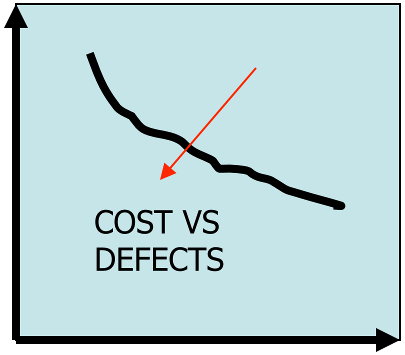


Introduction to the Toyota Production System (TPS)

2.810

T. Gutowski

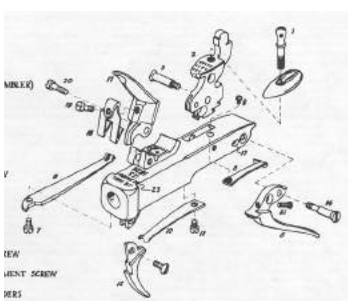
Nov 4, 2015

Three Major Mfg Systems from 1800 to 2000

Machine tools, specialized machine tools, Taylorism, SPC, CNC, CAD/CAM

1800 1900 2000

Interchangeable Parts at U.S. Armories

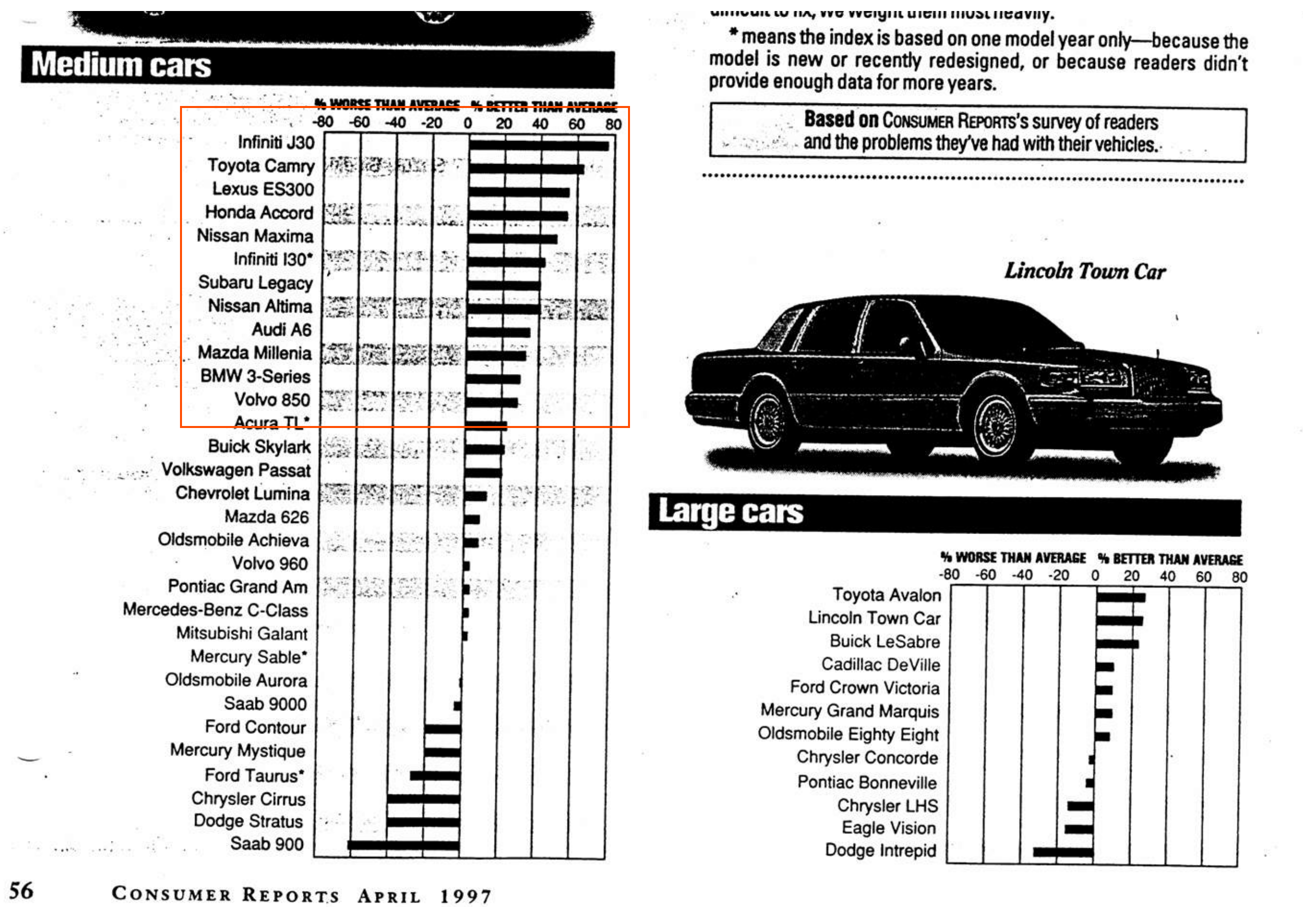


Mass Production at Ford

Toyota Production System

1980’s OPEC oil embargo drives up fuel prices, Japan imports small cars with increased fuel mileage

Consumer Reports



Medium cars

% WORSE THAN AVERAGE % BETTER THAN AVERAGE

-80 -60 -40 -20 0 20 40 60 80

Infiniti J30
Toyota Camry
Lexus ES300
Honda Accord
Nissan Maxima
Infiniti I30*
Subaru Legacy
Nissan Altima
Audi A6
Mazda Millenia
BMW 3-Series
Volvo 850
Acura TL*
Buick Skylark
Volkswagen Passat
Chevrolet Lumina
Mazda 626
Oldsmobile Achieva
Volvo 960
Pontiac Grand Am
Mercedes-Benz C-Class
Mitsubishi Galant
Mercury Sable*
Oldsmobile Aurora
Saab 9000
Ford Contour
Mercury Mystique
Ford Taurus*
Chrysler Cirrus
Dodge Stratus
Saab 900

56 CONSUMER REPORTS APRIL 1997

difficult to fix, we weight them most heavily.

* means the index is based on one model year only—because the model is new or recently redesigned, or because readers didn't provide enough data for more years.

Based on CONSUMER REPORTS's survey of readers and the problems they've had with their vehicles.

Lincoln Town Car

Large cars

% WORSE THAN AVERAGE % BETTER THAN AVERAGE

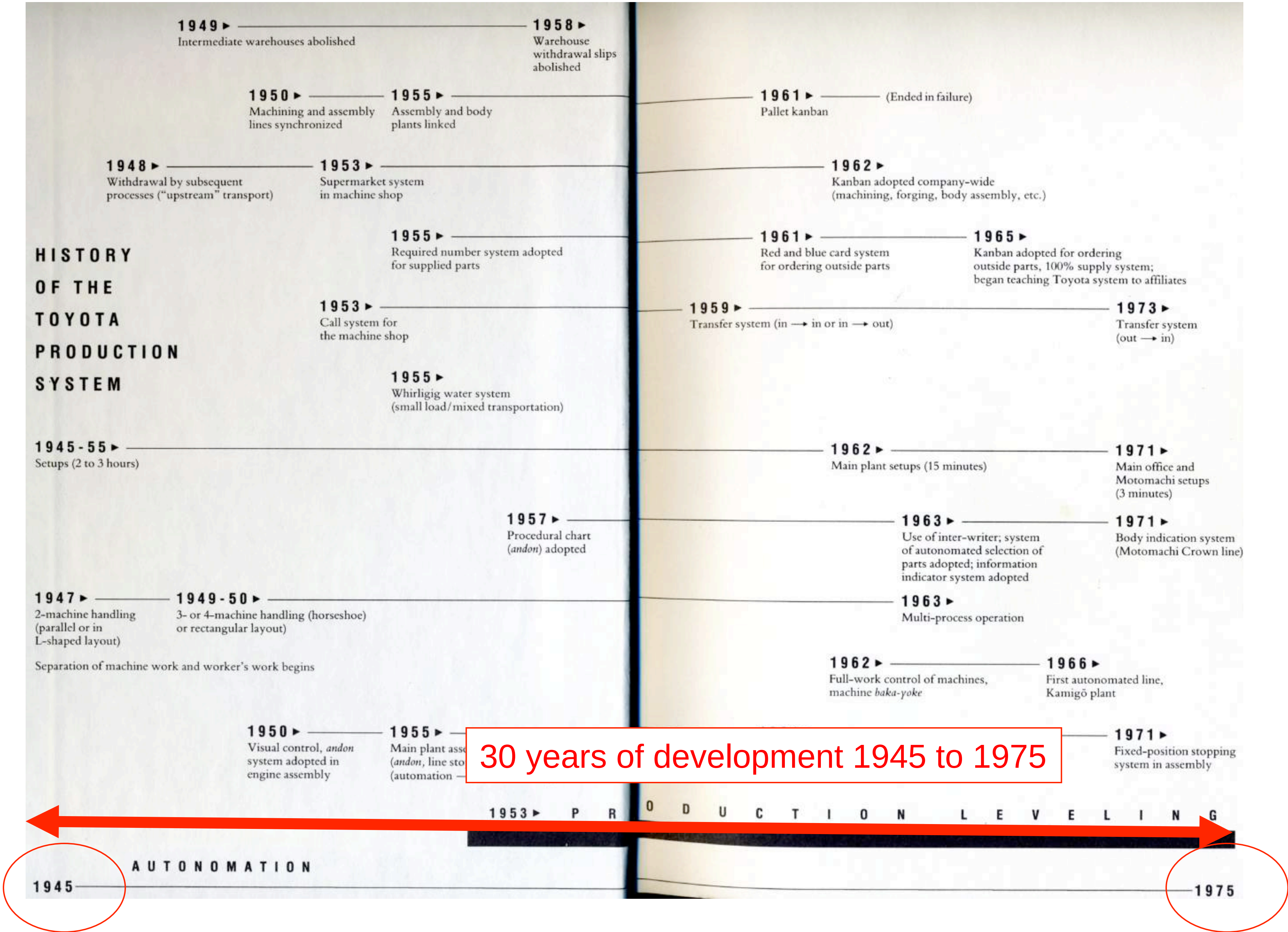
-80 -60 -40 -20 0 20 40 60 80

Toyota Avalon
Lincoln Town Car
Buick LeSabre
Cadillac DeVille
Ford Crown Victoria
Mercury Grand Marquis
Oldsmobile Eighty Eight
Chrysler Concorde
Pontiac Bonneville
Chrysler LHS
Eagle Vision
Dodge Intrepid

How we learned about TPS

- Quality of cars - but not right away
- Pilgrimages - Hayes, Wheelwright, Clark
- Joint ventures - Nummi-Geo…
- Japanese NA operations-Georgetown, KY
- Japanese sages- Ohno, Shingo, Monden
- American translation- "Lean", J T. Black..
- Consulting firms-…Shingjutsu,…

