Push and Pull Production Systems

You say yes.
I say no.
You say stop.
and I say go, go, go!

– The Beatles

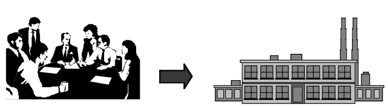
The Key Difference Between Push and Pull

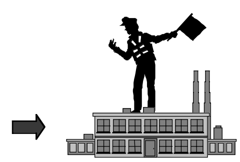
Push Systems: ***schedule*** work releases based on demand.

- inherently due-date driven
- control release rate, observe WIP level

Pull Systems: ***authorize*** work releases based on system status.

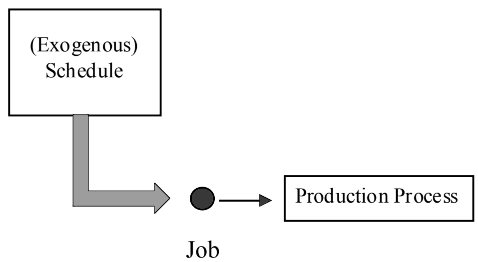
- inherently rate driven
- control WIP level, observe throughput





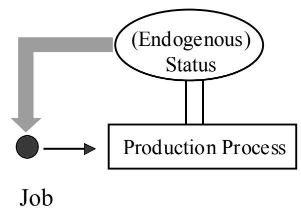
Push vs. Pull Mechanics

PUSH



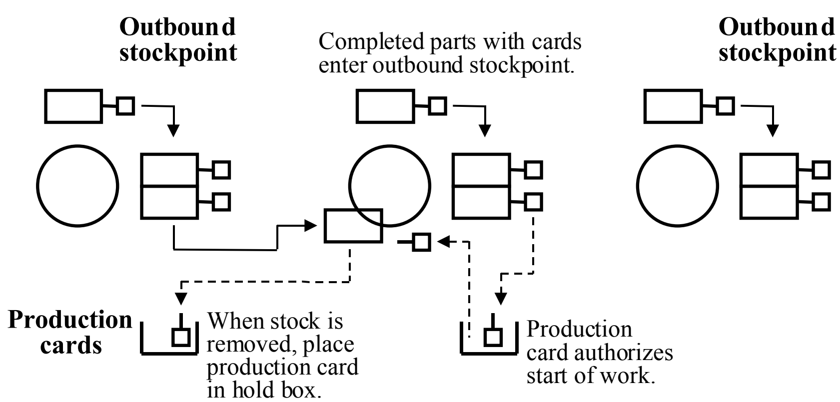
Push systems are inherently <u>make-to-order</u>.

PULL

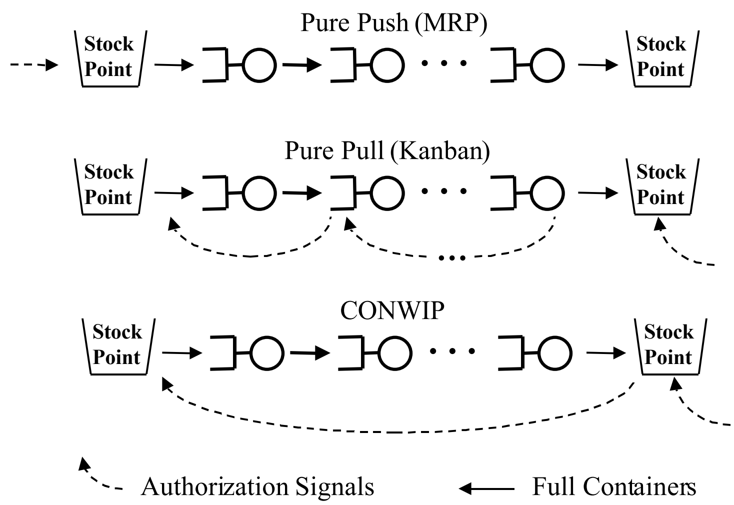


Pull systems are inherently <u>make-to-stock</u>.

