system.**	Less inventory and associated waste	Requires high process stability and short lead time to produce	Production lead time too long and paint process too unstable	Not pratical with current lead time and capability
3a. Hold only Cs in inventory and make A and B products to order daily–**mixed pull system.**	Less inventory	Requires mixed production control and daily stability	Daily stability a concern	Possible second step for future
3b. Hold A and B products in finished-goods inventory. Make Cs to order from semifinished components–**mixed pull system.**	Moderate inventory	Requires mixed production control and visibility on C items	Most applicable to current situation	Best fit for today

Replenishment pull system



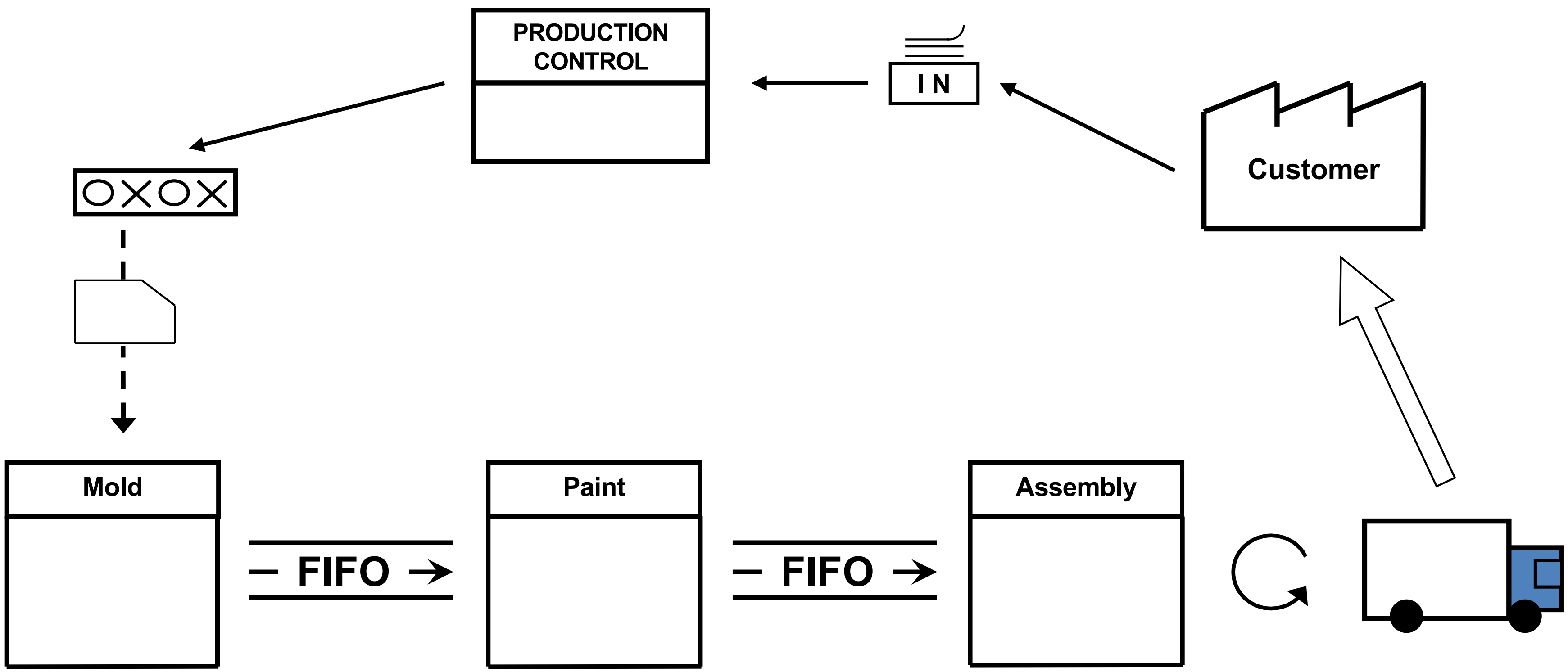


Production instruction kanban

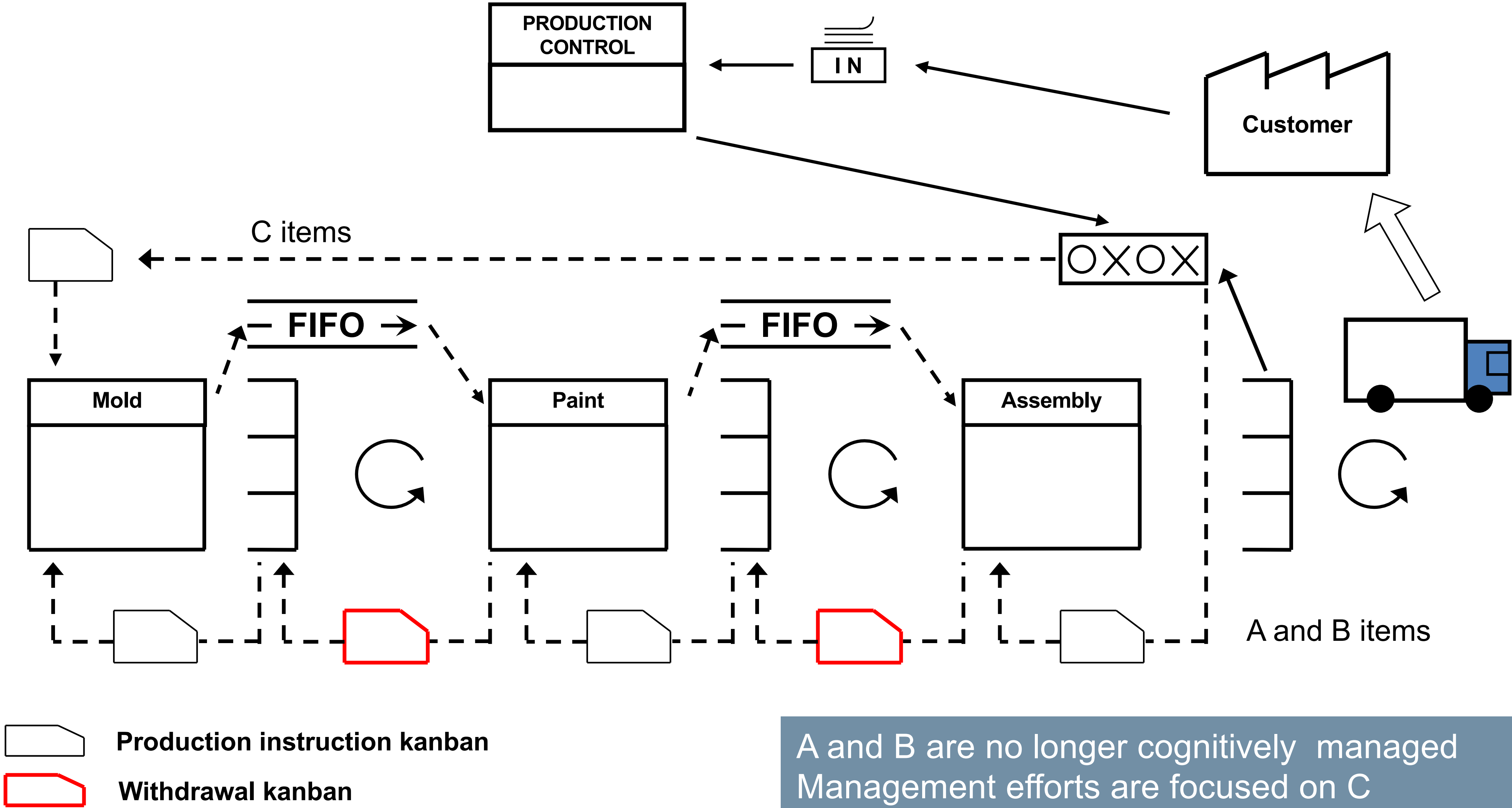


Withdrawal kanban

Sequential pull system

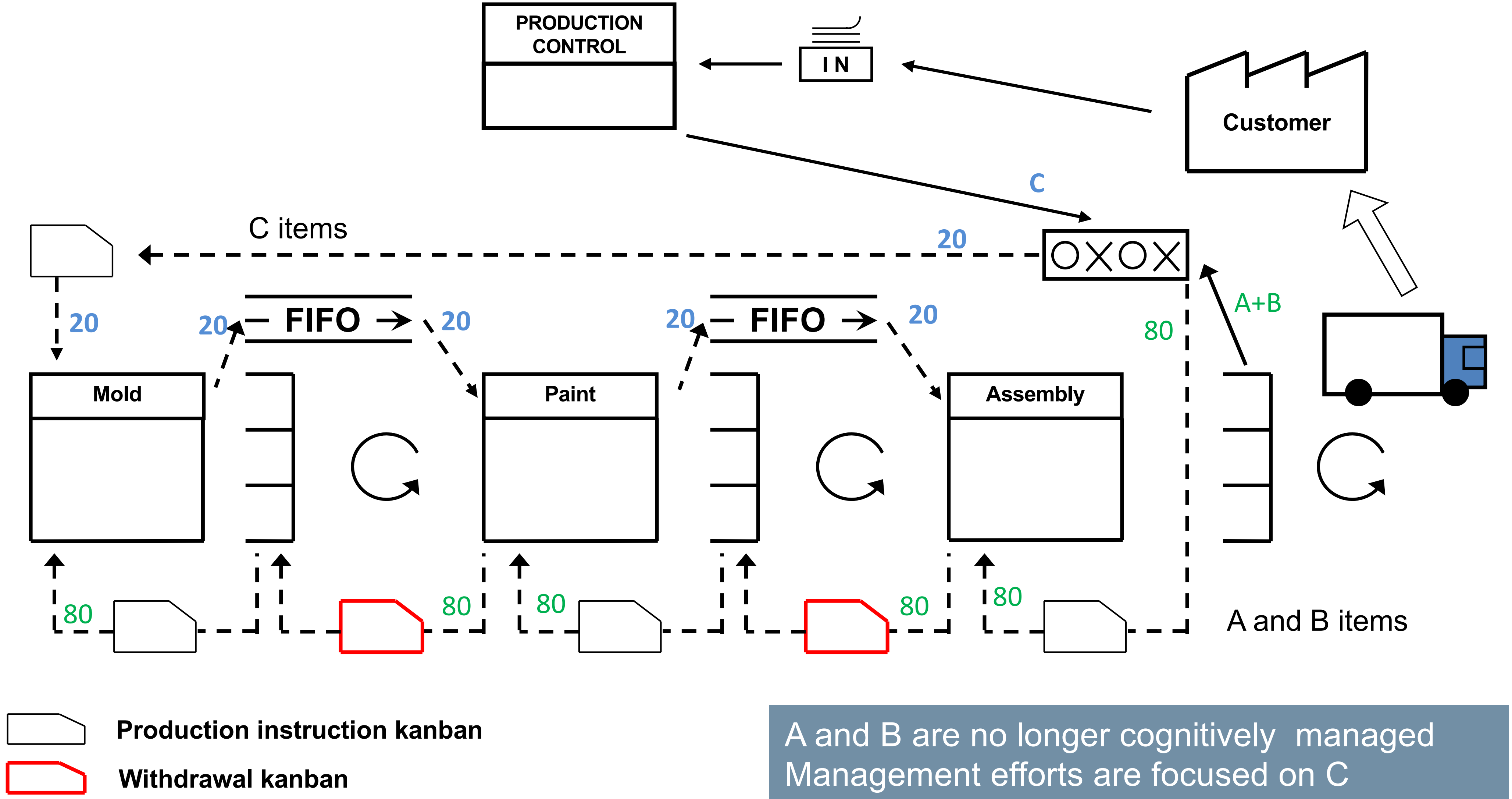


Mixed pull system



A and B are no longer cognitively managed
Management efforts are focused on C

Mixed pull system



A and B are no longer cognitively managed
Management efforts are focused on C

2. How much inventory?

Finished-Goods Calculation

	Average daily demand x Lead time to replenish (days)	**Cycle stock**
+	Demand variation as % of Cycle stock	**Buffer stock**
+	Safety factor as % of (Cycle stock + Buffer stock)	**Safety stock**
=		**Finished-goods inventory**