Toyota Production System Development History - Taiichi Ohno



From Hayes, Wheelwright, Clark; "Dynamic Mfg"

| 7 |

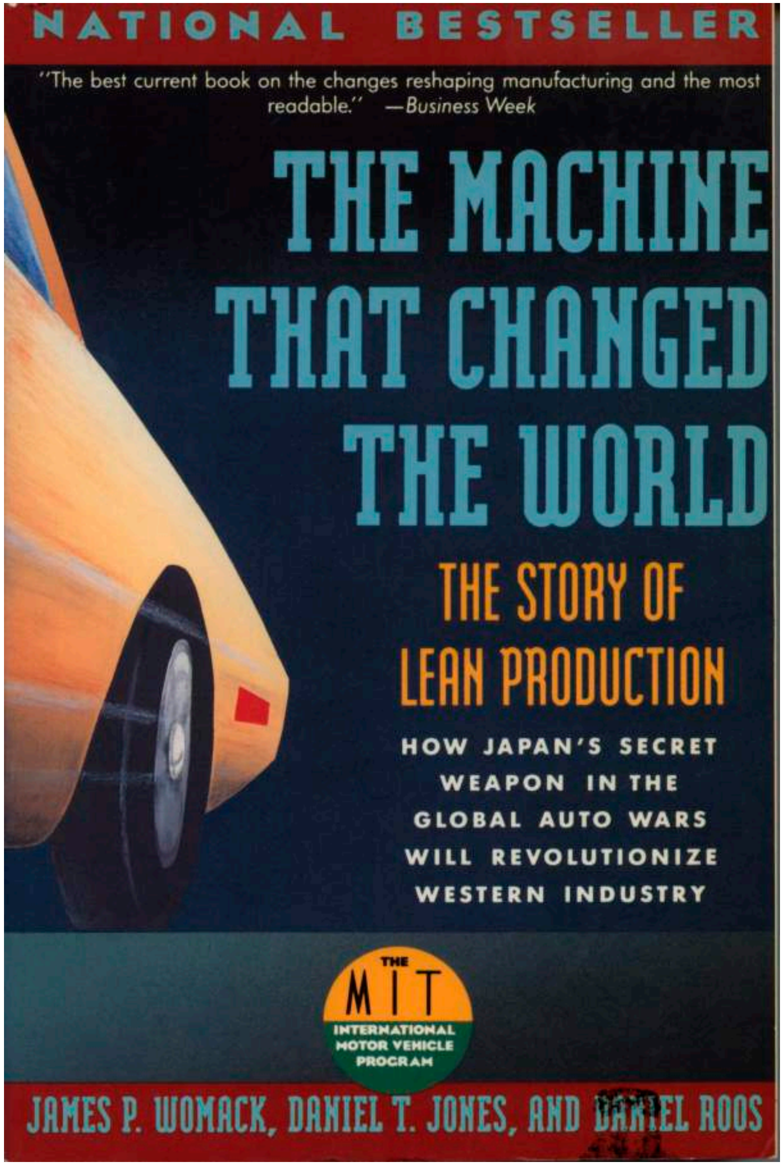
The Architecture of Manufacturing: Material and Information Flows

Introduction

The most striking thing about a factory is usually its machinery: in a steel mill, the sheer size, power, and noise of the electric arc furnace as it melts tons of scrap; in an automobile assembly plant, the rhythmic operation of the automated welding system; in a computer plant, the virtuosity of the assembly robots. But our research on high-performance manufacturing suggests that for all its sound and fury, the equipment, or hardware, by itself is rarely the primary source of a factory's competitive advantage. What matters is how that hardware is used, and how it is integrated with materials, people, and information through software—the systems and procedures that direct and control the factory's activities.

The "architecture" of a manufacturing system—which includes its hardware, its material and information flows, the rules and procedures used to coordinate them, and the managerial philosophy that underlies them all—largely determines the productivity of the people and assets in the factory, the quality of its products, and the responsiveness of the organization to customer needs. Indeed, two factories with almost identical hardware may perform very differently if they have different system architectures. Just how differently is demonstrated by the experience of Mazda, the Japanese auto firm, in the mid-1970s.

Translation: there is no "Silver Bullet".



1990

REFERENCES ON THE TOYOTA PRODUCTION SYSTEM;

Taiichi Ohno, "The Toyota Production System" Productivity Press 1988

Shigeo Shingo, "A Study of the Toyota Production System" Productivity Press 1989

Yasuhiro Monden, "Toyota Production System", 2nd Ed 1983

Hayes, Wheelwright and Clark, "Dynamic Manufacturing" Free Press 1988

Womack and Jones, "Lean Thinking" Simon and Schuster, 1996

Performance Observations

- Early observations of reliability, after some initial start-up problems
- IMVP got actual factory level data 1980’s
  - defect counts
  - direct labor hours for assembly
  - level of automation

Summary of Assembly Plant Characteristics, Volume Producers, 1989
(Average for Plants in Each Region)

	Japanese in Japan	Japanese in North America	American in North America	All Europe
Performance:				
Producvitity (hours/Veh.)	16.8	21.2	25.1	36.2
Quality (assembly defects/100 vehicles)	60	65	82.3	97
Layout:				
Space (sq.ft./vehicle/yr)	5.7	9.1	7.8	7.8
Size of Repair Area (as % of assembly space)	4.1	4.9	12.9	14.4
Inventories(days for 8 sample parts)	0.2	1.6	2.9	2
Work Force:				
% of Work Force in Teams	69.3	71.3	17.3	0.6
Job Rotation (0 = none, 4 = frequent)	3	2.7	0.9	1.9
Suggestions/Employee	61.6	1.4	0.4	0.4
Number of Job Classes	11.9	8.7	67.1	14.8
Training of New Production Workers (hours)	380.3	370	46.4	173.3
Absenteeism	5	4.8	11.7	12.1
Automation:				
Welding (% of direct steps)	86.2	85	76.2	76.6
Painting(% of direct steps)	54.6	40.7	33.6	38.2
Assembly(% of direct steps)	1.7	1.1	1.2	3.1

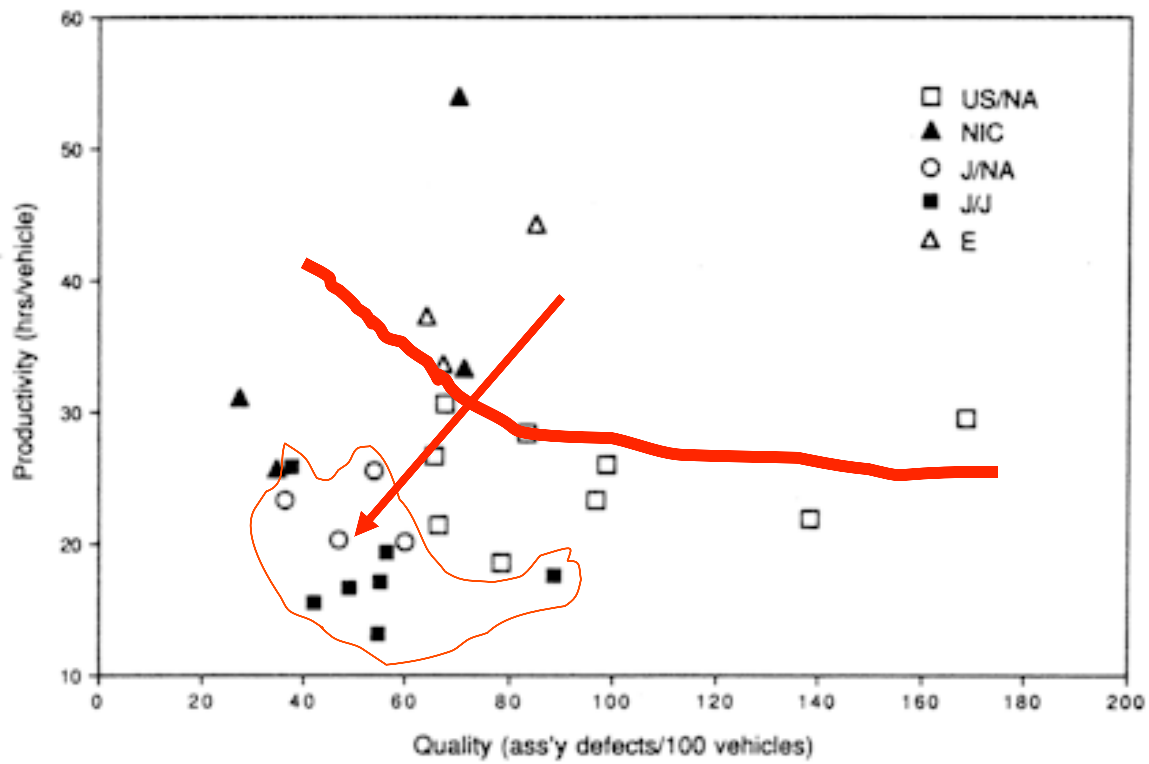
Source: IMVP World Assembly Plant Survey, 1989, and J. D. Power Initial Quality Survery, 1989

Cost Vs Defects

Ref. "Machine that Changed the World" Womack, Jones and Roos

FIGURE 4.8

Productivity versus Quality in the Assembly Plant, Volume Producers, 1989



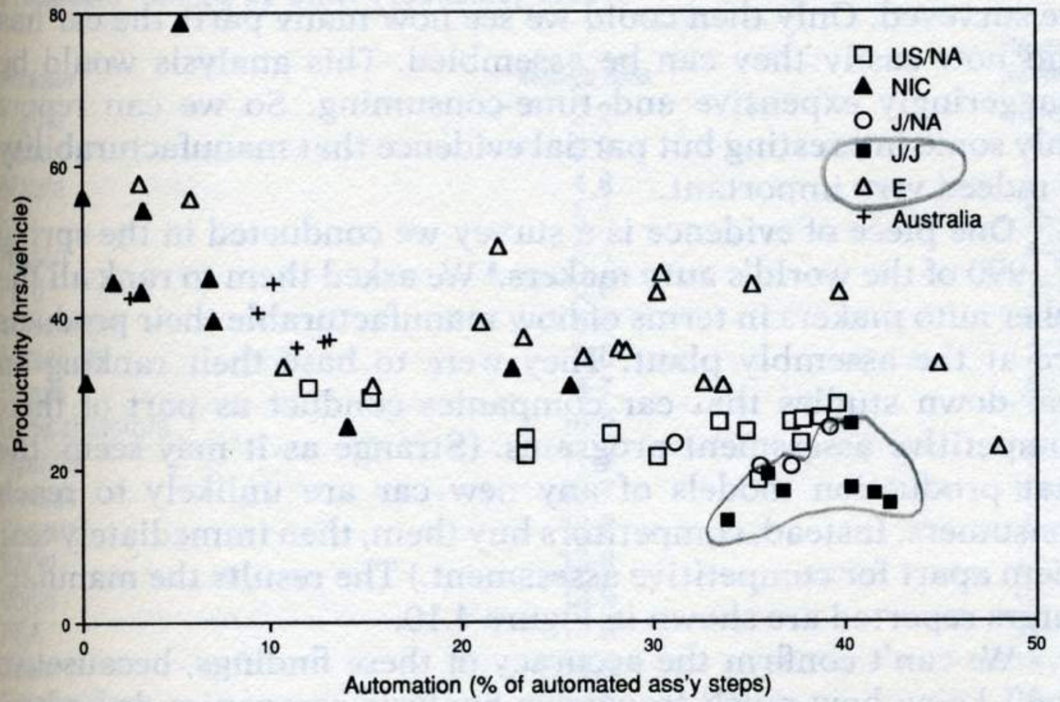
Source: IMVP World Assembly Plant Survey, 1989

