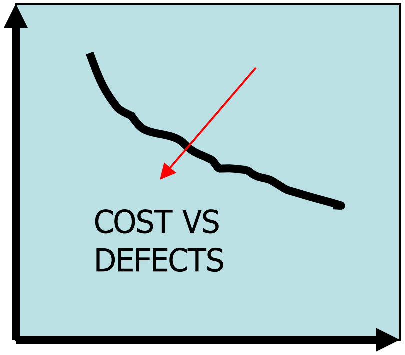


Introduction to the Toyota Production System (TPS)

2.810

T. Gutowski

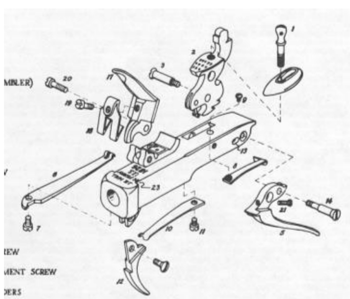
Nov 4, 2013

Three Major Mfg Systems from 1800 to 2000

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

1800 1900 2000

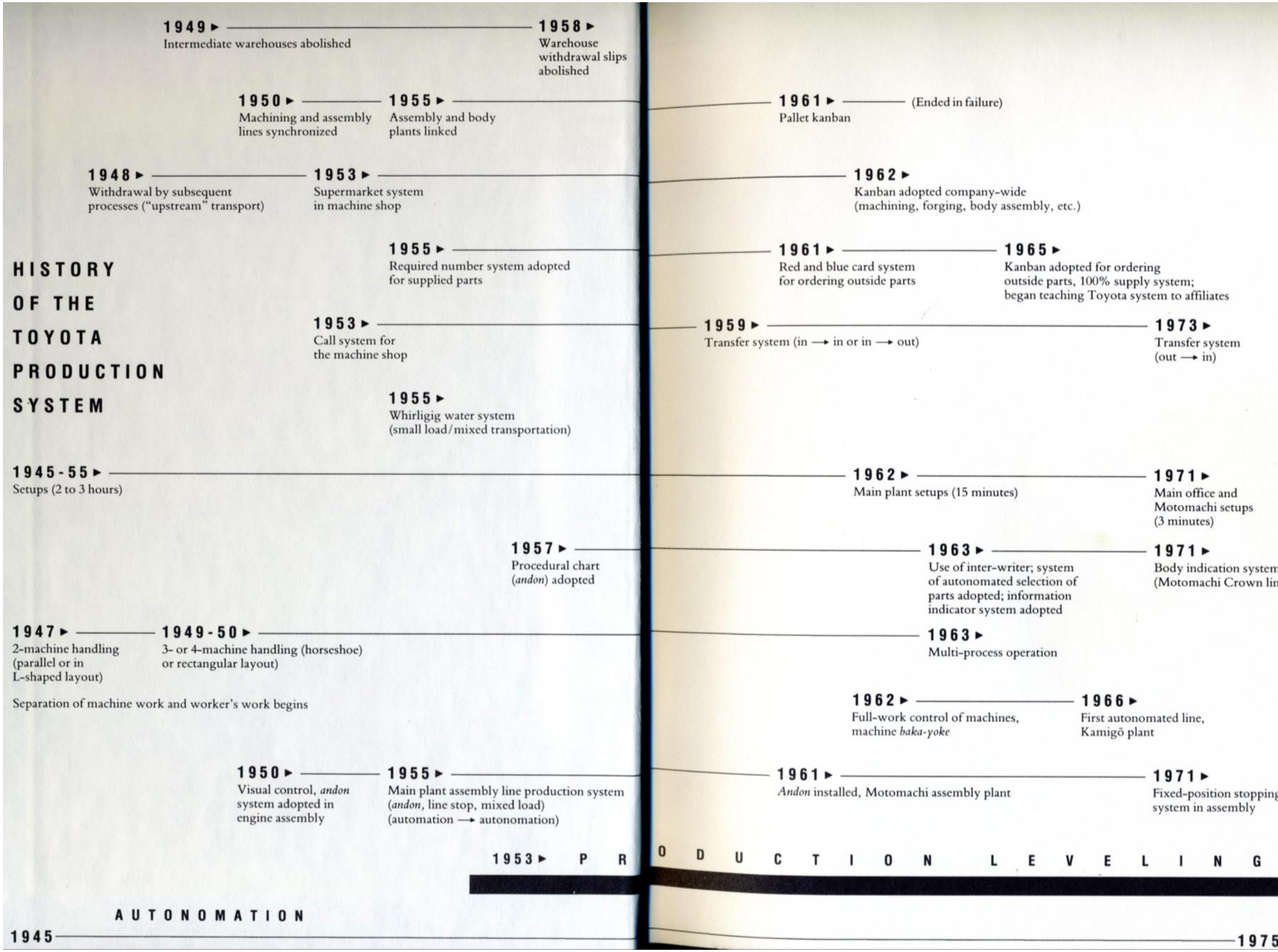
Interchangeable Parts at U.S. Armories



Mass Production at Ford

Toyota Production System

Toyota Production System Development History - Taiichi Ohno



How we learned about TPS

- Quality of cars
- 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,…

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

From Hayes, Wheelwright, Clark; “Dynamic Mfg”