Pulling with Kanban



Push and Pull Line Schematics



Push/Pull Interface

Eliminate: entire portion of cycle time by building to stock.

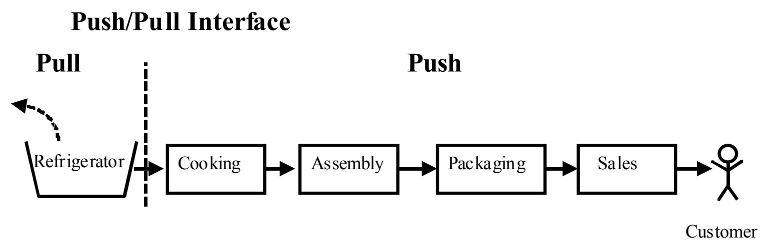
Requirements:

- Level demand.
- Relatively few distinct parts.
- Relatively constant product mix.

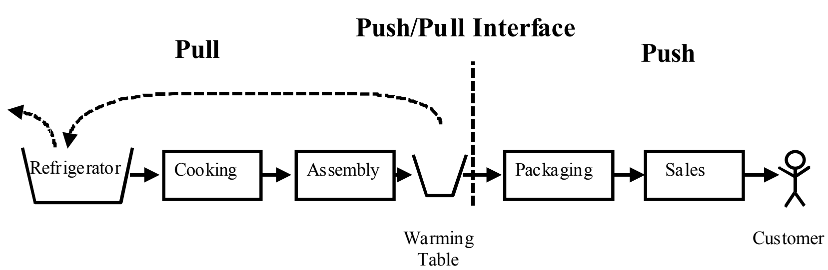
Implementation:

- kanban
- late customization (postponement)

Example - Custom Taco Production Line



Example - Quick Taco Production Line



The Magic of Pull

Pulling Everywhere?

> ***You don't never make nothin' and*** **send** ***it no place. Somebody has to come get it.***
>
> – Hall 1983

No! It's the WIP Cap:

- Kanban – WIP cannot exceed number of cards
- "WIP explosions" are impossible

Advantages of Pull Systems

Low Unit Cost:

- high throughput
- low inventory
- little rework

High External Quality:

- high internal quality
- pressure for good quality
- promotion of good quality (e.g., defect detection)

Good Customer Service:

- short cycle times
- steady, predictable output stream

Flexibility:

- avoids committing jobs too early
- tolerates mix changes (within limits)
- encourages floating capacity

Pull Benefits Achieved by WIP Cap

Reduces Manufacturing Costs:
- prevents WIP explosions
- reduces average WIP
- reduces engineering changes

Improves Quality:
- pressure for higher quality
- improved defect detection
- improved communication

Reduces Variability:
- reduces cycle time variability
- pressure to reduce sources of process time variability (e.g., long repair times)
- promotes improved customer service

Maintains Flexibility:
- accommodates engineering changes
- less direct congestion
- less reliance on forecasts
- air traffic control analogy

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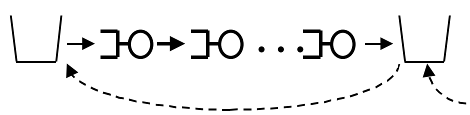
CONWIP

Assumptions:
1. Single routing
2. WIP measured in units



Mechanics: allow next job to enter line each time a job leaves (i.e., maintain a WIP level of *m* jobs in the line at all times).

Modeling:
- MRP looks like an open queueing network
- CONWIP looks like a closed queueing network
- Kanban looks like a closed queueing network with blocking