Cost Vs Automation

Ref. “Machine that Changed the World” Womack, Jones and Roos

FIGURE 4.9

Automation versus Productivity, Volume Producers, 1989

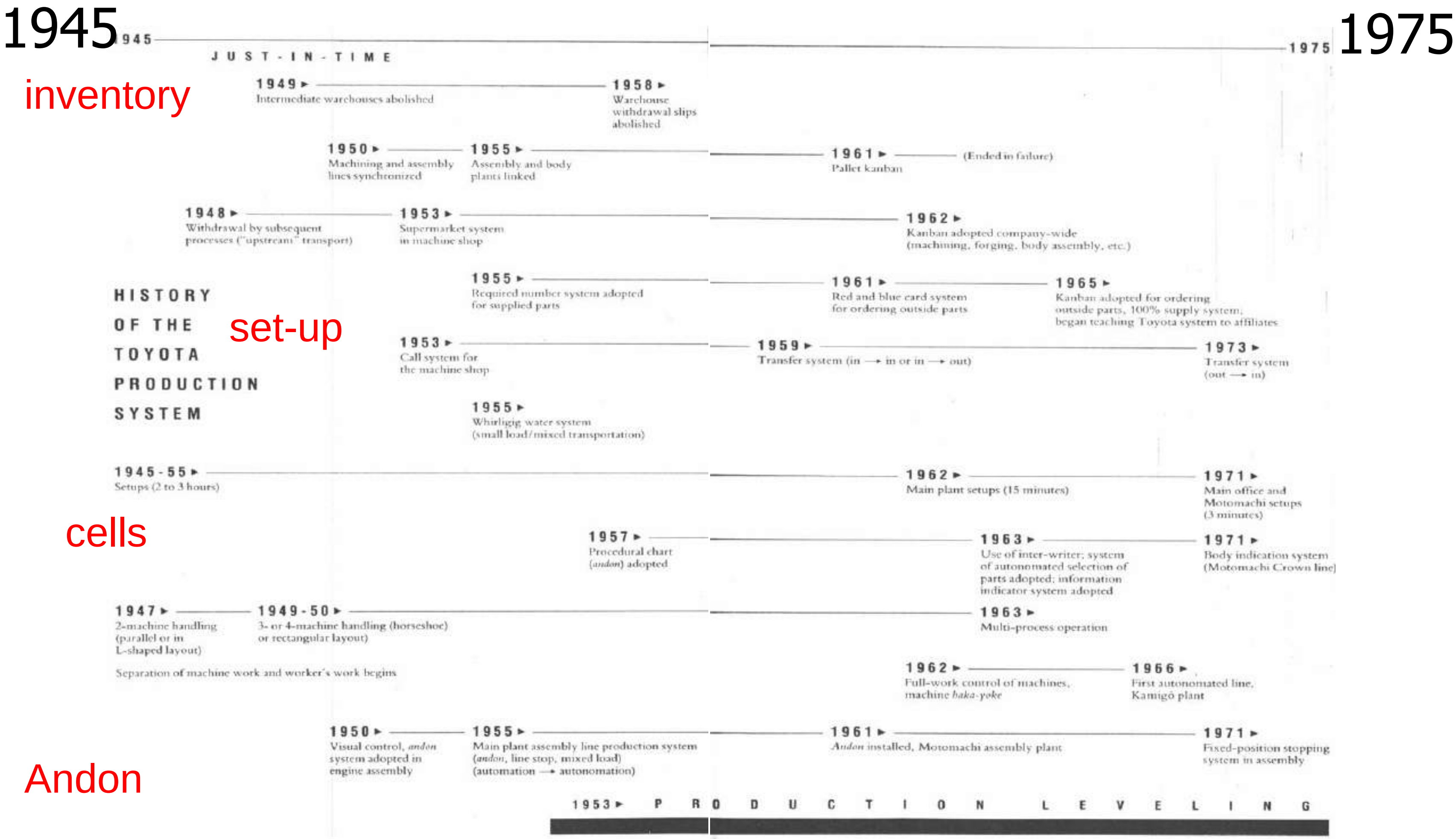


Note: “Automation” equals the percent of assembly tasks that have been automated. Automation includes both fixed automation such as multi-welders and flexible automation using robots. Automation of materials handling is not included.

Source: IMVP World Assembly Plant Survey, 1989

History of the Development of the Toyota Production System

ref; Taiichi Ohno



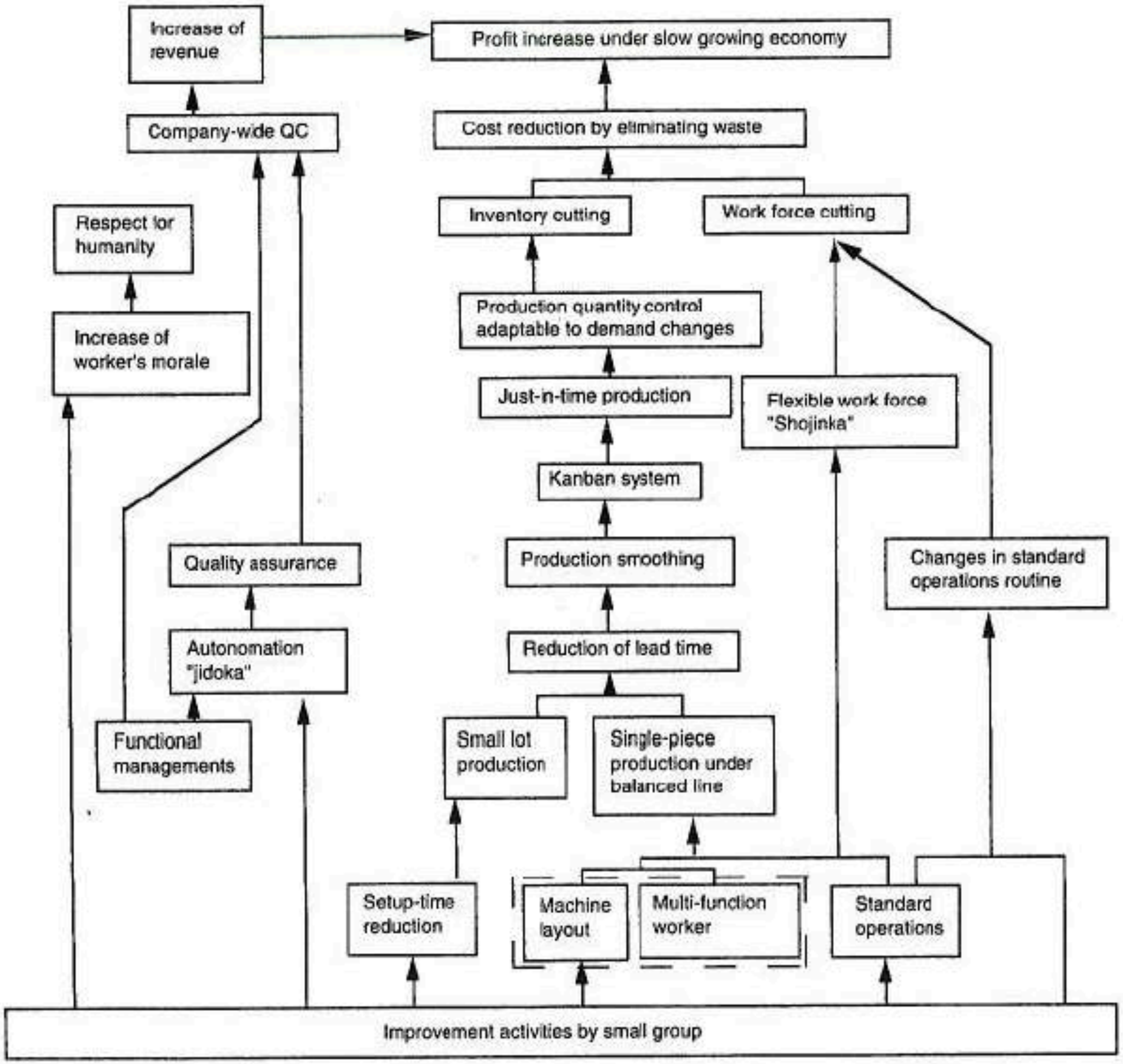


Figure 1.2. How costs, quantity, quality, and humanity are improved by the Toyota production system.

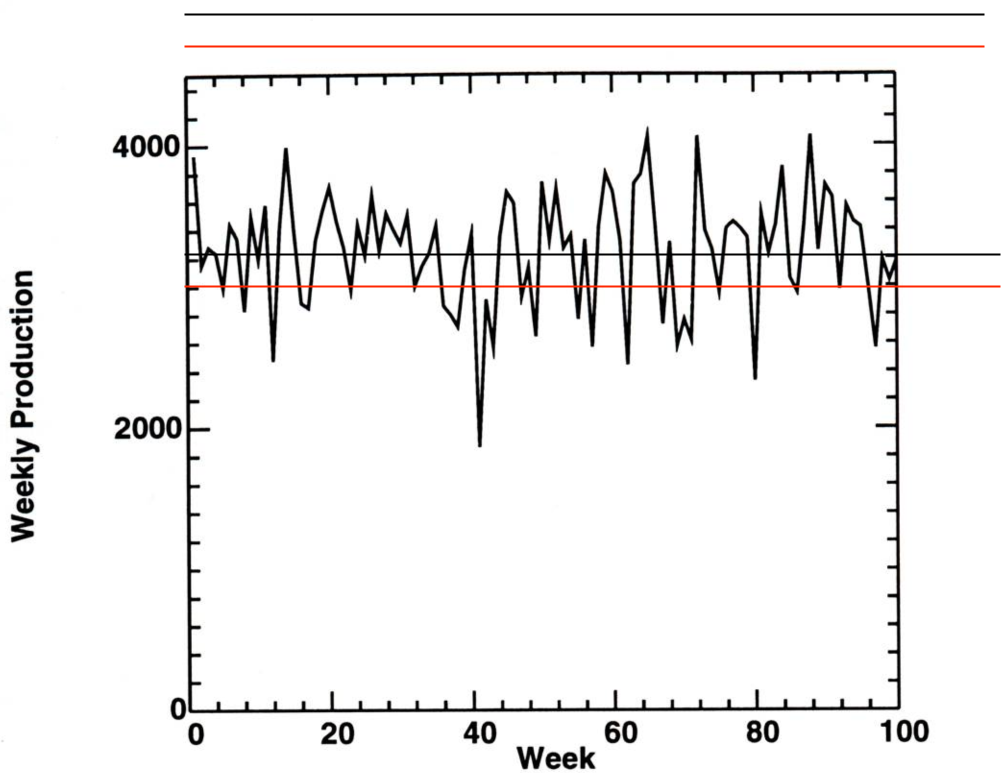
Ref Yasuhiro Monden

Basic Goal

- To reduce cost by -
- Elimination of waste
  - Excessive production resources
  - Overproduction
  - Excessive inventory
  - Unnecessary capital investment

See Toyota Production System, Yasuhiro Monden

Simulation of a 20 machine, 19 buffer (cap = 10 parts) Transfer line. Each machine with one minute cycle time could produce 4800 parts per week. MTTF 3880 minutes, MTTR 120 minutes. *See Gershwin p63-64*



Perfect machines, ∞buffer

∞ buffer

Ave (3249 sim, 3247 analy)

Zero buffer

N ≥ 240 parts*

Figure 3.2: Production Variability

Buffer capacity Vs MTTR

- MTTR = 120 minutes
- N* ~ 2 x 120 x 1 part/minute = 240
- 240 x 19 buffers = 4560 (~ one week)

- There must be a better way!

CHANGE THINKING, REDUCE VARIATION

What causes variation?

- Quality issues
- Delivery time issues
- Unavailable resources issues

What causes variation?