2. How much inventory?

Finished-Goods Calculation for Part #14509

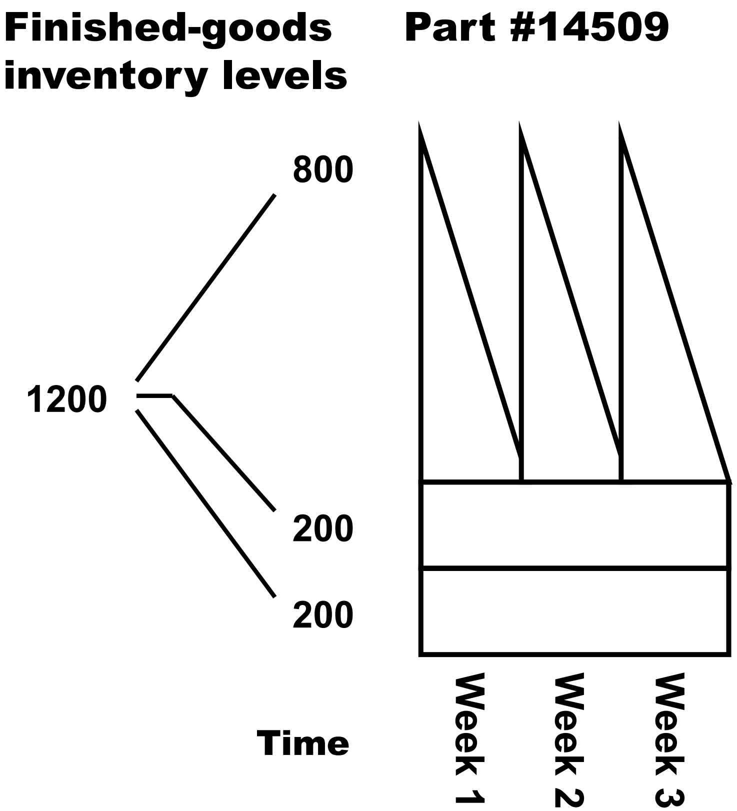
	160 x 5*	**Cycle stock**	**800**
+	25%** of 800	**Buffer stock**	**200**
+	20%*** of (800 + 200)	**Safety stock**	**200**
=		**Finished-goods inventory**	**1,200**

* Production Control schedules production of this part number once a week and average daily demand is 160.

** Reflects two standard deviations of demand and thus approximately 95% of normal order variation. If necessary, more standard deviations can be taken to cover a higher level of variation.

*** Reflects the worst-case example of scrap, rework, and typical downtime amounts at Apogee.

Finished-goods inventory example



Cycle* stock
Amount required to cover normal demand

Buffer stock
Amount required to cover customer-induced variation

Safety stock
Amount required to cover internal losses

Key drivers

- Average demand
- Lead time to replenish
- Demand volatility
- Forecast/MRP errors
- Downtime losses
- Quality losses

Statistical analysis

Worst Case

* Assumes an average customer demand and draw down during each of the three weeks. Greater than average demand or production shortfalls
due to quality problems and equipment downtime will require Apogee to consume some buffer and/or safety stock.

2. How much inventory?

Finished-Goods Calculation for Part #14509

	160 x 5*	**Cycle stock**	**800**
+	25%** of 800	**Buffer stock**	**200**
+	20%*** of (800 + 200)	**Safety stock**	**200**
=		**Finished-goods inventory**	**1,200**

* Production Control schedules production of this part number once a week and average daily demand is 160.

** Reflects two standard deviations of demand and thus approximately 95% of normal order variation. If necessary, more standard deviations can be taken to cover a higher level of variation.

*** Reflects the worst-case example of scrap, rework, and typical downtime amounts at Apogee.

What is the average inventory level?
What is maximum and average stock level if replenishment is done every 2.5 days?

3. How will you organise and control finished goods store?

Apogee created:

- dedicated locations per part number
- easy to reach locations for heavy items
- near begin of aisle for high volume demand
- stock control rule:
  - Buffer stock can be used only with Production Control Dep. authorisation
  - Operations and PCD review together the Buffer stock usage to identify fundamental changes
  - Safety stock can be used only with Plant Manager authorisation

Tracking Spreadsheet for Exterior-Mirror Finished-Goods Inventory

Finished-goods inventory				
Part #	**Safety** maximum/actual*	**Buffer** maximum/actual*	**Cycle** maximum/actual*	*Tues. 3:05 p.m.*
A items				
14509	**200/200**	**200/200**	**800/900**	***Over by 100***
14504	**175/175**	**175/175**	**700/600**	*OK*
14506	**150/150**	**150/150**	**600/450**	*OK*
14502	**125/125**	**125/125**	**600/300**	*OK*
14508	**100/100**	**100/105**	**600/0**	***Into buffer stock***
B items				
14505	**100/100**	**100/100**	**300/100**	*OK*
14503	**100/100**	**100/100**	**200/50**	*OK*
14507	**100/100**	**100/100**	**200/50**	*OK*
14501	**100/100**	**100/100**	**200/100**	*OK*
14510	**100/100**	**100/100**	**100/0**	***Out of cycle stock***
C items**				

* The actual amount is recorded at 3 p.m. each day after the first-shift production.

** C items are built to order and not held in finished-goods inventory. Under the current temporary plan, C items are blended into production between runs of the A and B items, using overtime when necessary.

Matching Production System Capability to Demand
Key to success

•Always go to the Gemba

•Determine whether your production system is stable enough to work around internal delays by buffering

•Segment your demand by A, B, C and define what type of pull system to adopt

•Carefully calculate the amount of Cycle, Buffer and Safety stock to satisfy customers and minimise expedite, overtime etc.

•Practice good workplace organisation and visual control in the finished goods store and shipping area

•Strive to make the status of finished goods / system clear: Normal Vs Abnormal

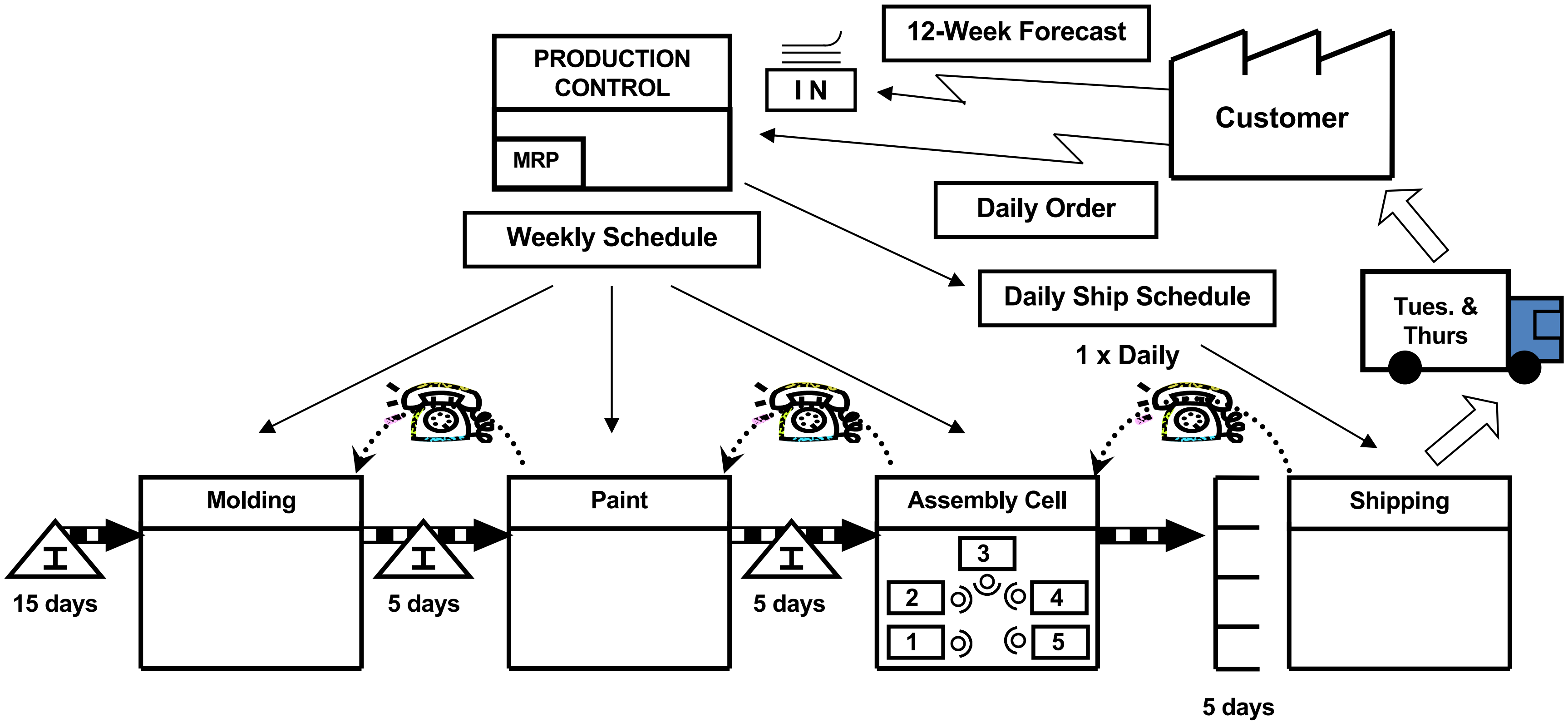
Creating the pacemaker

4. Where will you schedule the value stream?

5. How will you level production at the pacemaker?

6. How will you convey demand to the pacemaker to create pull?

Left-Hand exterior-mirror value stream



- Multi scheduling points
- Unreliable forecasts
- Long lead time
- Large batch size
- Department centric metric

4. Guidelines for selecting the pacemaker

- In **replenishment pull**, the pacemaker will be the final assembly in virtually every case.