| 7 |

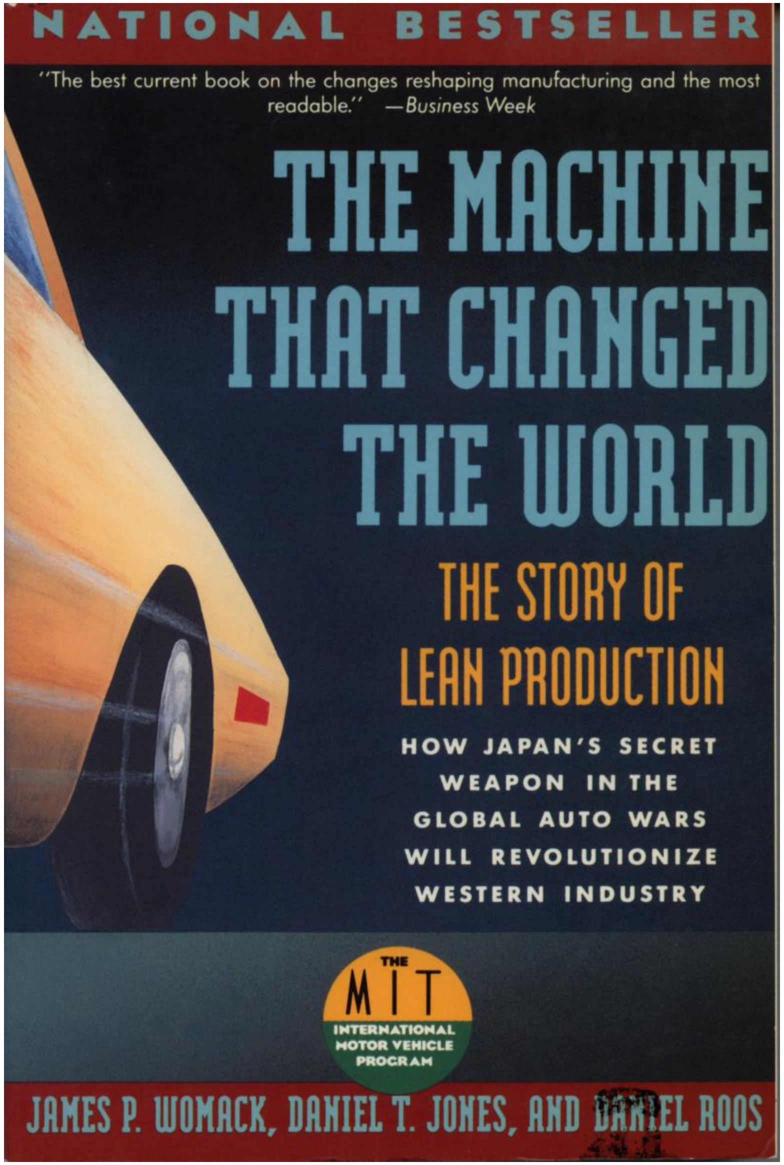
The Architecture of Manufacturing: Material and Information Flows

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", 1st 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