- Quality issues
  - Check quality, prevent propagation
- Delivery time issues
  - Just in Time, smooth flow, mix models
- Unavailable resources issues
  - Flexible machines and cross trained workers

Quality Issues

- Make quality problems obvious
  - Error checking (Pokeyoke), Pull system
- Reduce WIP, which hides problems
- Stop the line
- Fix it now
- Cooperative problem solving

Delivery Time Issues

- Kanban card: type & quantity needed
  - Smooth production
  - Standardize work
  - Reduce set-up
  - Design machine layout - TPS cells
  - Autonomation - autonomous defect control

Monden

Unavailable Resource Issues

- Fast set up
  - Single Minute Exchange of Dies (SMED)
- Flexible (general purpose) machines
  - Toyota Cells
- Cross-trained work force

Autonomation…

- Monden claims that the word "autonomation" comes from the Japanese word *Jidoka*. which has two meanings, the first is automation in the usual sense, to change from a manual process to a machine process. The second meaning is "automatic control of defects". He says this is the meaning coined by Toyota. This second meaning is sometimes referred to as *Ninbennoaru Jidoka*, which literally translates into automation with a human mind. Monden goes on to say that "although autonomation often involves some kind of automation, it is not limited to machine processes but can be used in conjunction with manual operations as well. In either case, it is predominantly a technique for detecting and correcting production defects and always incorporates the following devices; in mechanism to detect abnormalities or defects; a mechanism to stop the line or machine when abnormalities or defects occur. When a defect occurs, the line stops, forcing immediate attention to the problem, an investigation into its causes, and initiation of corrective action to prevent similar defects from occurring again…"

- Reference; Yasuhiro Monden, Toyota Production System,

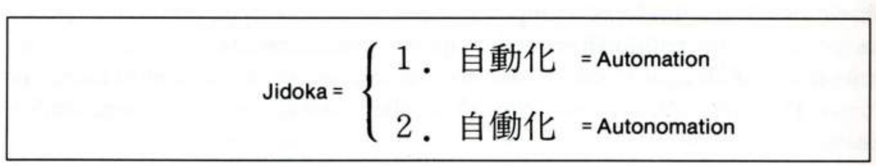


Figure 14.3. Two meanings of Jidoka.

J T. Black’s 10 Steps

Ref; JT. Black “Factory with a Future” 1991

1. Form cells
2. Reduce setup
3. Integrate quality control
4. Integrate preventive maintenance
5. Level and balance
6. Link cells – KANBAN
7. Reduce WIP
8. Build vendor programs
9. Automate
10. Computerize

J T. Black –1, 2

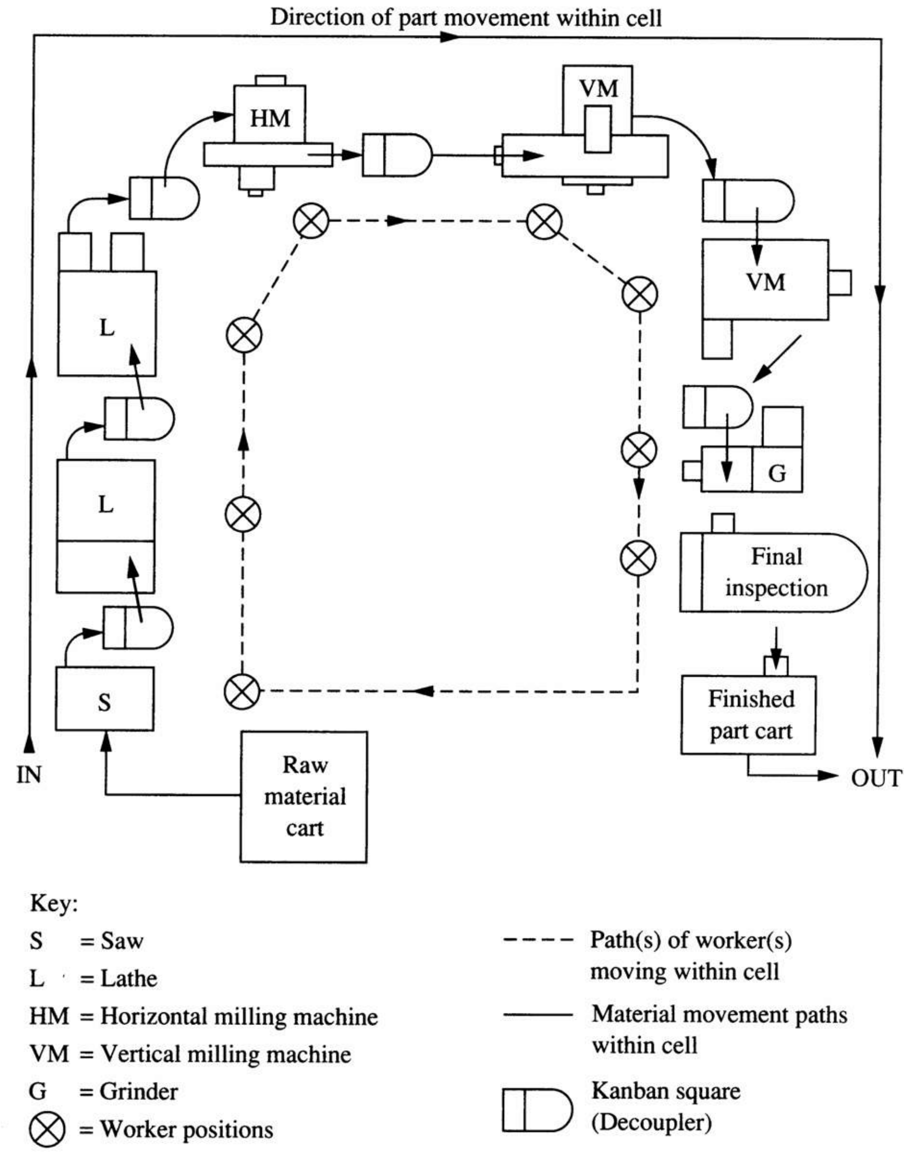
1. Form Cells

   Sequential operations, decouple operator from machine, parts in families, single piece flow within cell

2. Reduce Setup

   Externalize setup to reduce down-time during changeover, increases flexibility

Toyota Cell, one part is produced for every trip around the cell



J T. Black – 3, 4

3. Integrate quality control

   Check part quality at cell, poke-yoke, stop production when parts are bad, make problems visible, Andon

4. Integrate preventive maintenance

   worker maintains machine , runs slower, operator owns production of part

J T. Black – 5, 6

5. Level and balance

   Produce to Takt time, reduce batch sizes, smooth production flow, produce in mix to match demand

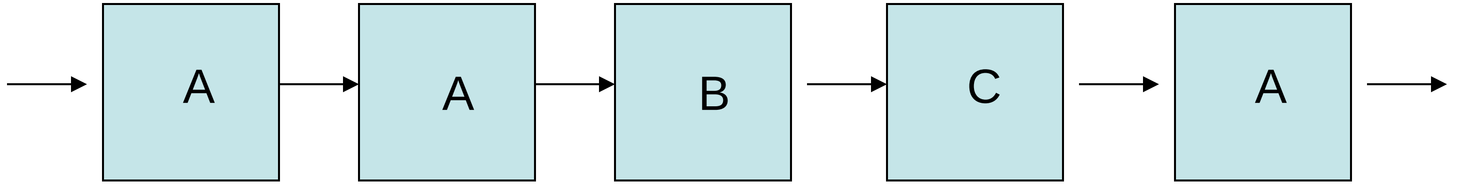
6. Link cells- Kanban

   Create "pull" system – "Supermarket" System that indicates the status of the system

Balancing and Leveling

- Balanced line: adjust process time for smooth flow "Takt time"

- Leveled Line: each product is produced in the needed distribution.



J T. Black – 7, 8

7. Reduce WIP

   Make system reliable, build in mechanisms to self correct,reduce inventory

8. Build Vendor program

   Propagate low WIP policy to your vendors, reduce # of vendors, make on-time performance part of expectation

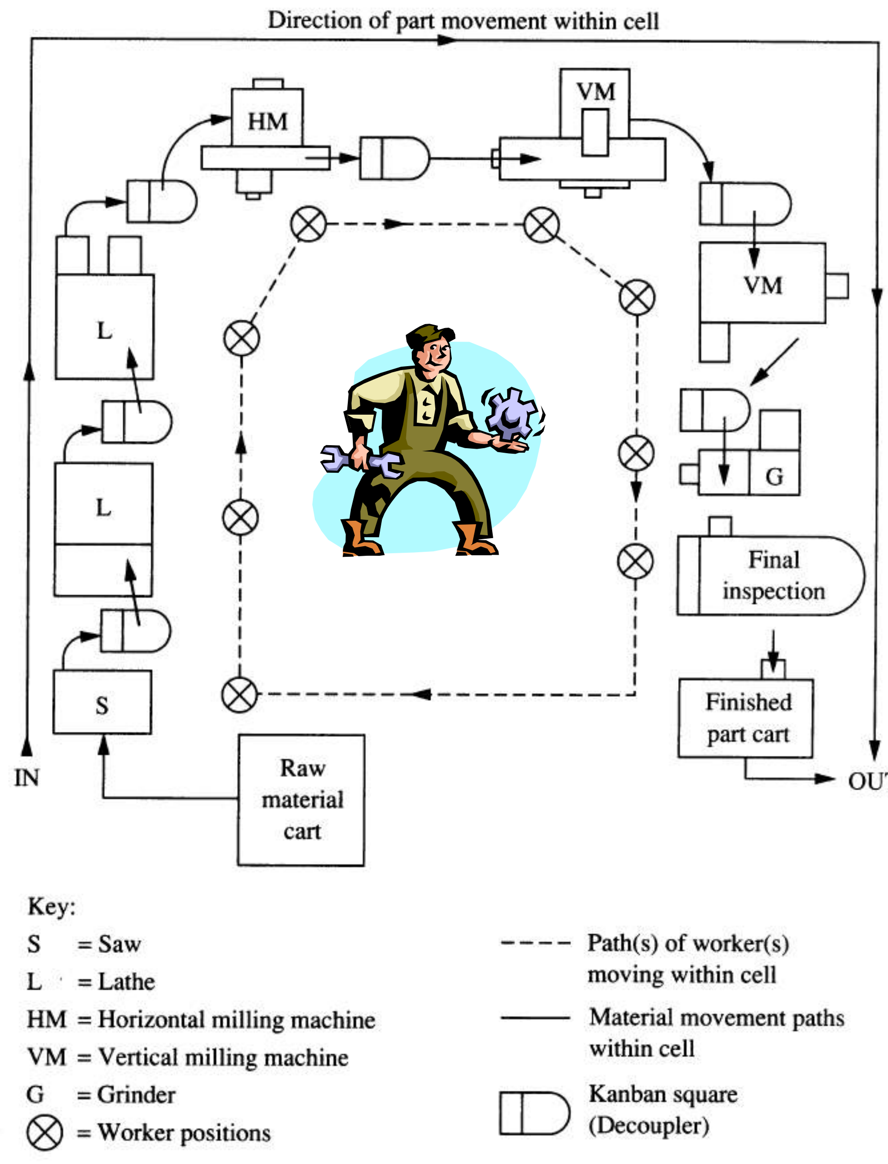
TPS Cell: Example

1. Work flow (part separate from worker)
2. Standard work (highly specified)
3. Production rate flexibility

Ref: J T. Black Ch 4

Machining Cell

Operator moves part from machine to machine (including “decouplers”) by making traverse around the cell.