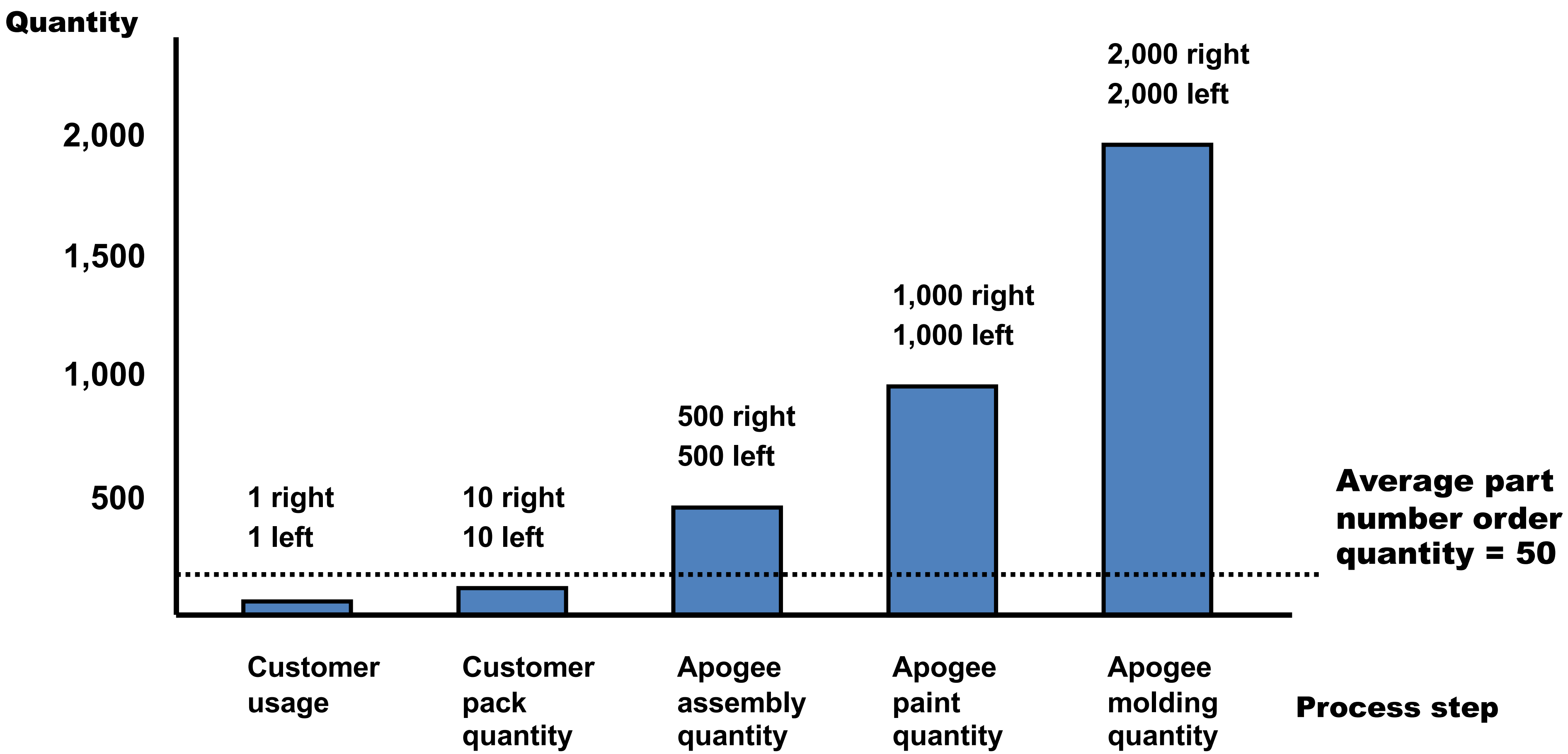
- In **sequential pull**, the pacemaker often is the first process at the beginning of the value stream. It can be located further downstream, just before inventory types proliferate (product design gives a fundamental contribution)

5. How will you level production at the pacemaker?

Apogee Orders vs. Apogee Build Schedule

			Customer requirements	Final-assembly build schedule (left-hand cell)	
Part #	Demand category	Mirror description	Monday orders	Monday 1st shift	Monday 2nd shift
14509	A	Black heated	140	500	0
14504	A	Black unheated	110	0	500
14506	A	White heated	120	0	0
14502	A	White unheated	120	0	0
14508	A	Red heated	110	0	0
14505	B	Silver heated	70	0	0
14503	B	Yellow heated	60	0	0
14507	B	Bronze heated	70	0	0
14511	C	Purple unheated	100	0	0
14512	C	Gold unheated	100	0	0
		Total	1,000	500	500

Sample Lot Size Comparisons across the Extended Value Stream



Different perspective

Production change-over is a productivity loss

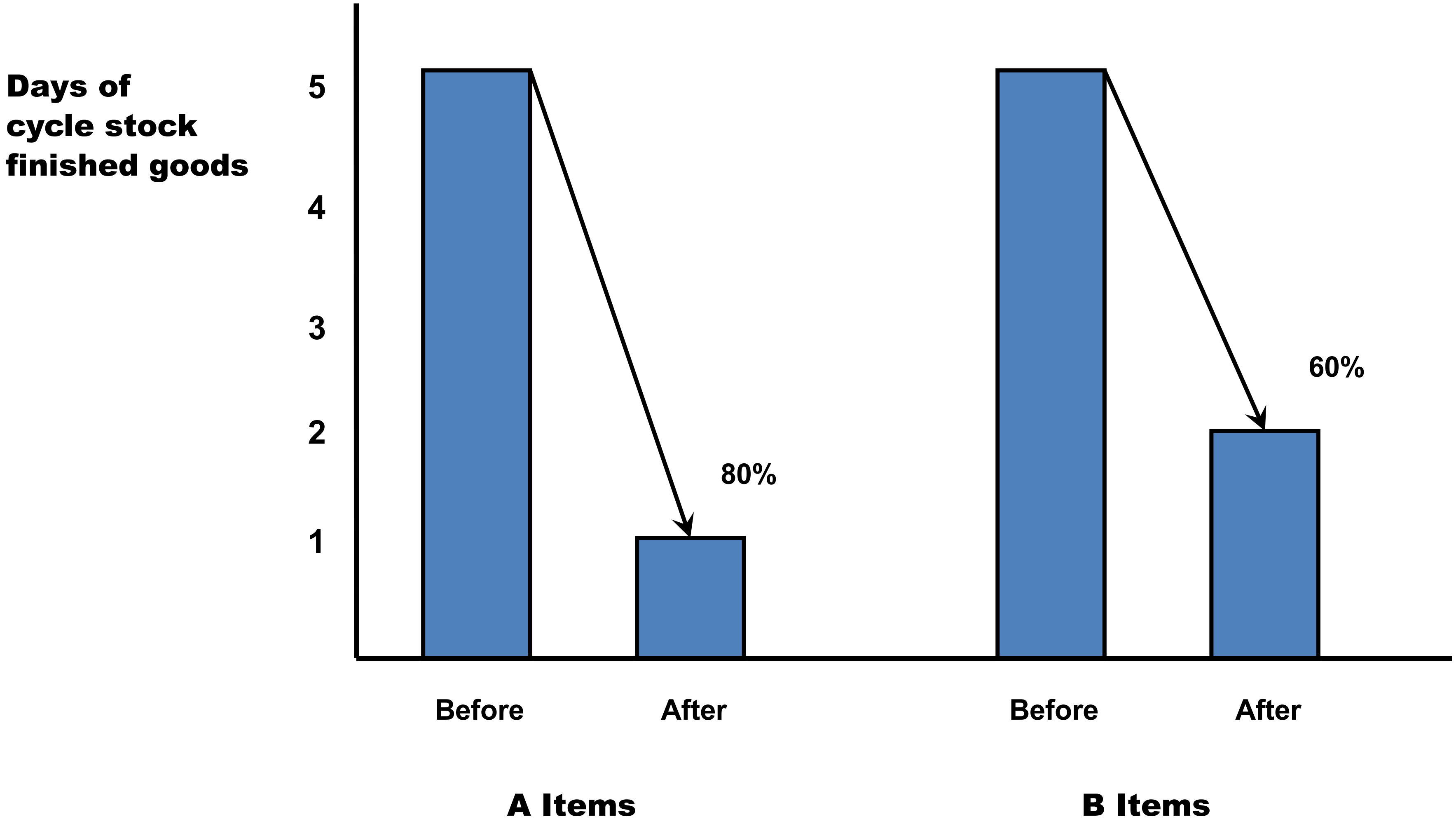
Increase batch size to minimize loss

Decrease production Change-over time to minimise fluctuation

Increase losses in **other** departments

Minimise **overall** losses

Shorter lead times reduce finished-goods inventory



Batch size minimization at pacemaker

Batch sizes should be **minimised** subject to the following constraints:

- Work content differences between products (Best if all items are below TT)
- Changeover requirements between part numbers (Effective cycle time)
- Production pitch interval (Typically TT * Pack size, but consider also material handling effort and need of control)

Production Pitch Calculation

Takt time	x	Pack quantity	=	Pitch
54 sec.	x	10 pieces	=	540 sec. (9 min.)

Pitch Interval Calculation

Time available	/	Pitch	=	Intervals
450 min.	/	9 min.	=	50 intervals

Time Intervals per A, B, and C items

Total interval	x	% of production mix	=	Intervals per item	(equivalent time)
50 intervals	x	60%	=	30 reserved for As	(9 min. x 30 = 270 min.)
50 intervals	x	20%	=	10 reserved for Bs	(9 min. x 10 = 90 min.)
50 intervals	x	20%	=	10 reserved for Cs	(9 min. x 10 = 90 min.)

After setting pich intervals, define which item

A: 30 intervals (300 pieces) / 5 items = 60 pcs

B: 10 intervals (100 pieces) / 5 items = 20 pcs

(much smaller than now. B not ordered every day => 50 pcs)

C: 10 intervals (100 pieces) => do order size if smaller

Planning Production by Product Type and Part Number

	A items **270 total min.** 30 time intervals					B items **90 total min.** 10 intervals		C items **90 total min.** 10 intervals
Shift 1	6 #14509	6 #14502	6 #14504	6 #14506	6 #14508	5 #14501	5 #14510	To be determined
Shift 2	6 #14509	6 #14502	6 #14504	6 #14506	6 #14508	5 #14507	5 #14503	To be determined
Shift 1	6 #14509	6 #14502	6 #14504	6 #14506	6 #14508	5 #14505	5 #14501	To be determined
Shift 2	6 #14509	6 #14502	6 #14504	6 #14506	6 #14508	5 #14510	5 #14507	To be determined
Shift 1	6 #14509	6 #14502	6 #14504	6 #14506	6 #14508	5 #14503	5 #14505	To be determined
Etc.								
Average shift demand Total finished-goods types	**300 units** **5 A items**					**100 units** **5 B items**		**100 units** **15 C items**

6. How will you convey demand to the pacemaker to create pull?

What kanban?