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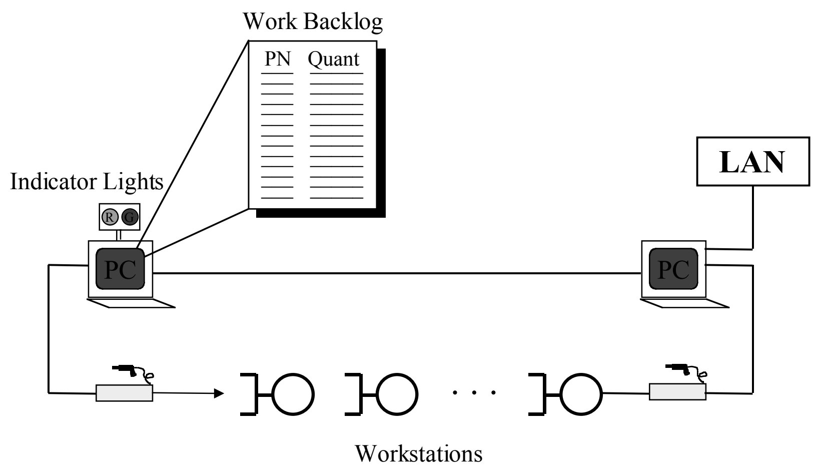
CONWIP Controller



CONWIP vs. Pure Push

Push/Pull Laws: A CONWIP system has the following advantages over an equivalent pure push system:

1) Observability**:** WIP is observable; capacity is not.

2) Efficiency**:** A CONWIP system requires less WIP on average to attain a given level of throughput.

3) Robustness**:** A profit function of the form

$$\text{Profit} = p\text{Th} - h\text{WIP}$$

is more sensitive to errors in TH than WIP.

CONWIP Efficiency Example

Equipment Data:

- 5 machines in tandem, all with capacity of one part/hr ($u=TH \cdot t_e=TH$)
- exponential (moderate variability) process times

CONWIP System: looks like PWC, so

$$TH(w) = \frac{w}{w+W_0-1} r_b = \frac{w}{w+4}$$

Pure Push System: looks like series of M/M/1 queues, so

$$w(TH) = 5\frac{u}{1-u} = 5\frac{TH}{1-TH}$$

Comparison: WIP needed in CONWIP to match push throughput

$$w\left(\frac{w}{w+4}\right) = \frac{5(w/(w+4))}{1-(w/(w+4))} = \frac{5w}{4}$$

in this example, WIP is always 25% higher for same TH in push than in CONWIP

CONWIP Robustness Example

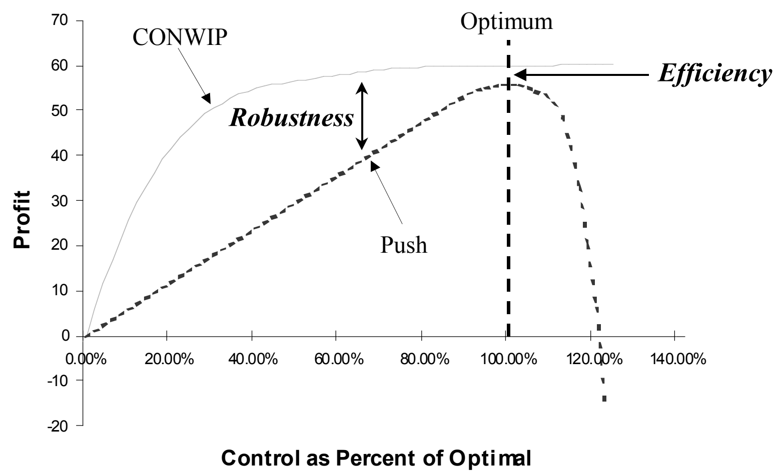
Profit Function: $\text{Profit} = pTH - hw$

CONWIP: $\text{Profit(w)} = p\left(\frac{w}{w+4}\right) - hw$ ***need to find "optimal" WIP level***

Push: $\text{Profit(TH)} = pTH - h\left(\frac{5\,TH}{1-TH}\right)$ ***need to find "optimal" TH level (i.e., release rate)***

Key Question: ***what happens when we don't choose optimum values (as we never will)?***

CONWIP vs. Pure Push Comparisons



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Modeling CONWIP with Mean-Value Analysis

Notation:

$u_j(w)$ = utilization of station j in CONWIP line with WIP level w

$CT_j(w)$ = cycle time at station j in CONWIP line with WIP level w

$CT(w) = \sum_{j=1}^{n} CT_j(w)$ = cycle time of CONWIP line with WIP level w

$TH(w)$ = throughput of CONWIP line with WIP level w

$WIP_j(w)$ = average WIP level at station j in CONWIP line with WIP level w

Basic Approach: Compute performance measures for increasing w assuming job arriving to line "sees" other jobs distributed according to average behavior with w-*1* jobs.