Cell Features

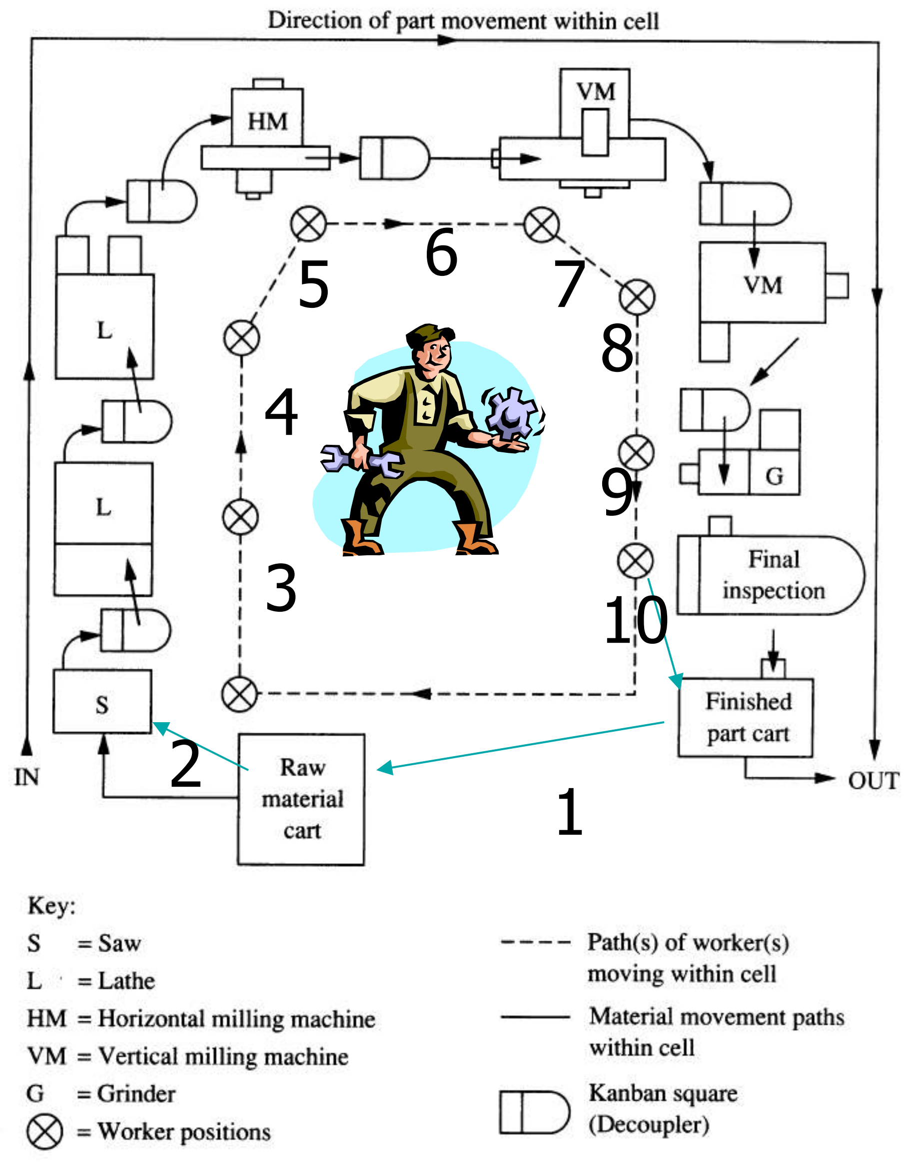
- "Synchronized", sequential production
- Operator decoupled from individual machines
- Operator integrated into all tasks
- Goal: single piece Flow
- Best with single cycle automatics, but can be done manually too

See Brigg & Stratton Video

Walking segments - 10

Machining Cell

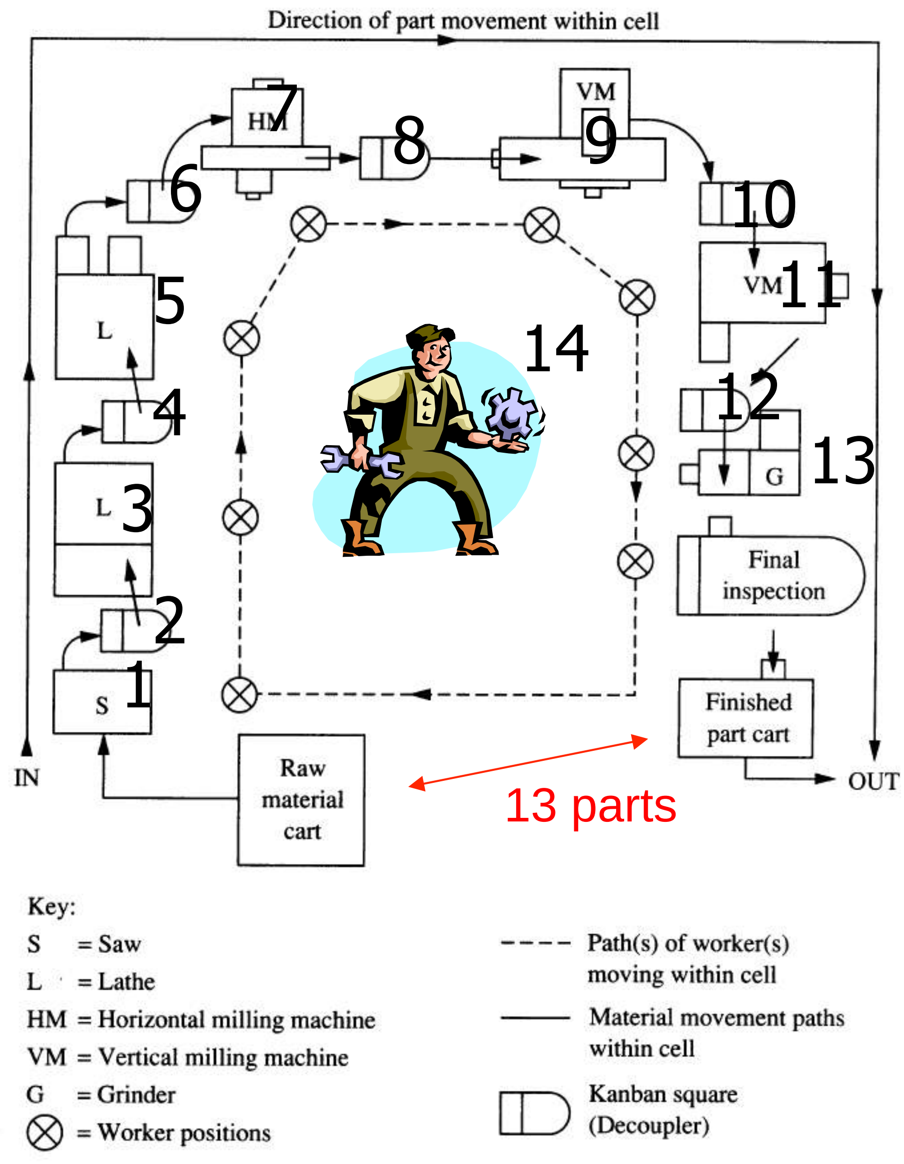
segment		Manual (Sec)	Walk to (Sec)	Machine (Sec)
1	Raw		3	
2	Saw	15	3	60
3	L1	10	3	70
4	L2	12	3	50
5	HM	12	3	120
6	VM1	20	3	70
7	VM2	20	3	60
8	G	15	3	60
9	F.I.	19	3	
10	Finish part		3	
	Totals	**M+W**	**= 153**	**490**



Parts in the cell ~ 14

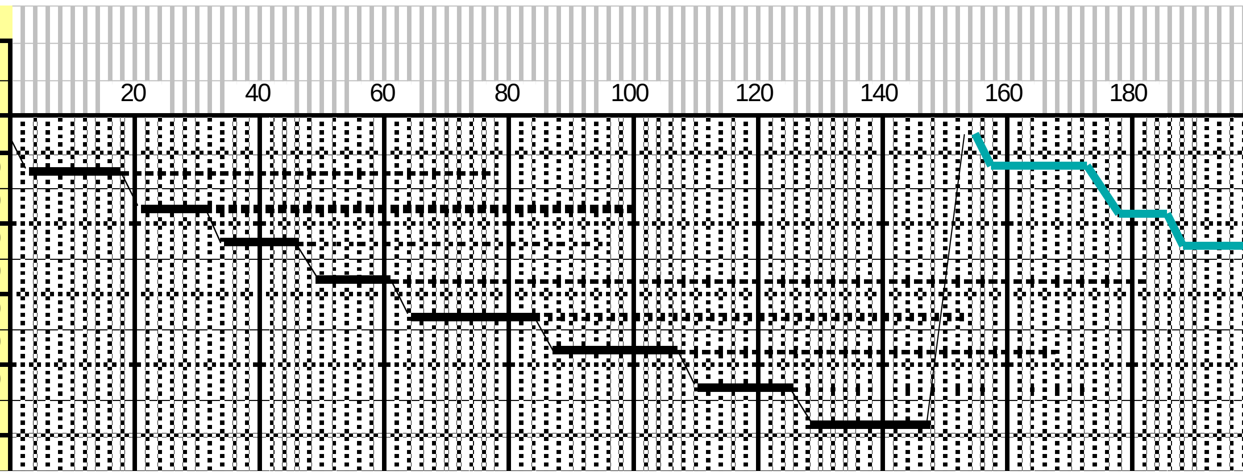
Machining Cell

	Manual (Sec)	Walk to (Sec)	Machine (Sec)
Raw		3	
Saw	15	3	60
L1	10	3	70
L2	12	3	50
HM	12	3	120
VM1	20	3	70
VM2	20	3	60
G	15	3	60
F.I.	19	3 + 3	
Totals	**M+W**	**= 153**	**490**



Standard Work for Cell

PA JT. Black Cell		**Operators:**		
PROCESS		**TIME {secs}**		
#	**OPERATION**	Man	Walk	Auto
1	Raw		3	
2	Saw	15	3	60
3	L1	10	3	70
4	L2	12	3	50
5	HM	12	3	120
6	VM1	20	3	70
7	VM2	20	3	60
8	G	15	3	50
9	F.I.	19	6	



Cell produces one part every 153 sec

Note: machine time Max (MTj) < cycle time CT

i.e. 120+12 < 153

TPS Cell

1. Production rate = λ

$$\lambda = \frac{1 part}{153 \text{ sec}} = 23.5 \text{ parts/hr}$$

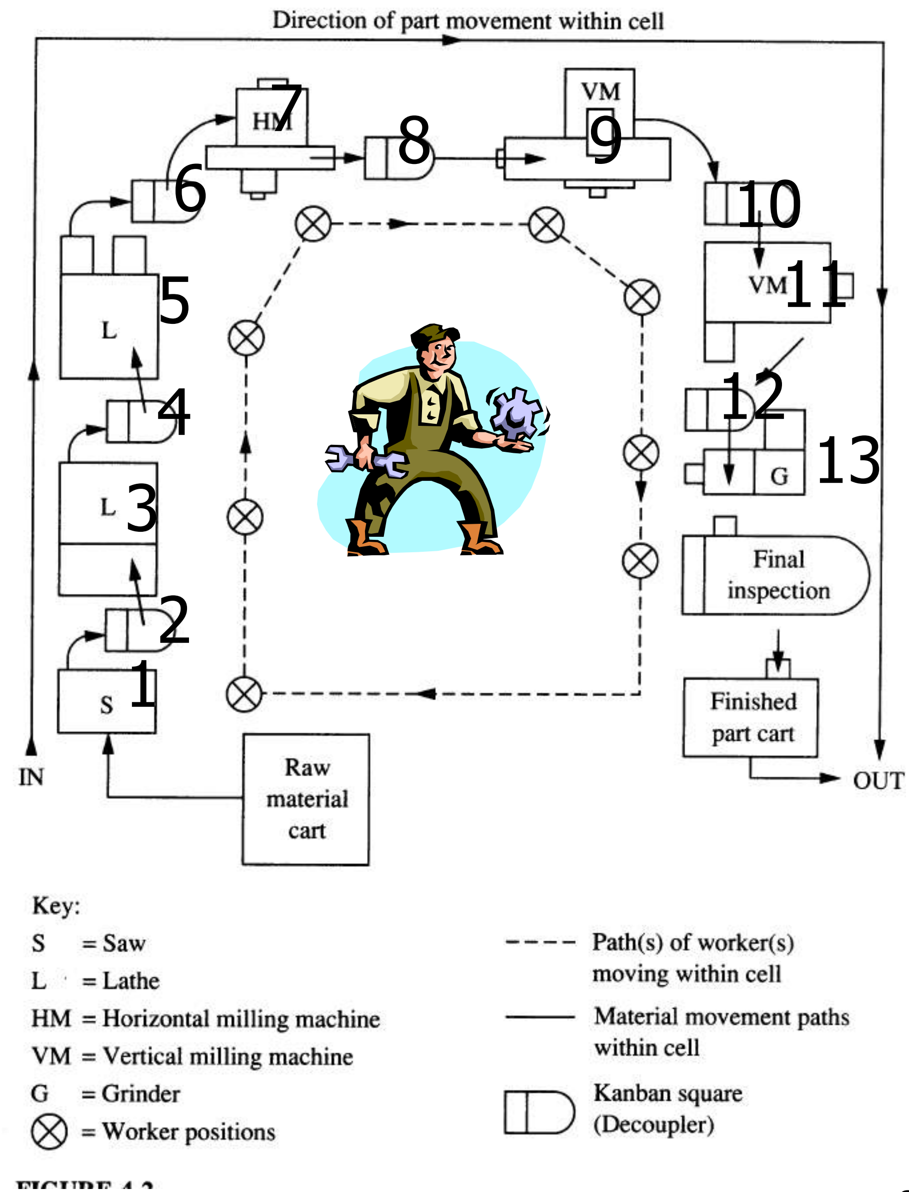
2. WIP = L?
3. Time in the system = W?