In what sequence?

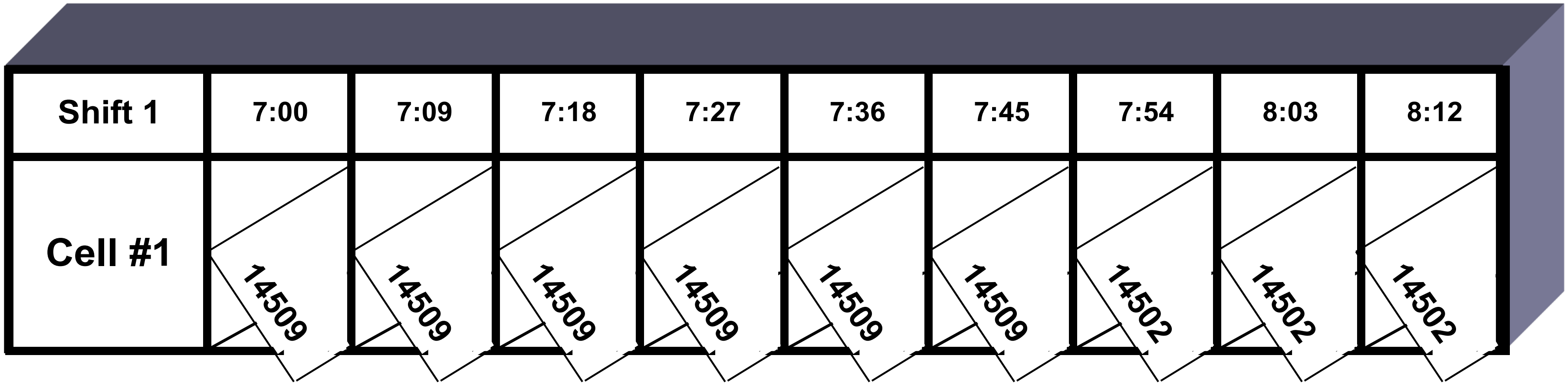
Types of kanban

- Kanban
  - Production instruction
    - In-process kanban for scheduling flow processes
    - Signal kanban for scheduling batch processes
  - Parts withdrawal
    - Interprocess kanban for internal purposes
    - Supplier kanban for external purposes

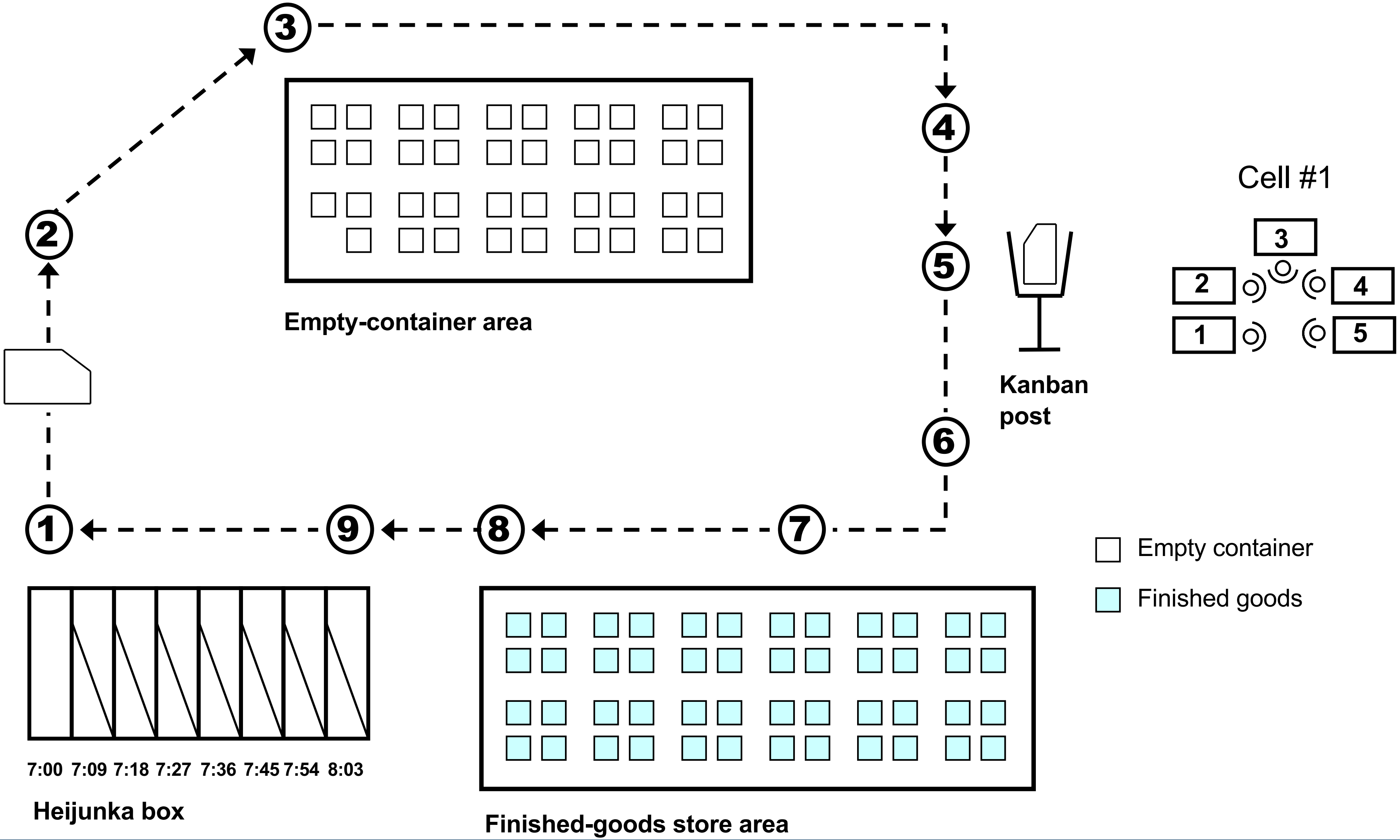
Example of In-Process Instruction Kanban

Finished-goods storage information	Product information area	Production area
Finished-goods market	**Part #:** **14509**	**Line address:** Assembly Cell # 1
Supplier: Internal	**Part description:** LH Exterior Mirror Heated Black	**Location:** Final Assembly Department
Market location: A4 R2	**Quantity:** 10	

Heijunka Box – Nine Minute Interval



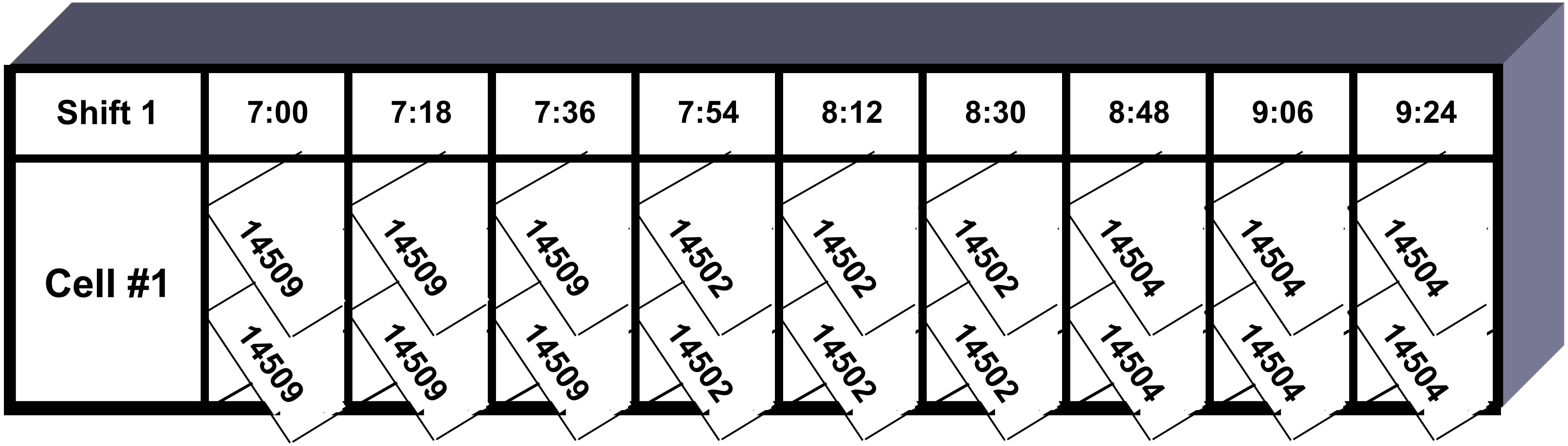
Conveyance route for information and materials



Apogee Conveyance Route Activity List

Step	Activity	Time
1.	Pick up instruction kanban from the heijunka box.	*10 sec.*
2.	Travel to obtain empty finished-goods container.	*1 min.*
3.	Obtain empty finished-goods container for delivery to the assembly cell.	*30 sec.*
4.	Travel time to the assembly cell.	*30 sec.*
5.	Drop off an instruction kanban and an empty finished-goods. container at the cell, pick up finished goods from the previous cycle.	*1 min.*
6.	Travel time to the finished-goods market.	*1 min.*
7.	Drop off finished goods to their correct storage location.	*30 sec.*
8.	Log product into finished-goods inventory (e.g., scan bar code).	*1 min.*
9.	Return to heijunka box for next instruction.	*30 sec.*
	Total time	*6 min. 10 sec.*

Heijunka Box – 18 Minute Interval



9 minutes pitch was too fast at present level of stability (could not recover from any problem) => 18

But this gives a cycle of 6 min work every 18 min => inefficiency

Heijunka Box – Exterior mirror cells

Shift 1	7:00	7:18	7:36	7:54	8:12	8:30	8:48	9:06	9:24
Cell #1	14509 14509	14509 14509	14509 14509	14502 14502	14502 14502	14502 14502	14504 14504	14504 14504	14504 14504
Cell #2	24509 24509	24509 24509	24509 24509	24502 24502	24502 24502	24502 24502	24504 24504	24504 24504	24504 24504

Purpose of pitch and conveyance withdrawal cycle:

- create a strong sens of pace (the smaller the pitch the better)
- create a tool to see if production is maintaining the scheduled amount througout the shift