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Mean-Value Analysis Formulas

Starting with $WIP_j(0)=0$ and $TH(0)=0$, compute for w=1,2,…

$$CT_j(w) = \frac{t_e^2(j)}{2}[c_e^2(j)-1]TH(w-1) + [WIP_j(w-1)+1]t_e(j)$$

$$CT(w) = \sum_{j=1}^{n} CT_j(w)$$

$$TH(w) = \frac{w}{CT(w)}$$

$$WIP_j(w) = TH(w)CT_j(w)$$

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Computing Inputs for MVA

MEASURE:	STATION:		1	2	3	4	5
Natural Process Time (hr)	t_0		0.090	0.090	0.094	0.090	0.090
Natural Process CV	c_0^2		0.500	0.500	0.500	0.500	0.500
Number of Machines	m		1	1	1	1	1
MTTF (hr)	m_f		200	200	200	200	200
MTTR (hr)	m_r		2	2	8	4	4
Availability	A		0.990	0.990	0.962	0.980	0.980
Effective Process Time (failures only)	t_e'		0.091	0.091	0.098	0.092	0.092
Eff Process CV (failures only)	$c_e^{2\prime}$		0.936	0.936	6.795	2.209	2.209
Jobs Between Setups	N_s		100.000	100.000	100.000	100.000	100.000
Setup Time (hr)	t_s		0.500	0.500	0.500	0.500	0.500
Setup Time CV	c_s^2		1.000	1.000	1.000	1.000	1.000
Eff Process Time (failures+setups)	t_e		0.096	0.096	0.103	0.097	0.097
Eff Station Rate	r_e		10.428	10.428	9.731	10.331	10.331
Eff Process Time Var (failures+setups)	σ_e^2		0.013	0.013	0.070	0.024	0.024
Eff Process CV (failures+setups)	c_e^2		1.382	1.382	6.621	2.517	2.517
	r_b	9.731					
	T_0	0.488					
	W_0	4.750					

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Output of MVA

w	TH Actual	CT Actual	$CT_1(w)$	$CT_2(w)$	$CT_3(w)$	$CT_4(w)$	$CT_5(w)$
1	2.049	0.488	0.096	0.096	0.103	0.097	0.097
2	2.928	0.683	0.118	0.118	0.185	0.131	0.131
3	3.644	0.823	0.134	0.134	0.245	0.155	0.155
4	4.185	0.956	0.149	0.149	0.303	0.177	0.177
5	4.629	1.080	0.163	0.163	0.357	0.198	0.198
6	5.000	1.200	0.176	0.176	0.410	0.219	0.219
7	5.317	1.317	0.189	0.189	0.462	0.238	0.238
8	5.592	1.431	0.202	0.202	0.513	0.257	0.257
9	5.834	1.543	0.214	0.214	0.563	0.276	0.276
10	6.049	1.653	0.226	0.226	0.614	0.294	0.294
11	6.241	1.763	0.237	0.237	0.664	0.312	0.312
12	6.414	1.871	0.249	0.249	0.714	0.330	0.330
13	6.572	1.978	0.260	0.260	0.763	0.347	0.347
14	6.715	2.085	0.271	0.271	0.813	0.364	0.364
15	6.846	2.191	0.283	0.283	0.863	0.381	0.381