Number of round trips; 13

Machining Cell

Saw	3+15	+ 153
#1 decoupler	1.5	+153
L1	1.5+ 10	+153
	…….	…….
Grind	1.5+ 15	+153
Manual and walk	19+3	out
	150	153X13 =1989

1989 + 150 = 2139

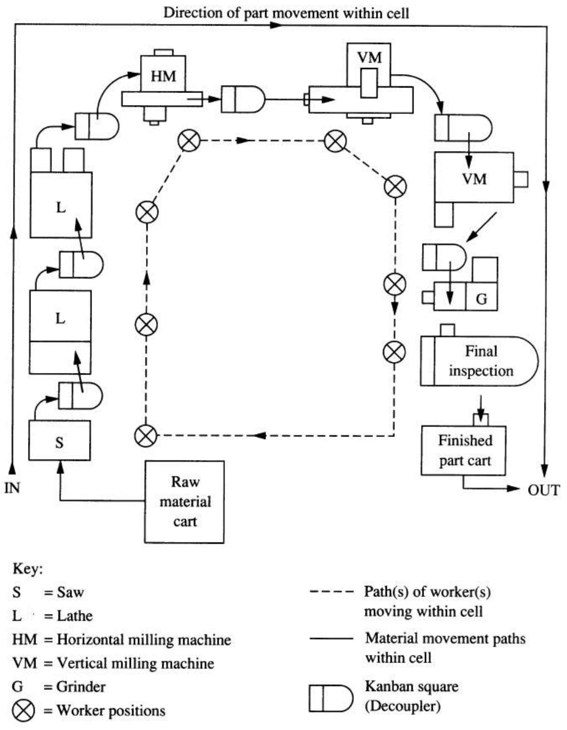


By Little's Law

L = (13 + 1) X (150/153) +
13 X (3/153) = 13.98 parts

rate, λ = 1/153 parts/second

W = 153 X 13.98 = <u>2139 sec</u>



TPS Cell

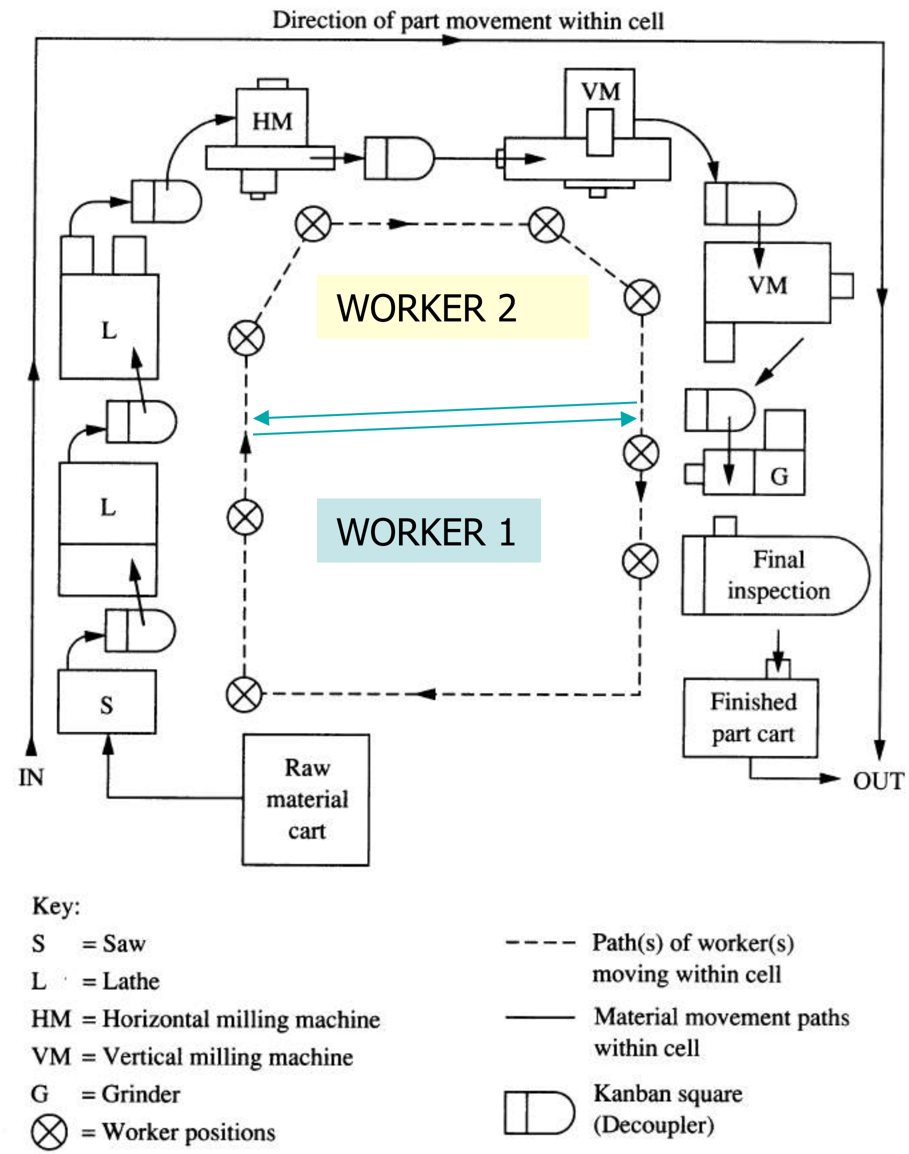
Increase production rate:

a) add additional worker to cell

b) modify machine bottlenecks

To increase production rate add 2nd worker

	Manual (Sec)	Walk to (Sec)	Machine (Sec)
Raw		3	
Saw	15	3	60
L1	10	3+3	70
L2	12	3	50
HM	12	3	120
VM1	20	3	70
VM2	20	3+3	60
G	15	3	60
F.I.	19	3 + 3	
Totals	**M+W**	**= 159**	**490**
Work 1		**80**	
Work 2		**79**	



What is the production rate for this new arrangement?

Check max(MTj) < CT

Worker 1; 80 = 80

Worker 2; 12+120 >79

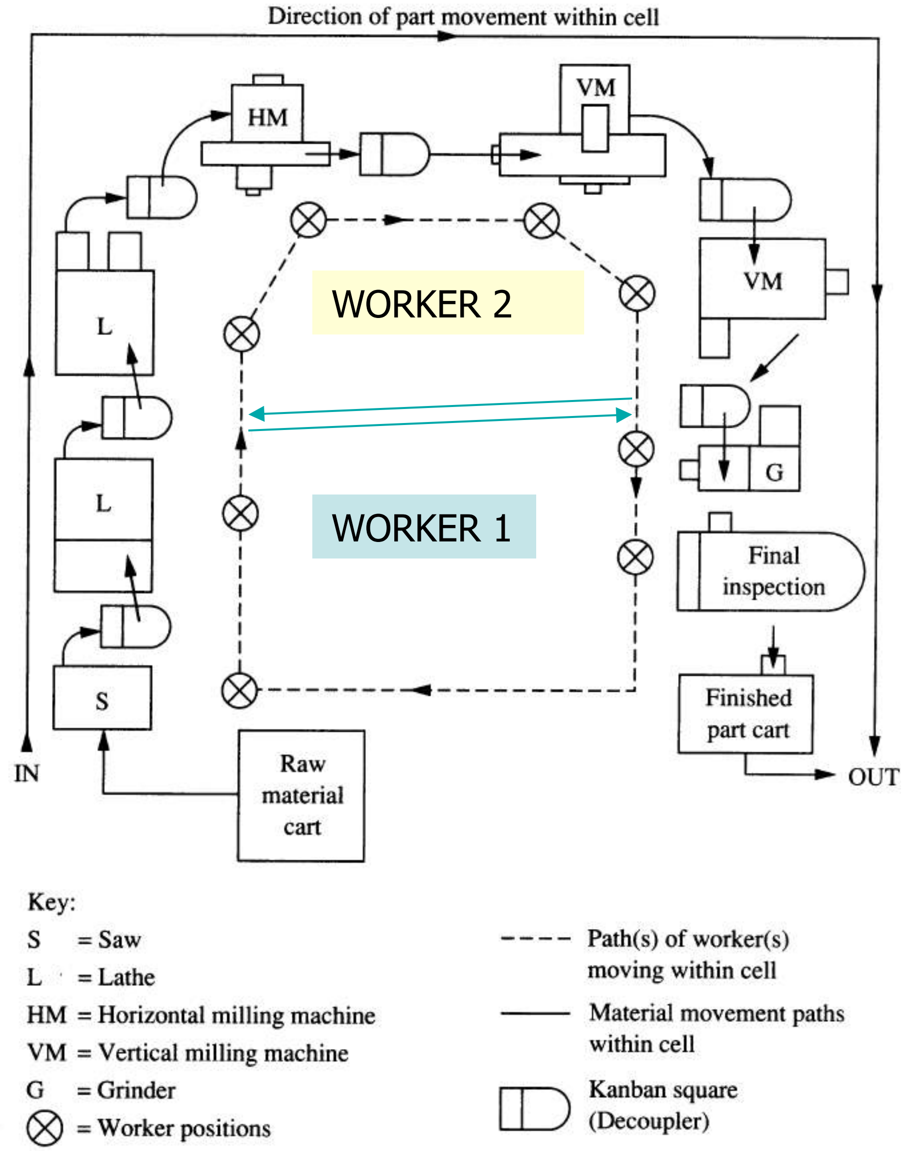
One part every 132 seconds

We are limited by the HM (horizontal mill)

$$\lambda = \frac{1 part}{132 \text{ sec}} = 27.3 \text{ parts/hr}$$

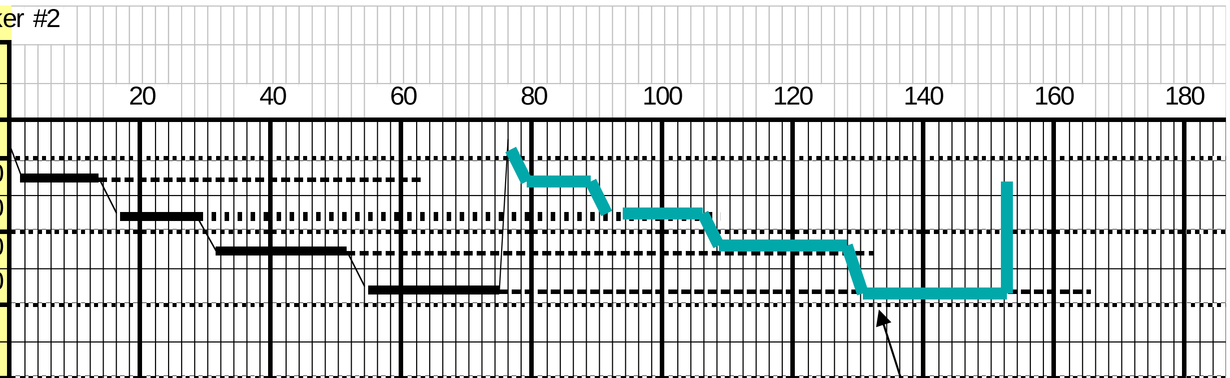
Can we shift work off of the HM to reduce the cycle time?