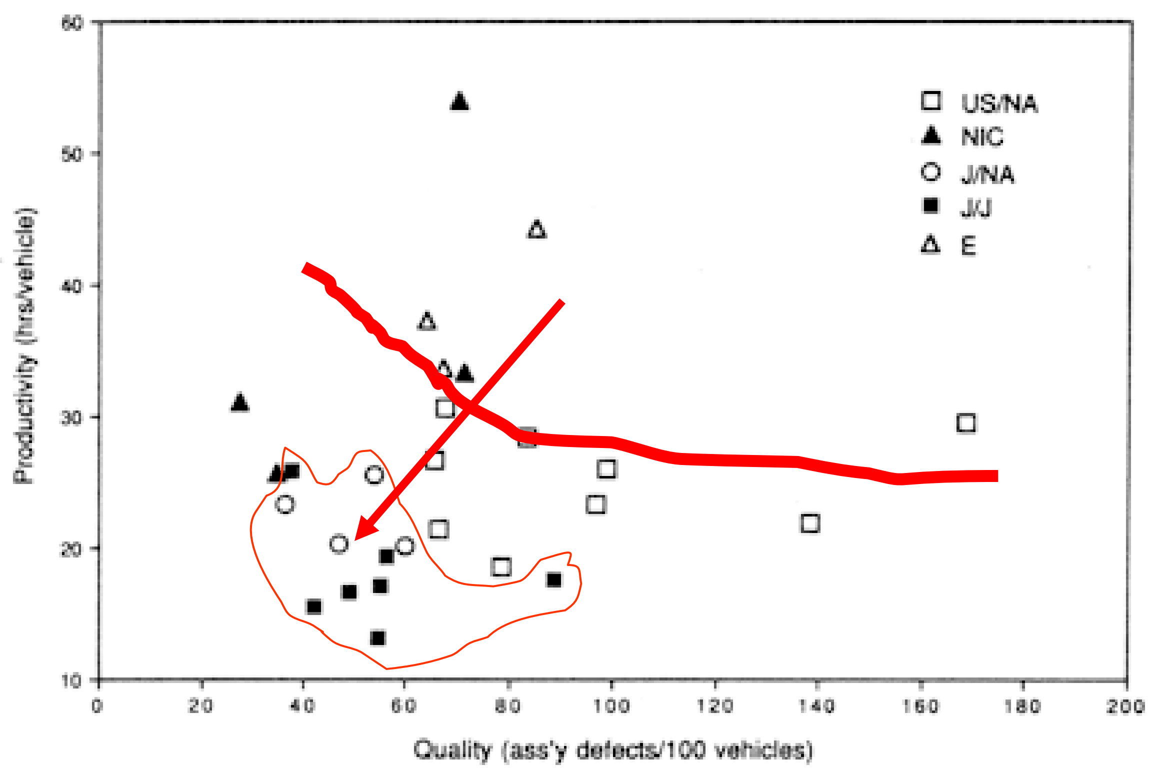
Source: IMVP World Assembly Plant Survey, 1989, and J. D. Power Initial Quality Survery, 1989

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



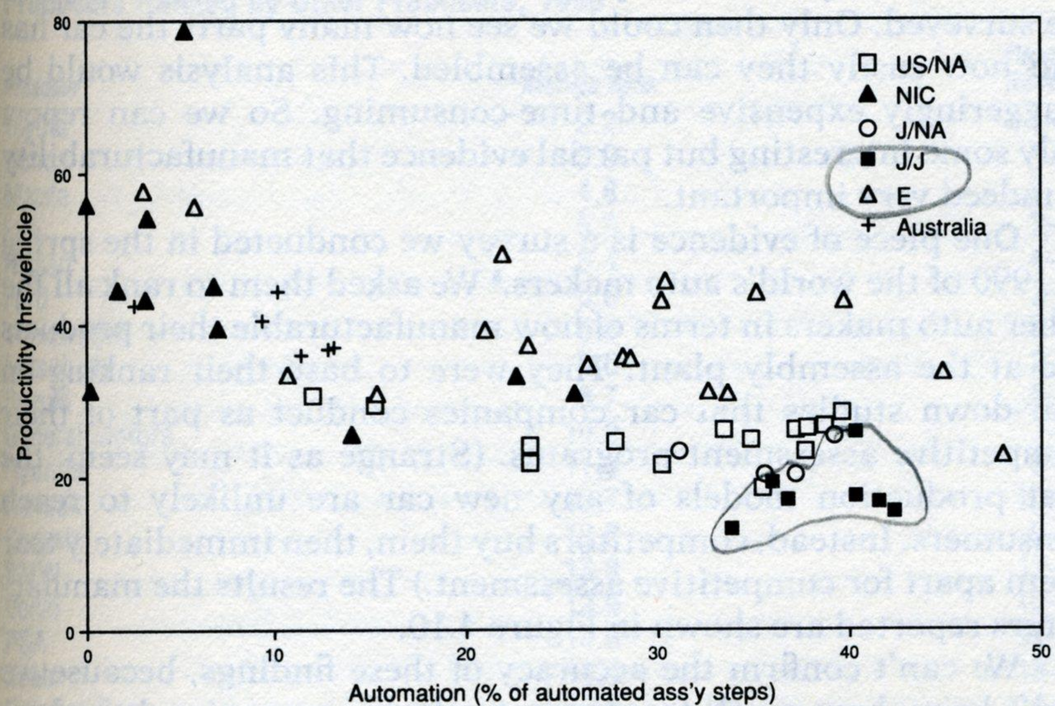
Source: IMVP World Assembly Plant Survey, 1989