Creating the pacemaker
Key to success

- Use the guidelines provided to select the best location for your pacemaker
- Do not unplug the entire scheduling system immediately
- Set final assembly lot size (considering mentioned constraints). Best if it is close to average customer order size
- To help pace assembly cell to customer demand link the pitch interval for instruction to the cycle of conveyance operations
- Select a pitch size for the pacemaker which is close to your capability to react to problems in operations
- Create standardized work for conveyance of information and materials based on the pitch cycle

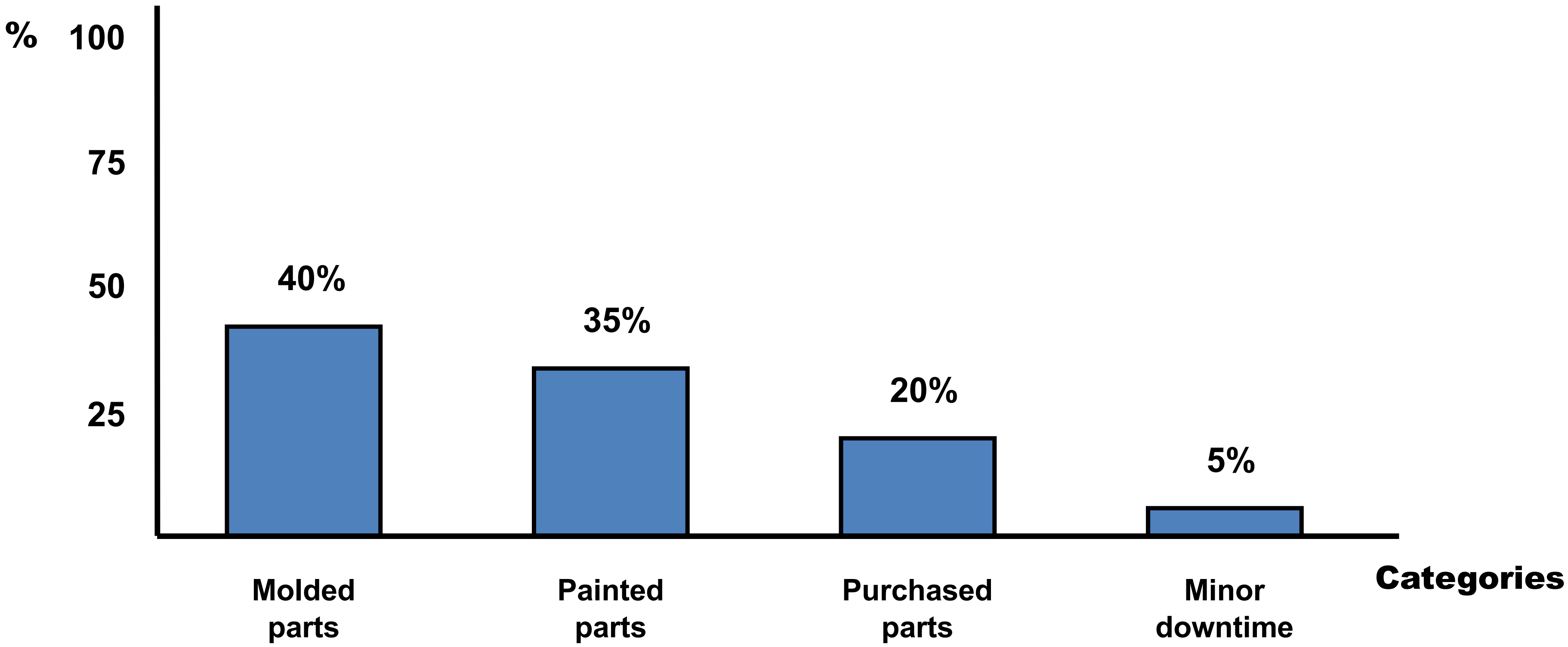
Controlling production upstream

7. How will you manage information and materials flow upstream from the pacemaker?

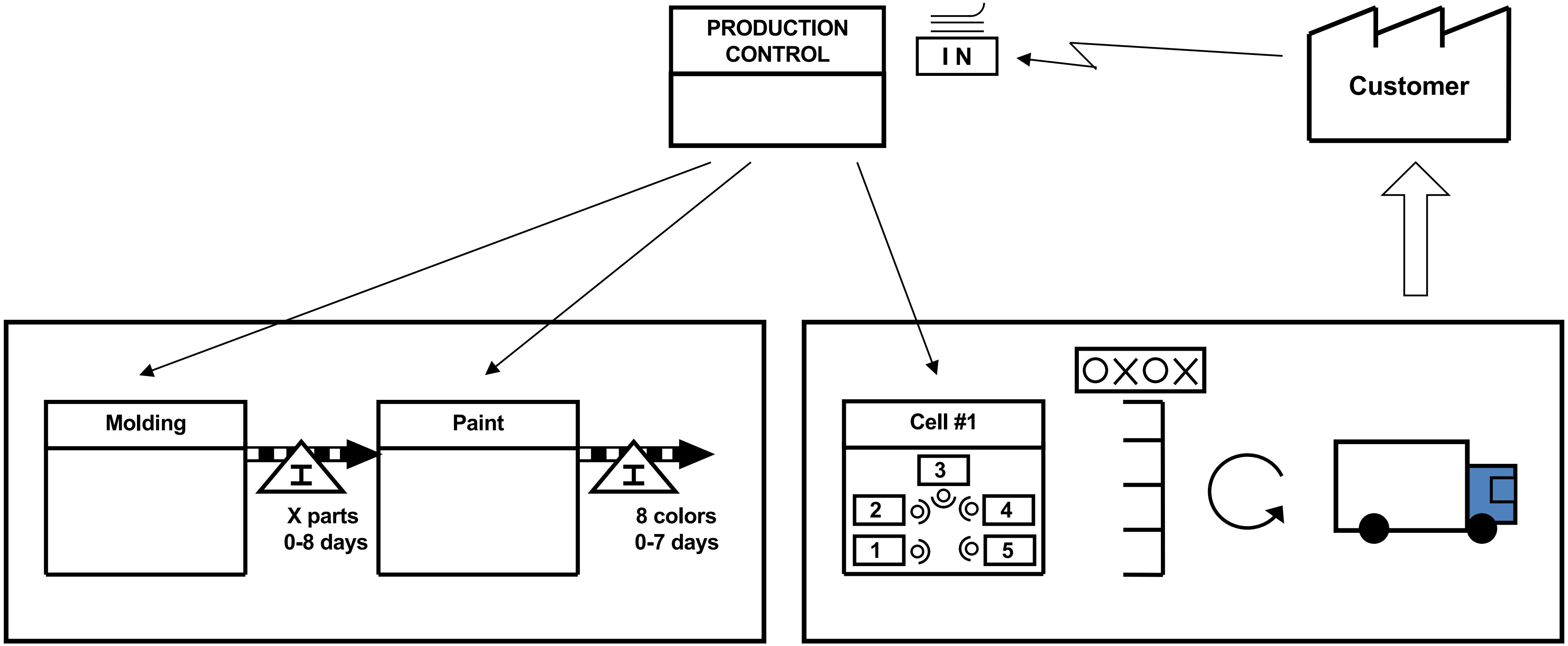
8. How will you size the markets and trigger withdrawal kanban?

9. How will you control batch processes upstream from the market?

Assembly delays



Apogee's Push/Pull Conflict



Push **Pull**

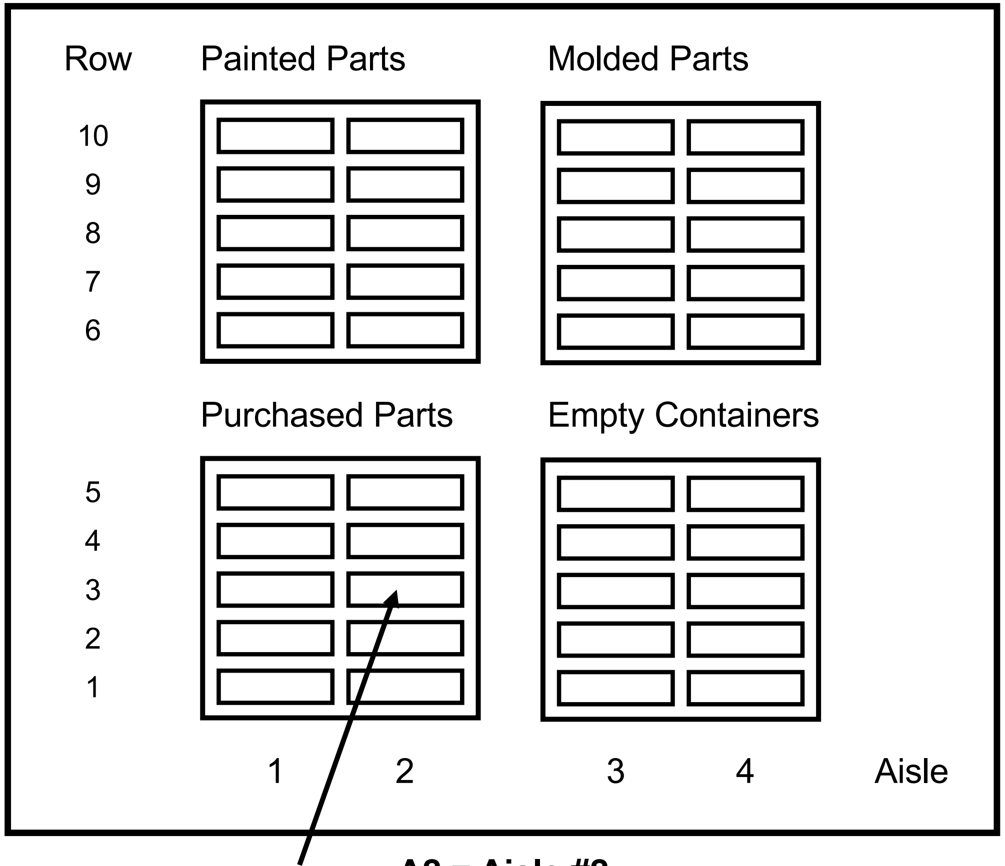
Exterior-mirror process review

Process	Supplier exterior-mirror value stream?	Batch process with changeovers?	Long distance to next area?	Different shift pattern?
Paint	Yes	Yes	No	Yes
Molding	Yes	Yes	No	No
Purchased parts	Yes	No	Yes	No

A formal market mechanism is needed for upstream processes with different operating patterns (PFEP, locations, etc.)