	Manual (Sec)	Walk to (Sec)	Machine (Sec)
Raw		3	
Saw	15	3	60
L1	10	3+3	70
L2	12	3	50
HM	12	3	120 → 80
VM1	20	3	70 → 80
VM2	20	3+3	60 → 90
G	15	3	60
F.I.	19	3 + 3	
Totals	**M+W**	**= 159**	**490**
Work 1		**80**	
Work 2		**79**	



Standard Work for Worker #2

Rod Support	Operators: Worker #2		
OCESS	**TIME {secs}**		
OPERATION	Man	Walk	Auto
from decoupler		1.5	
L2	12	3	50
HM	12	3	80
VM1	20	3	80
VM2	20	1.5	90



Cycle # 1

Cycle # 2

+3

Operator waiting
On machine

What is the new production Rate?

Check max(MTj) < CT

Worker 1;   80 = 80

Worker 2;   110 > 79

Hence Worker #2 will be waiting on Vertical Mill #2

What is the new production Rate?

- The new production rate is;

  one part every 110 sec

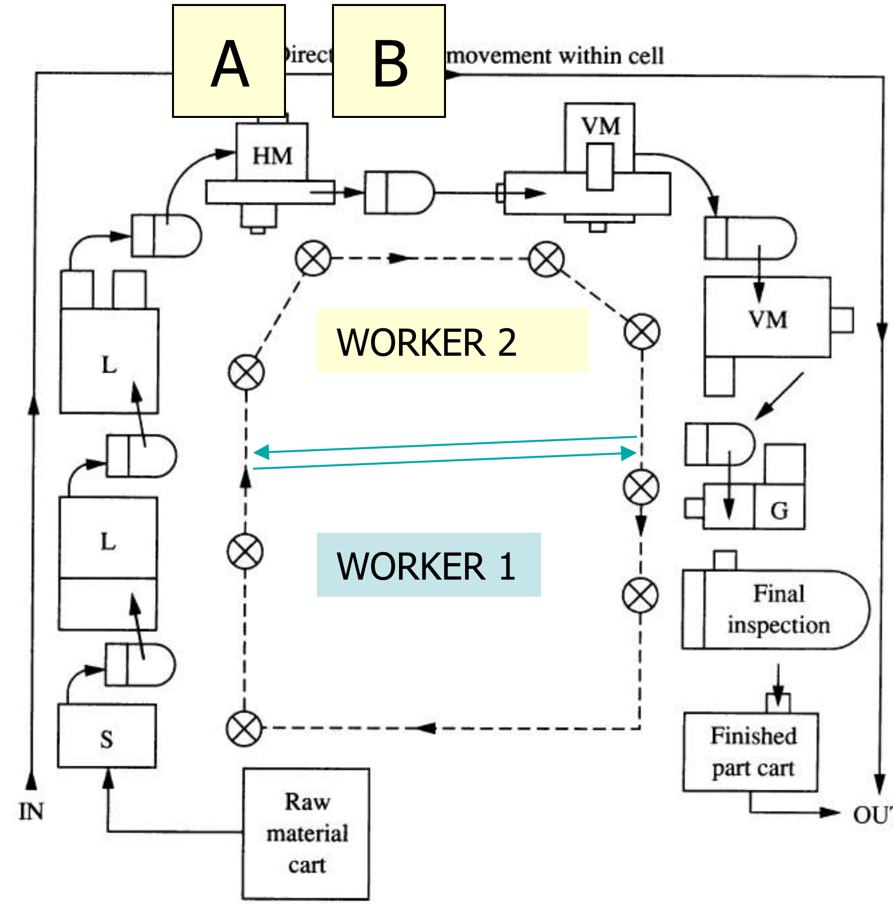
- Pro and Cons; Worker "idle", can't speed up by adding additional worker
- Design for flexibility make;

  Max(MTj) < CT/2

$$\lambda = \frac{1 \, part}{110 \text{ sec}} = 32.7 \text{ parts/hr}$$

Alternative solution add 2 HM's

	Manual (Sec)	Walk to (Sec)	Machine (Sec)
Raw		3	
Saw	15	3	60
L1	10	3+3	70
L2	12	3	50
HM	12	3	120
VM1	20	3	70
VM2	20	3+3	60
G	15	3	60
F.I.	19	3 + 3	
Totals	**M+W**	**= 159**	**490**
Work 1		**80**	
Work 2		**79**	



$$\lambda = \frac{1 part}{90\ sec} = 40 \text{ parts/hr}$$

Almost double!

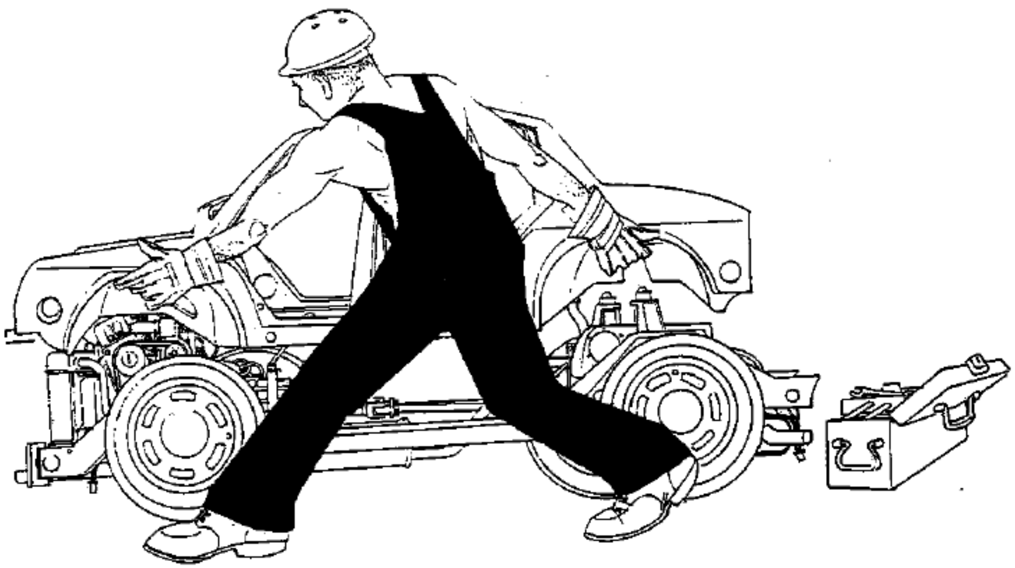
TPS cell summary

1. Original cell - 23.5 parts/hr
2. Additional worker- 27.3 parts/hr
3. + Shift work- 32.7 parts/hr
4. ++ add additional VM 40 parts/hr

TPS Implementation

- Physical part (machine placement, standard work etc)
- Work practices and people issues
- Supply-chain part
- Corporate Strategy (trust, job security)

Is there a best way to build a car?



- *Maccoby HBR 1997*
- *Other Ref: "Just Another Car Factory" Rinehart, Huxley and Robertson, "Farewell to the Factory", Milkman*

Work practices and people issues

- "Failed" TPS attempts; GM Linden NJ, CAMI, GM-Suzuki, Ontario Canada.
- Successes GM NUMMI, Saturn. Toyota Georgetown, KY
- *Maccoby HBR 1997*
- *Other Ref: "Just Another Car Factory" Rinehart, Huxley and Robertson, "Farewell to the Factory", Milkman*

According to Maccoby’s Review

- Failure Examples:
  - failures at middle management
  - pressure from above to meet targets, lack of trust from below, but…
  - both plants adopted some aspects of lean, and
  - both plants improved

NUMMI and Georgetown

- workers have different attitude
- do not fear elimination
- play important role
- ...go to Georgetown and find out

NUMMI plant today - Tesla

“The DNA of the TPS”

- Spear and Bowen
- 4 years 40 plants
- HBR Sept-Oct 1999
- Four Rules:

Four Rules…

- Rule 1: All work shall be highly specified as to content, sequence, timing and outcome.
- Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.
- Rule 3: The pathway for every product and service must be simple and direct.
- Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

Spear and Bowen

TPS Summary

- High quality and low cost paradigm shift
- Many elements to the system
  - Make system observable
  - Produce to demand
  - Study defects and eliminate
  - Institutionalize change
  - Trust
- Many companies have imitated TPS

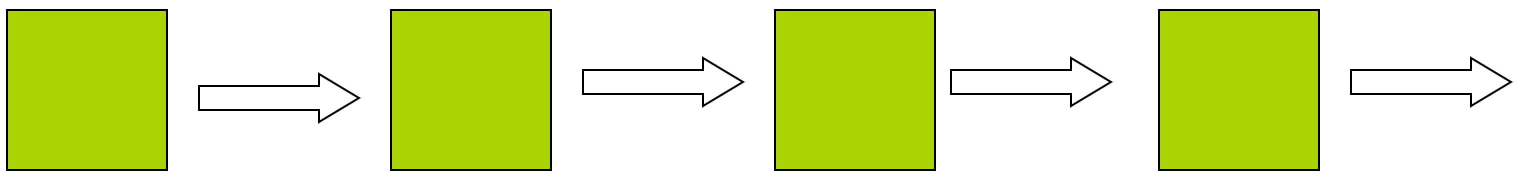
Key Elements for New Mfg Systems

Element/ System	Need of Society	Work Force Motivation	Enabling Technology	Leader	Resources
Interchange-able Parts	Military	"Yankee Ingenuity"	Machine Tools, Division of Labor	Roswell Lee/ John Hall	U.S. Govt
Mass Production	Trans-portation	$5/day Immigrant	Moving Assembly Line,etc	Henry Ford	Earnings
Toyota Production System	Post War	Jobs, Security	Systems approach	Taiichi Ohno	Japanese Banks