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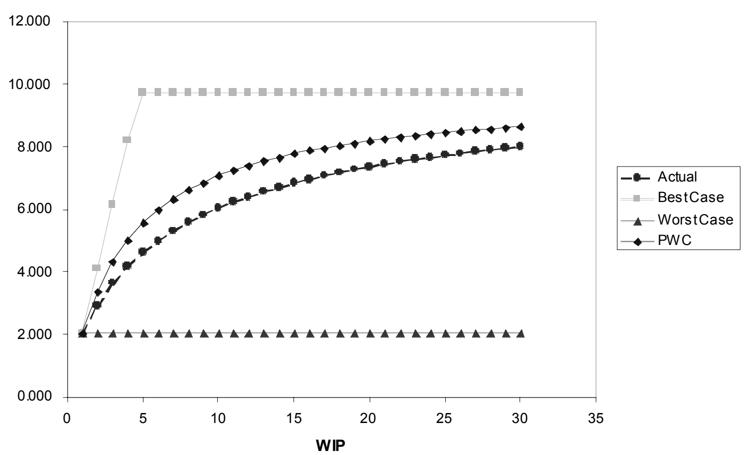
Using MVA to Evaluate Line Performance



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Implementing Pull

Pull is Rigid:

- replenish stocks quickly (just in time)
- level mix, volume, sequence

JIT Practices

- capacity buffers
- setup reduction
- flexible labor
- facility layout

Capacity Buffers

Motivation: facilitate rapid replenishments with minimal WIP

Benefits:

- Protection against quota shortfalls
- Regular flow allows matching against customer demands
- Can be more economical in long run than WIP buffers in push systems

Techniques:

- Planned underutilization (e.g., use u = 75% in aggregate planning)
- *Two shifting*: 4 – 8 – 4 – 8
- Schedule dummy jobs to allow quick response to hot jobs

Setup Reduction

Motivation: Small lot sequences not feasible with large setups.

Internal vs. External Setups:

- External – performed while machine is still running
- Internal – performed while machine is down

Approach:

1. Separate the internal setup from the external setup
2. Convert as much as possible of the internal setup to the external setup
3. Eliminate the adjustment process
4. Abolish the setup itself (e.g., uniform product design, combined production, parallel machines)

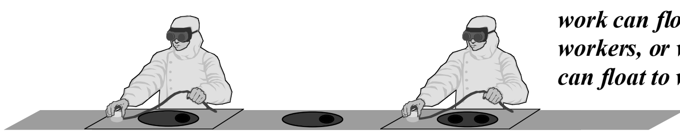
Flexible Labor

Cross-Trained Workers:

- float where needed
- appreciate line-wide perspective
- provide more heads per problem area

Shared Tasks:

- can be done by adjacent stations
- reduces variability in tasks, and hence line stoppages/quality problems



work can float to workers, or workers can float to work…

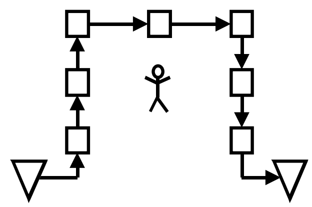
Cellular Layout

Advantages:

- Better flow control
- Improved material handling (smaller transfer batches)
- Ease of communication (e.g., for floating labor)

Challenges:

- May require duplicate equipment
- Product to cell assignment



Focused Factories

Pareto Analysis:

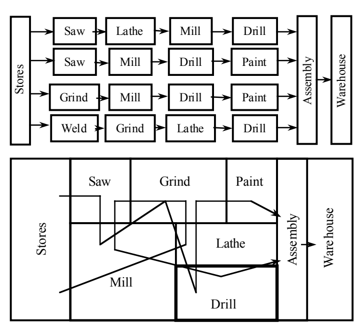
- Small percentage of sku's represent large percentage of volume
- Large percentage of sku's represent little volume but much complexity

Dedicated Lines:

- for families of high runners
- few setups
- can use pull effectively

Job Shop Environment:

- for low runners
- many setups
- poorer performance, but only on smaller portion of business
- may need to use push



Push/Pull Takeaways

Magic of Pull: the WIP cap

Logistical Benefits of Pull:

- observability
- efficiency
- robustness (this is the key one)

Overcoming Rigidity of Pull:

- capacity buffers
- setup reduction
- flexible labor
- facility layout
- many others (postponement, push/pull hybrids, etc.…)