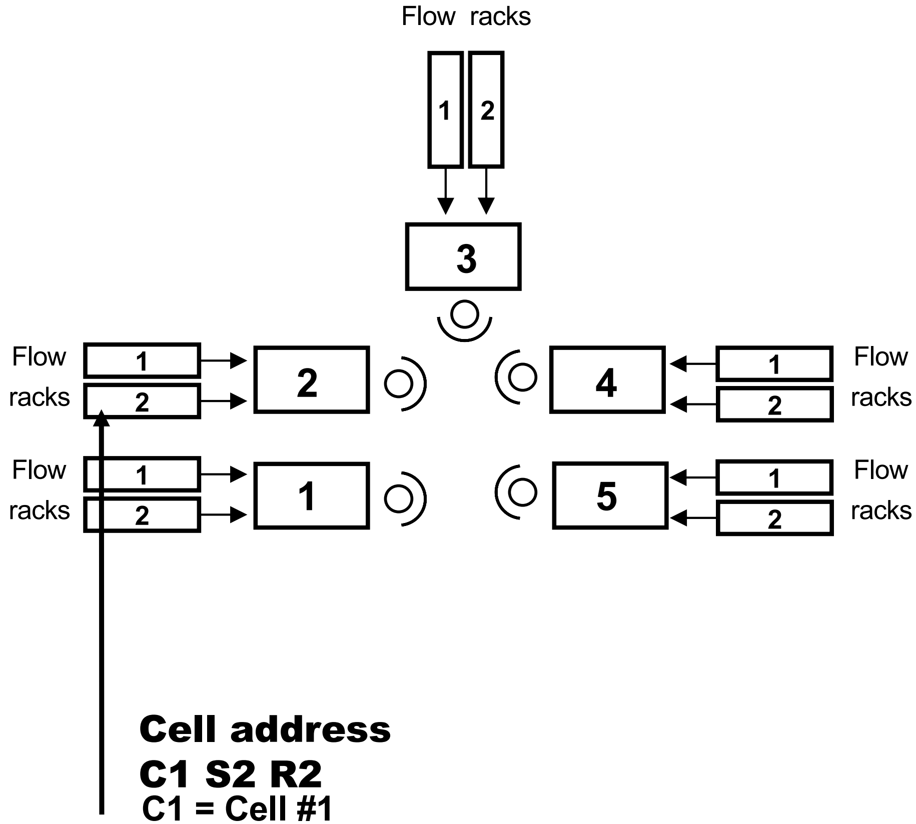
Markets and Point-of-Use Addressing

Central Market Area | **Assembly Cell**



Market address
A2 R3 S1

A2 = Aisle #2
R3 = Row #3
S1 = Shelf #1



Cell address
C1 S2 R2
C1 = Cell #1
S2 = Station #2
R2 = Rack #2

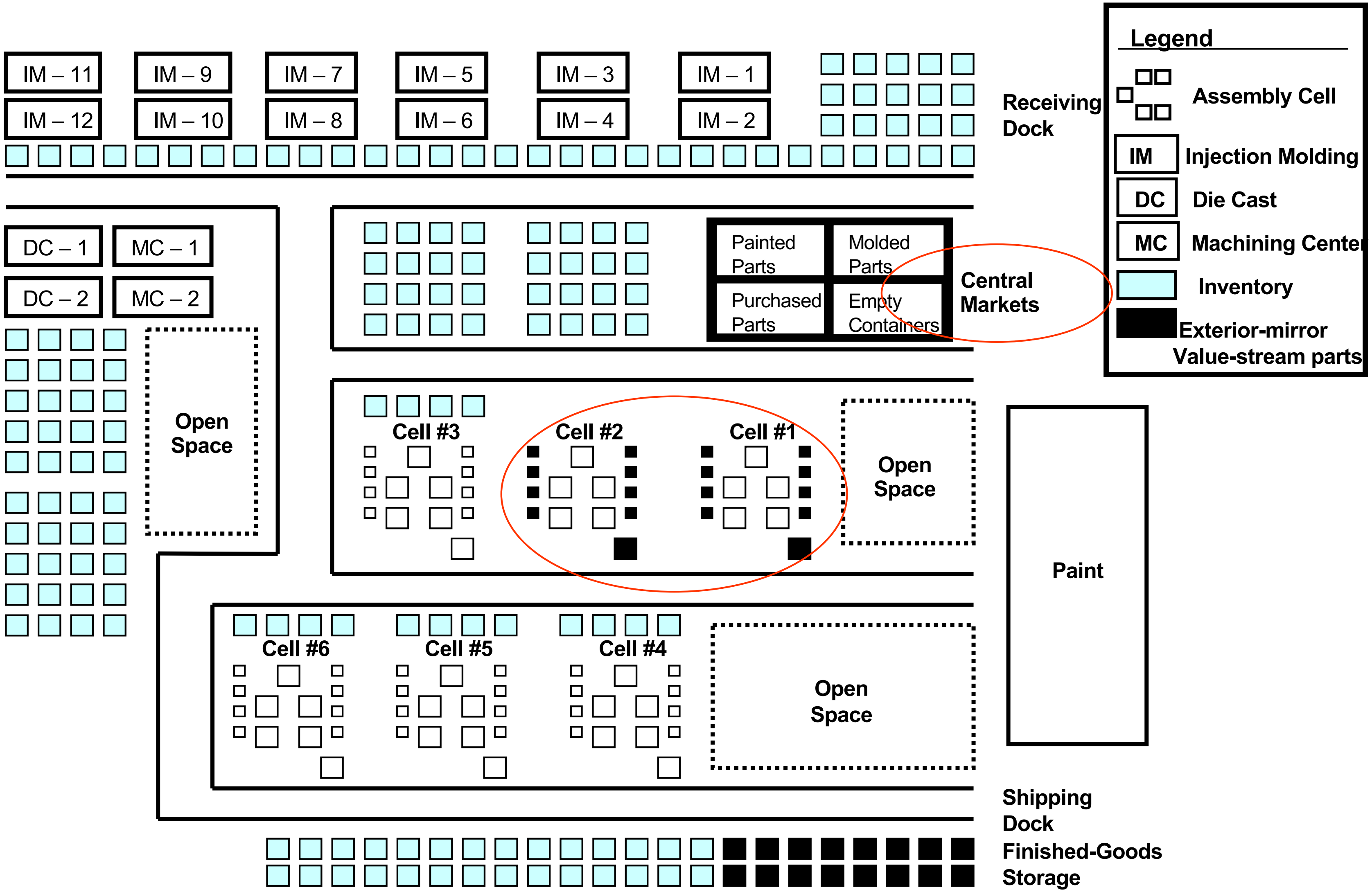
Rules for market locations

- **Traditional Toyota**: close to the producing process
- Facilities with many **internally produced** parts can use centrally located markets
- Facilities with many **purchased** parts can set markets near
- the receiving docks

In any case:

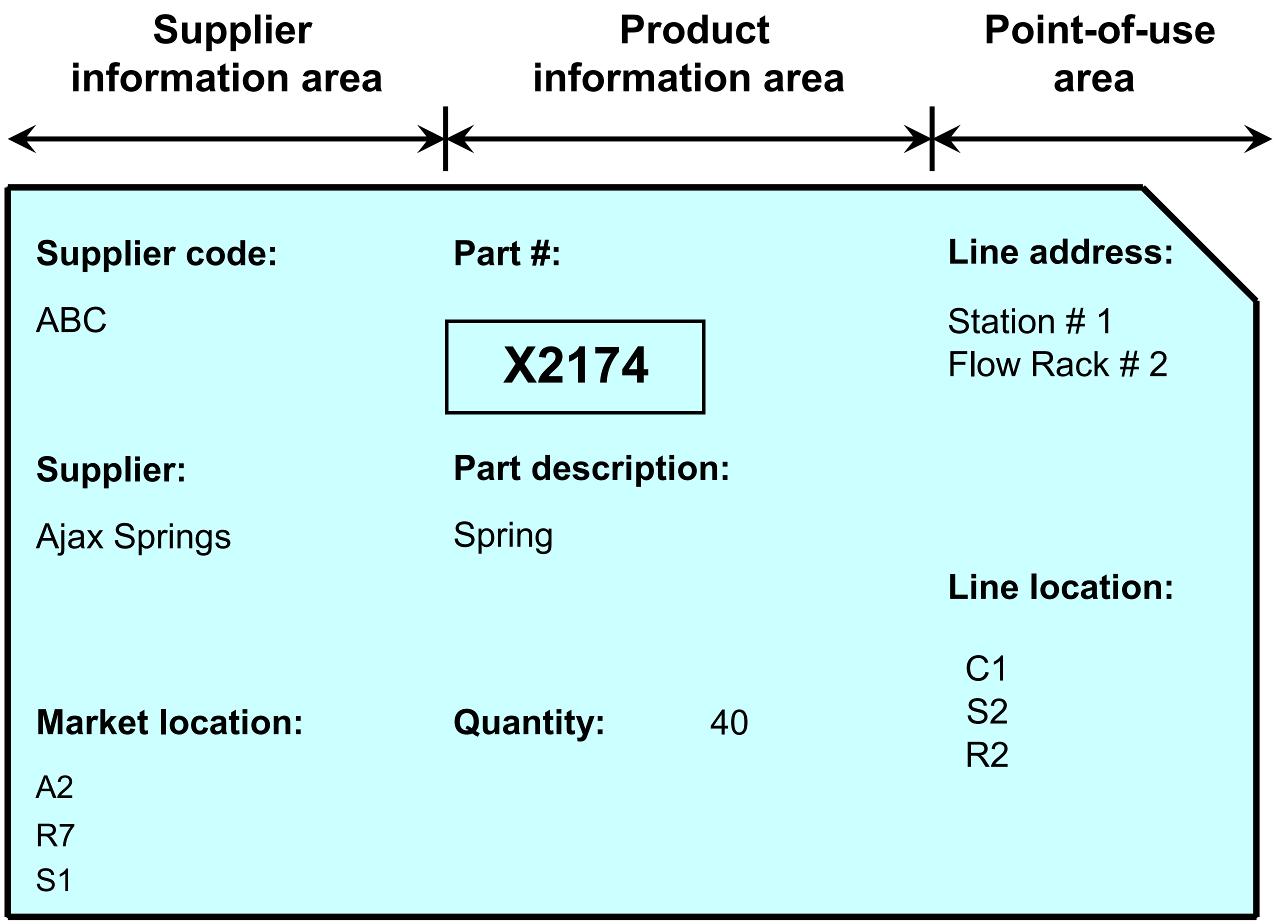
- Make clear that producing process has ownership of inventories
- Ensure that downstream processes pull what they need, when they need, on a regular basis
- Ensure there are signal exchanged between the processes regarding what has been taken away