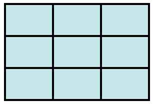
Push Vs Pull

Push and Pull Systems

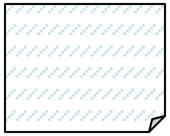
Machines



1 2 3 4



Parts

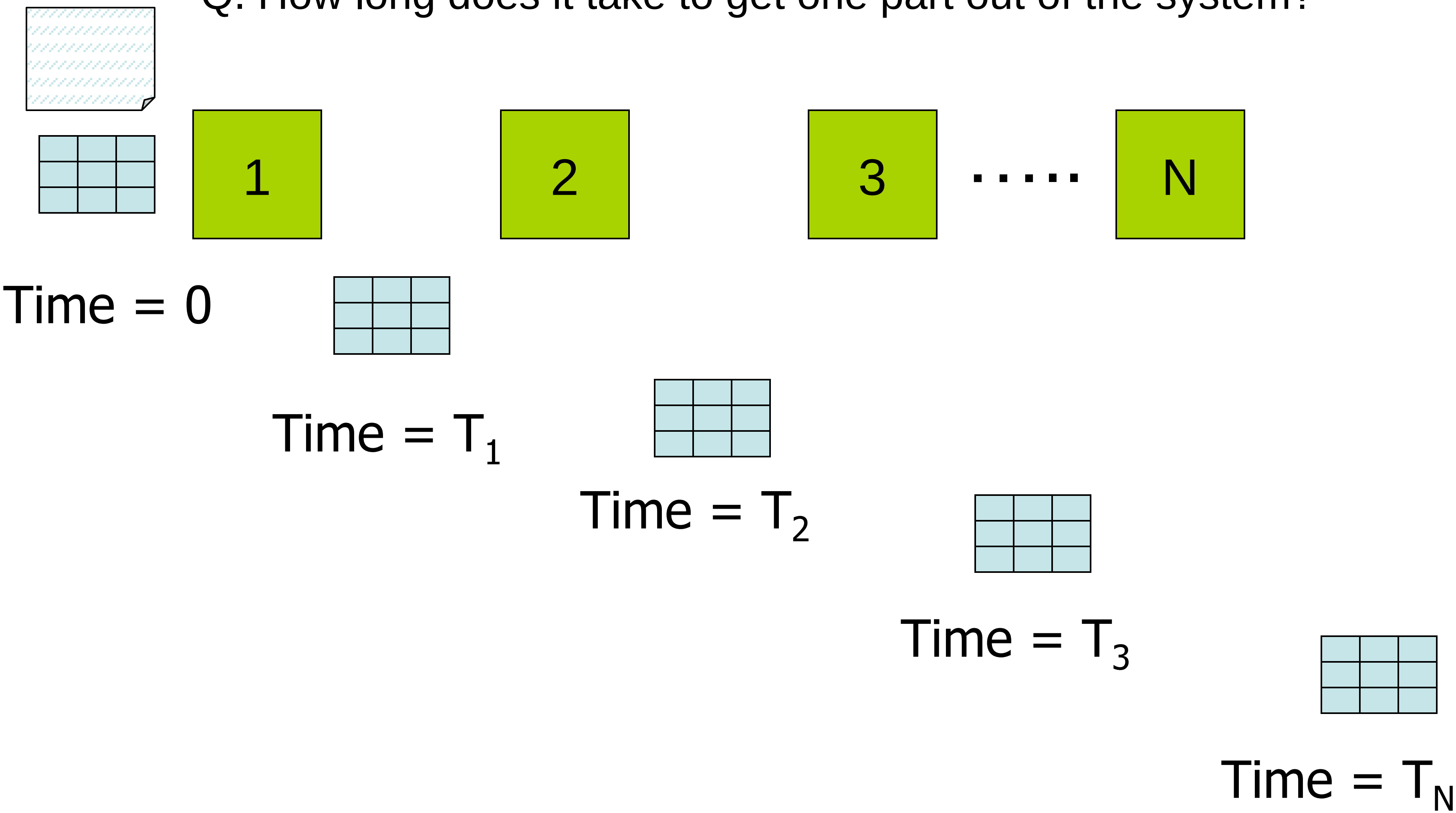


Orders

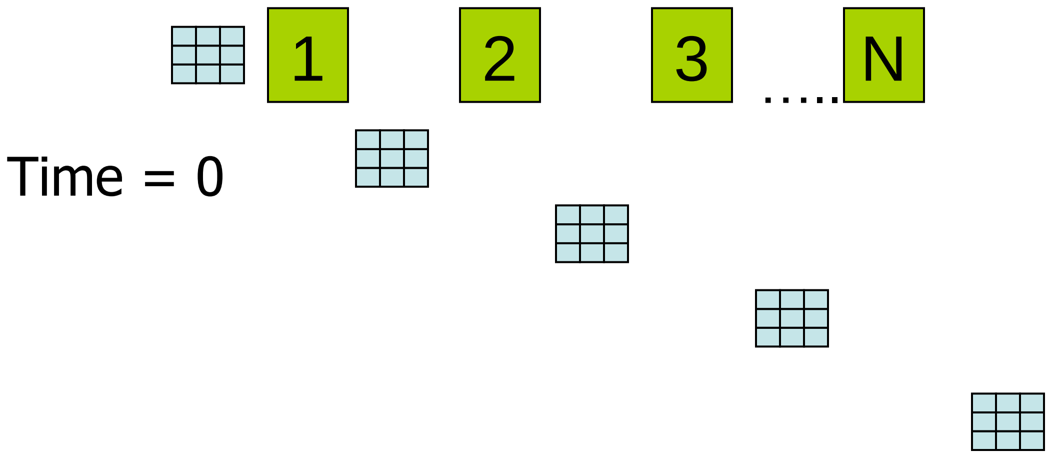
Push Systems –

Order (from centralized decision process) arrives at the front of the system and is produced in batches of size “B”.

Q. How long does it take to get one part out of the system?



Push Systems –



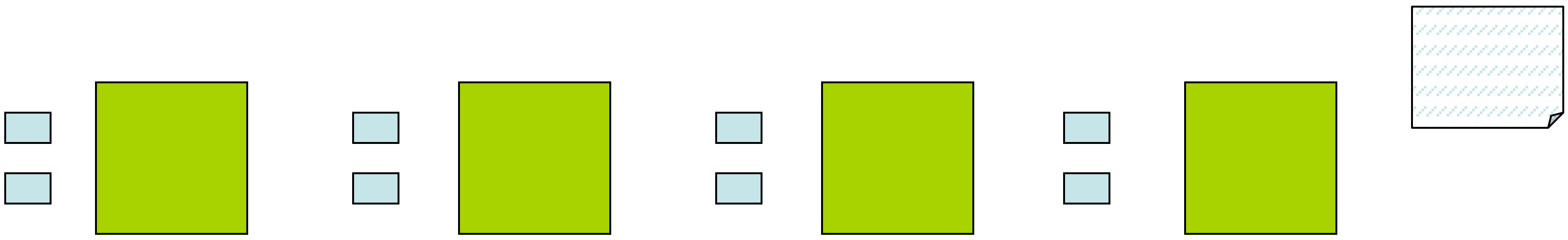
Time = T_N

Comment; Of course, this part can come from inventory in a much shorter time, but the point is that the push system is not very responsive.

If the process time per part is "t" at each of "N" processes, and the batch size is "B", it takes time T_N = "NBt" to get one part through the system.

Pull Systems-

The order arrives at the end of the line and is "pulled" out of the system. WIP between the machines allows quick completion.



Q.How long does it take to pull out one part?

A.The time to finish the last operation "t".

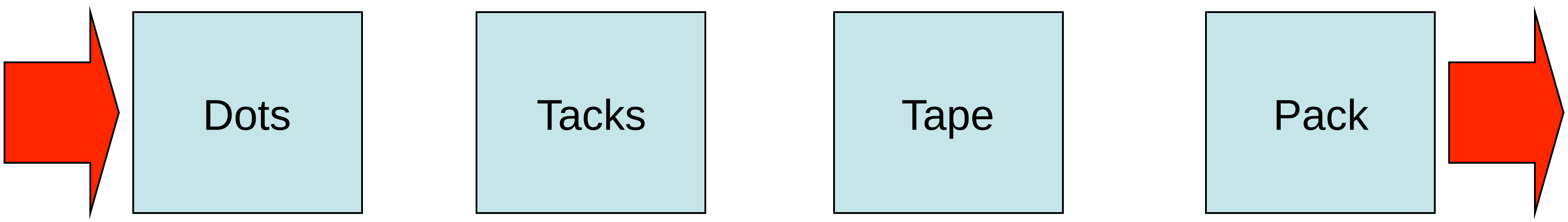
Comparison between Push and Pull Systems

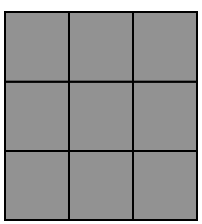
Push system characteristics: Central decision making, large inventories and a sluggish system.

Pull system characteristics: Local decision making, WIP, best with product differentiation at the end

HP Video if time

HP Video





Inventory in the system = L

Time in the system = W

Little's Law $L = \lambda W$

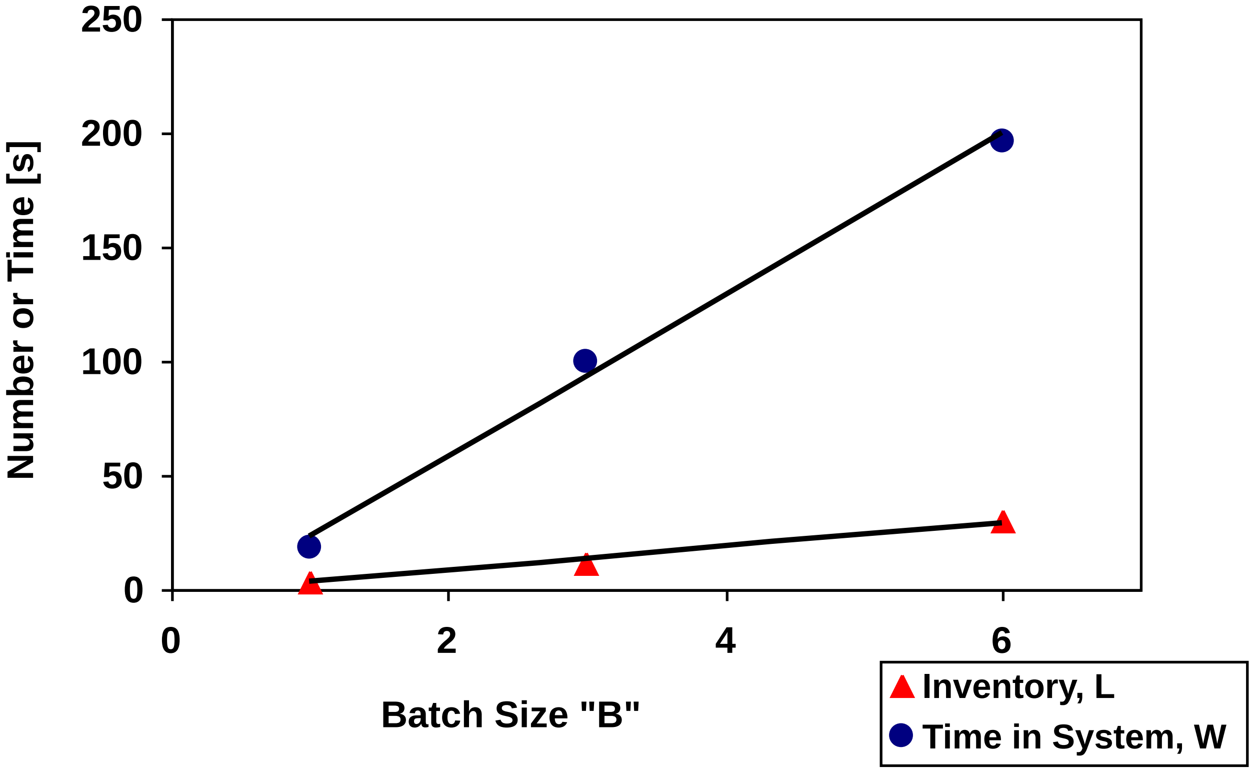
HP Video Results

	Push system (6)	**Pull (3)**	**Pull (1)**
Space	2 Tables	2 Tables	1 Table
WIP	30	12	4
“Cycle time” = **W**	3:17	1:40	0:19
Rework Units ≈ **WIP***	26	10	3
Quality Problem	Hidden	Visible	Visible

HP Video Results

	Push system (6)	**Pull (3)**	**Pull (1)**
Space	2 Tables	2 Tables	1 Table
WIP	30	12	4
"Cycle time" = **W**	3:17	1:40	0:19
Rework Units ≈ **WIP***	26	10	3
Quality Problem	Hidden	Visible	Visible
Production Rate **λ = L* / W**	7.9 parts/min	6 parts/min	9.4 parts/min

Graphical Interpretation



$$L = \lambda W$$

$$\left.\begin{array}{l} L \approx k_1 B \\ W \approx k_2 B \end{array}\right\}$$

$$\boxed{\lambda = L / W = k_1 / k_2}$$

Readings

James Womack, Daniel T. Jones and Daniel Roos, The Machine that Changed the World, 1990, Ch 3 and 4

J T. Black "The Factory with a Future" Ch 2 & 4

Yasuhiro Moden Ch 1

Michael Maccoby, "Is There a Best Way to Build a Car?" HBR Nov-Dec 1997