Updated market layout with market area



8. How will you size the markets and trigger withdrawal kanban?

Example of Interprocess Withdrawal Kanban



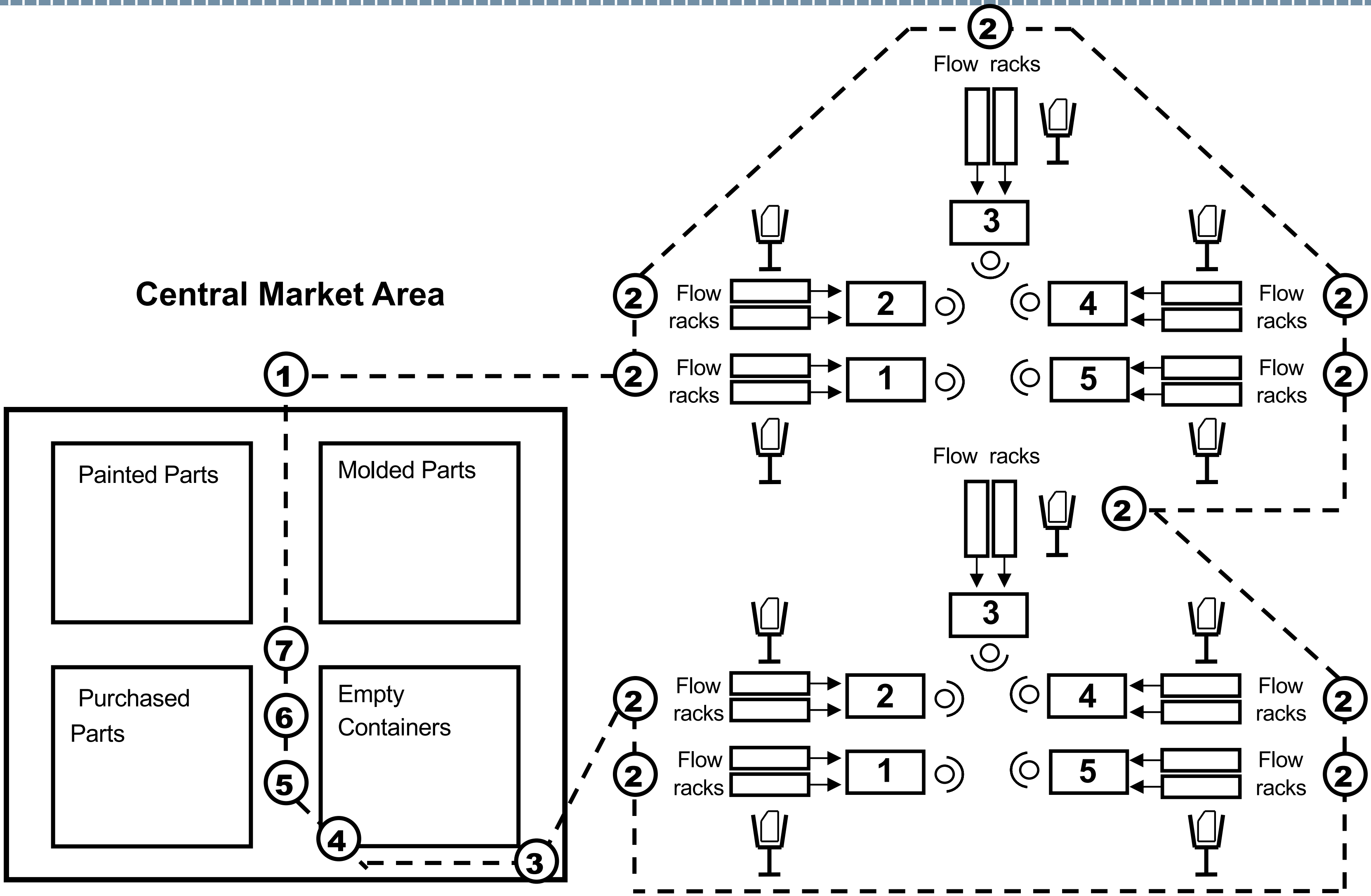
Three tasks to successfully trigger pull from the assembly cells to the central market

1. Set a standard amount of inventory of each part to hold at the assembly cells, based on the nature and frequency of the conveyance route

2. Create a separate withdrawal kanban for each container stored in the cells

3. Determine the right amount of inventory to hold in the central market

Withdrawal Material-Handling Loop



Standard Work Flow and Times for Withdrawal Material-Handling Loop

Step	Standard work elements	Conveyance time estimate
	Cell operator withdraws kanban card from a container upon removing the first part out of the container. The withdrawal kanban cards collect inside a kanban post at each cell station.	*N/A*
1.	The material handler travels from the central market and arrives at assembly cells.	*2 min.*
2.	The material handler visits and picks up all the withdrawal kanban at each station of each assembly cell as well as any empty containers, delivers parts to cells, and returns to the central market.	*4 min.*
3.	Once back at the store, the material handler sorts the cards for the best pick order.	*15 sec.*
4.	Empty containers picked up on the route are dropped off in the specified location in the market.	*1 min.*
5.	Any necessary bins for small items, such as nuts, bolts, screws, washers, etc., are obtained.	*1 min.*
6.	Parts are picked from the store and placed on the material-handling cart (an average of 10 withdrawal items each at 20 sec. per pick).	*3 min. 20 sec.*
7.	The withdrawal kanban cards are placed into their respective containers.	*15 sec.*
	Total route time	***11 min. 50 sec.***

Apogee could hold 30 min stock at the cell, but not till the system is refined. Thus they started with 60’

Size your markets

Market Inventory Calculation

	Average daily demand x Lead time to replenish (days)*	**Cycle stock**
+	Demand variation as % of Cycle stock	**Buffer stock**
+	Safety factor as % of (Cycle stock + Buffer stock)	**Safety stock**
=		**Market inventory**

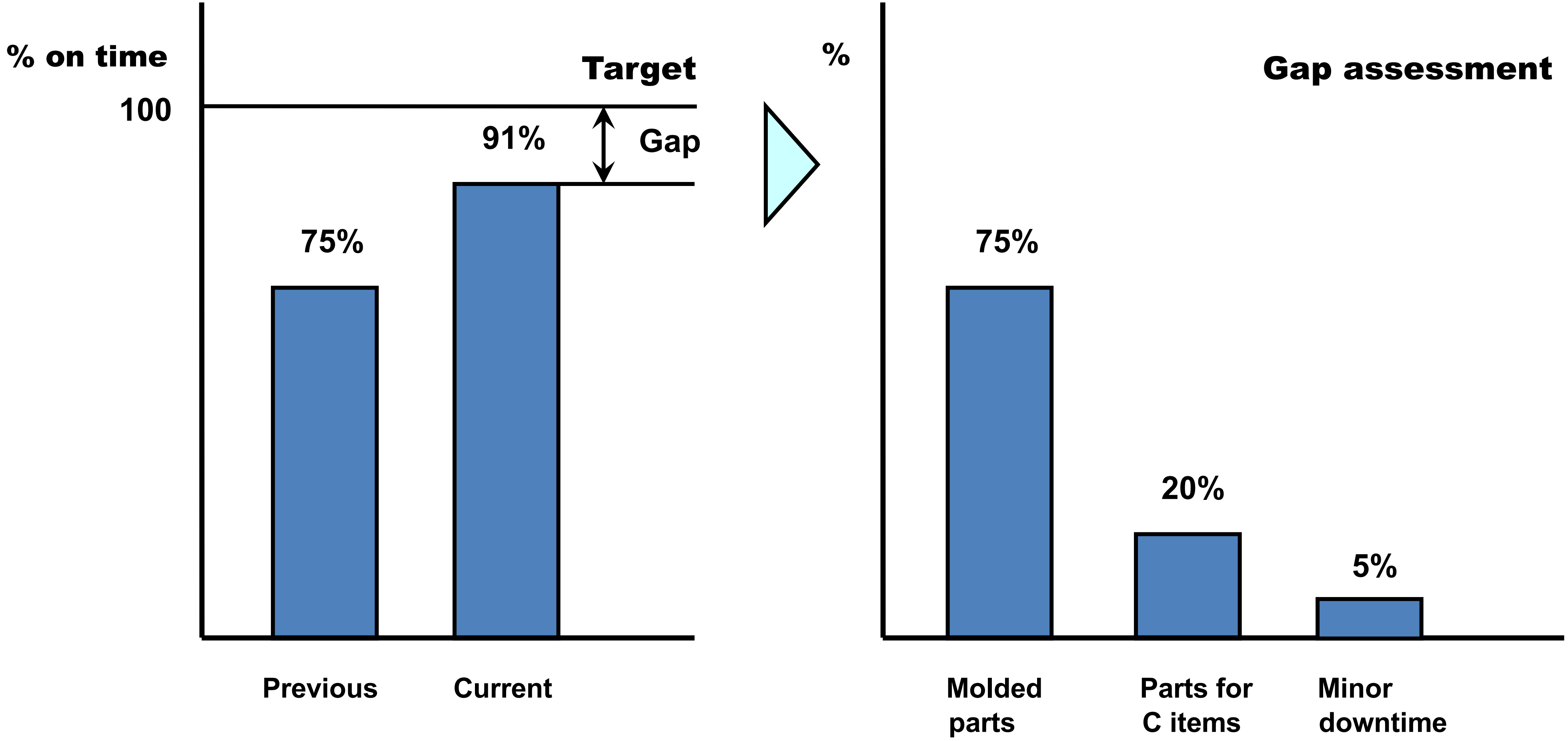
Market Inventory Calculation for Part #14117 (Painted Bracket)

	100 x 5*	**Cycle stock**	**500**
+	10%** of 500	**Buffer stock**	**50**
+	10%*** of (500 + 50)	**Safety stock**	**55**
=		**Market inventory**	**605**

* Lead time for paint process to replenish this item
** Two standard deviations of internal variation for this part number
*** Average scrap rate and downtime for this part number

Buffer stock is much lower here, because production downstream has been levelled

Apogee ready-to-assemble performance



Managing the flow for part C

Build to order from molding or Assemble to order?

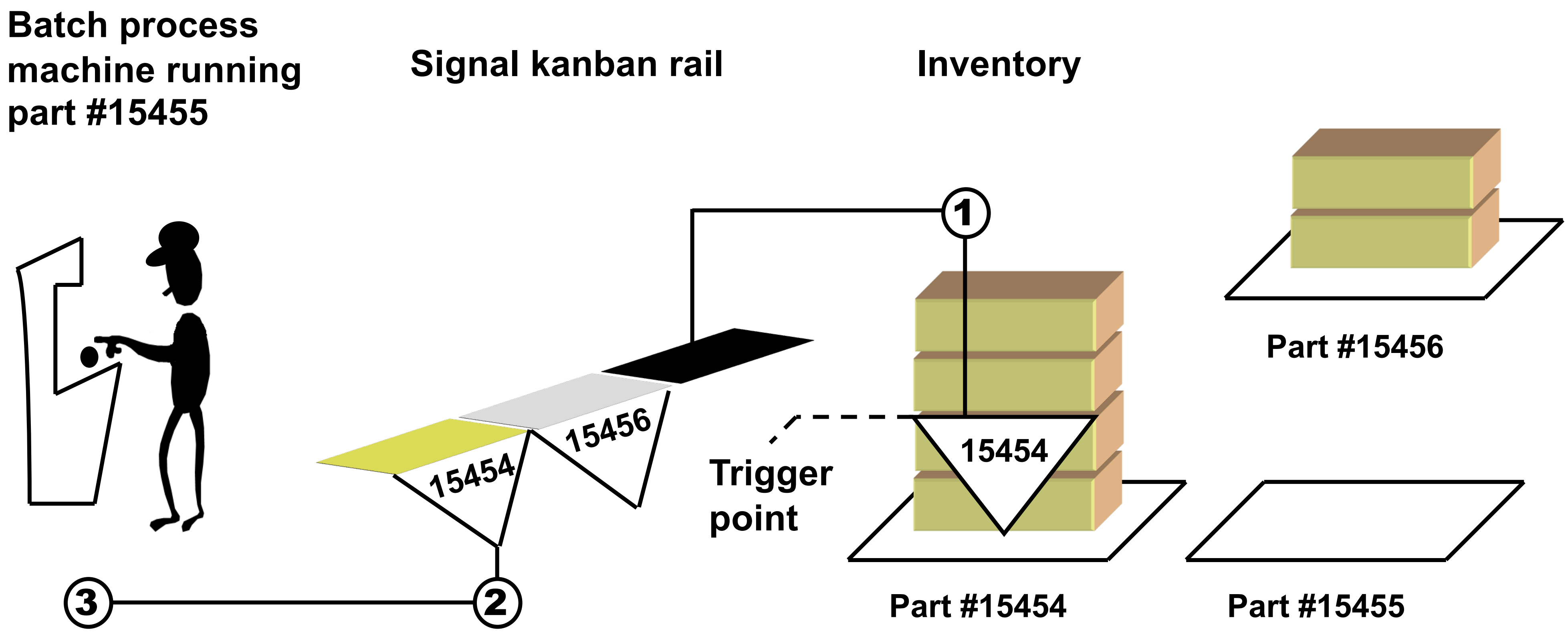
Apogee decided to **Assemble To Order**

9. How will you control batch processes upstream from the market?

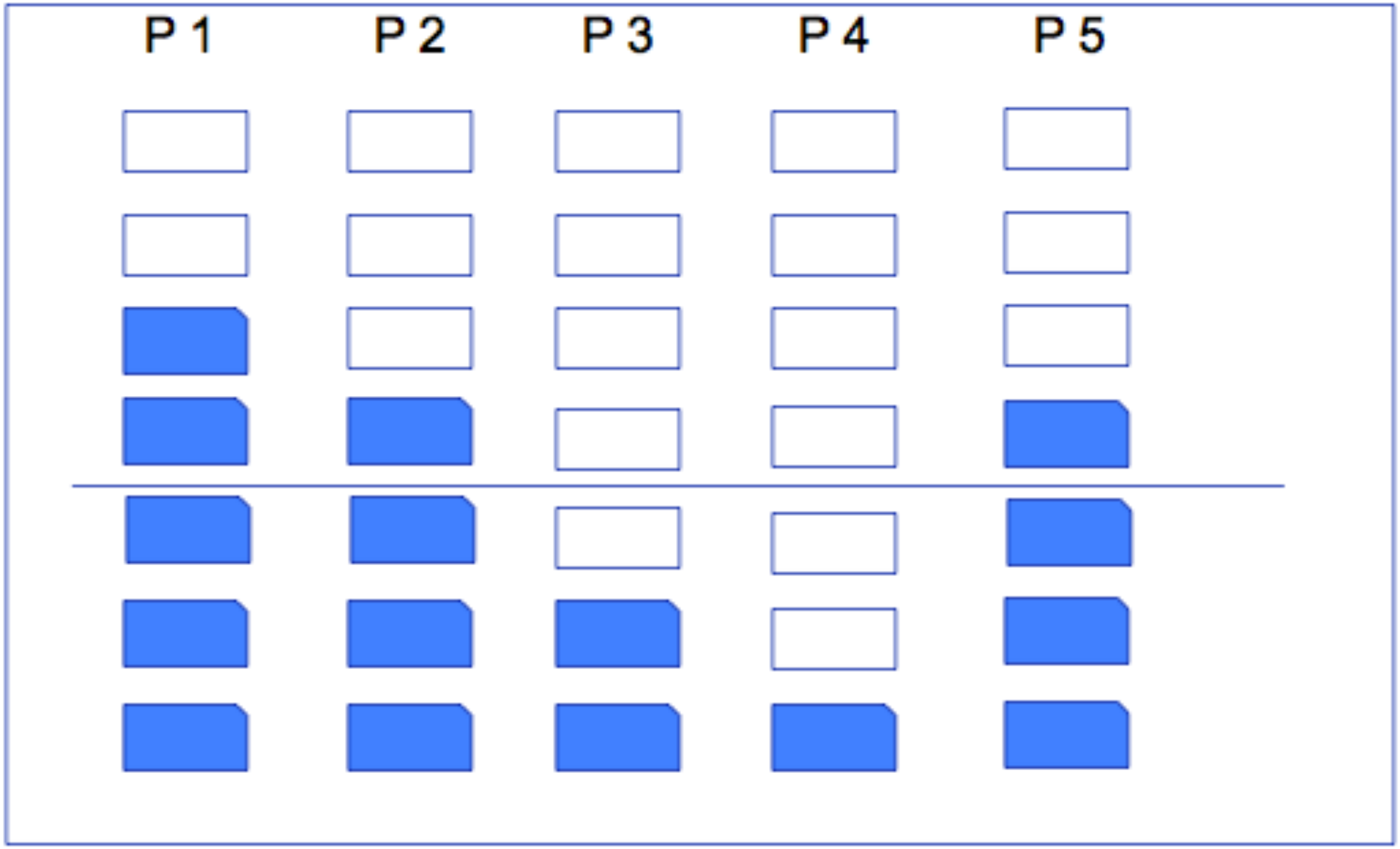
- At Apogee, lot size is presently defined on the base of **EOQ**
- Operators run longer than planned lots
- Operators and plant manager are measured on machine utilisation

9. How will you control batch processes upstream from the market?

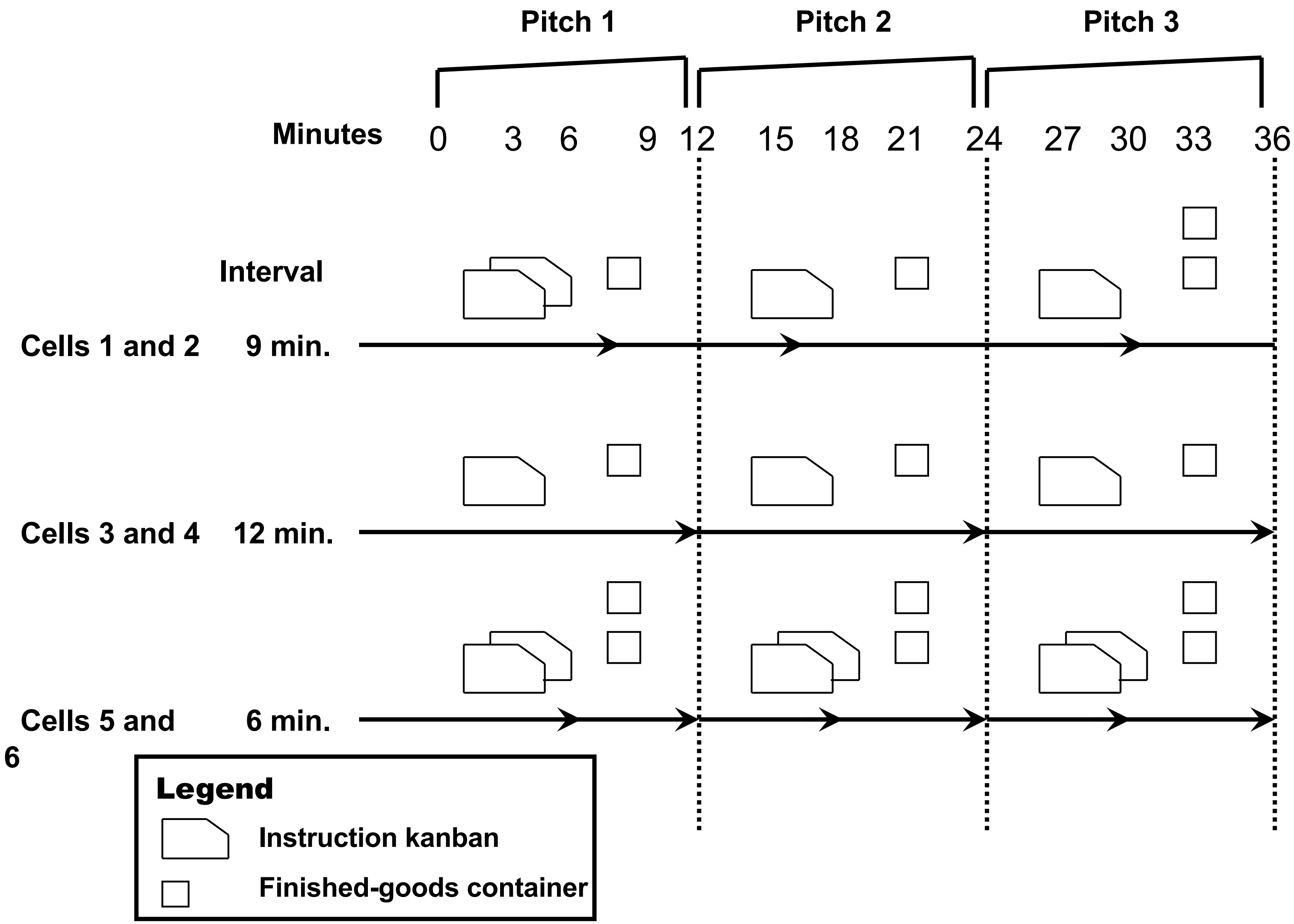
Production Control Using Triangle Kanban



Batch board



Pitch interval delivery



Instructions for Material Handler

Drop off 2 kanban start of interval. Pick up 1 finished-goods container at end of interval and drop off 1 more kanban. Repeat next interval. Pick up 2 finished-goods containers at end of next interval and drop off 2 kanban. Cycle repeats.

Drop off 1 kanban at start of interval. Pick up 1 finished-goods container at end of interval and drop off next kanban. Cycle repeats.

Drop off 2 kanban at start of interval. Pick up 2 finished-goods containers at end of interval and drop off next 2 kanban. Cycle repeats.

POLITECNICO
MILANO 1863