Cost Vs Automation

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

FIGURE 4.9

Automation versus Productivity, Volume Producers, 1989

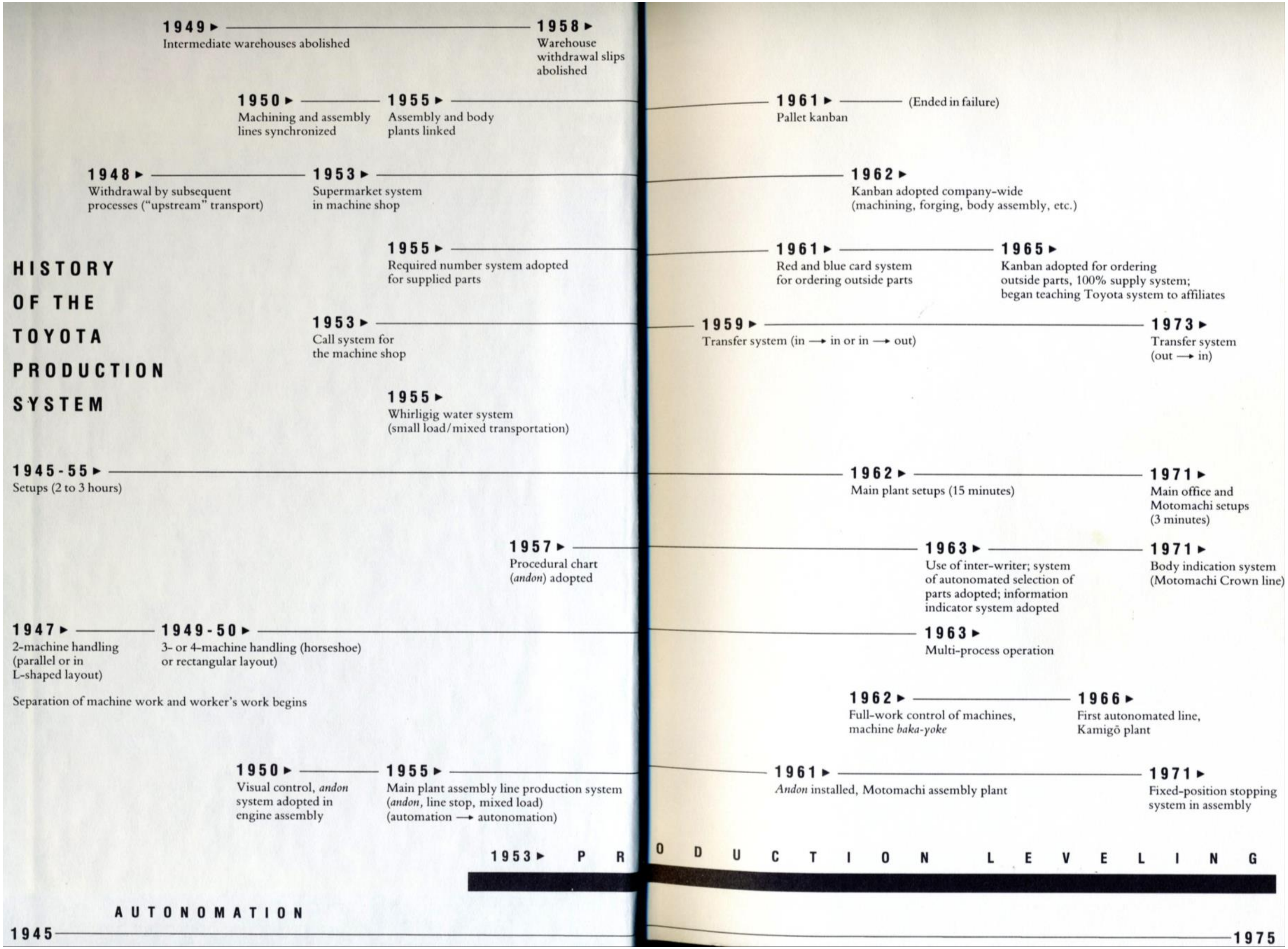


Note: “Automation” equals the percent of assembly tasks that have been automated. Automation includes both fixed automation such as multi-welders and flexible automation using robots. Automation of materials handling is not included.

Source: IMVP World Assembly Plant Survey, 1989

Source: IMVP World Assembly Plant Survey, 1989

Toyota Production System Development History - Taiichi Ohno



Elements:

Basic goal: reduce cost

1. Quantity control

   Low volumes, variety, avoid overproduction

2. Quality assurance

   Avoid producing out of spec products

3. Respect for humanity

   Labor strike and new agreement

Refs, mainly Monden, + Womack et al

Quantity Control

- Set-up time reduction
- Small lots production
- Reduction in lead time
- Production smoothing
- Kanban - JIT
- Adapt to demand changes
- Inventory cutting

Ref Monden

Quality Assurance

- "Autonomation"
  - Detect defects
  - Stop production
  - Fix problem

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,

Workforce

- Decouple worker from machine
- Multifunctional (empowered) worker
- Standard operations
- Flexibilization of workforce
- Source of ideas

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

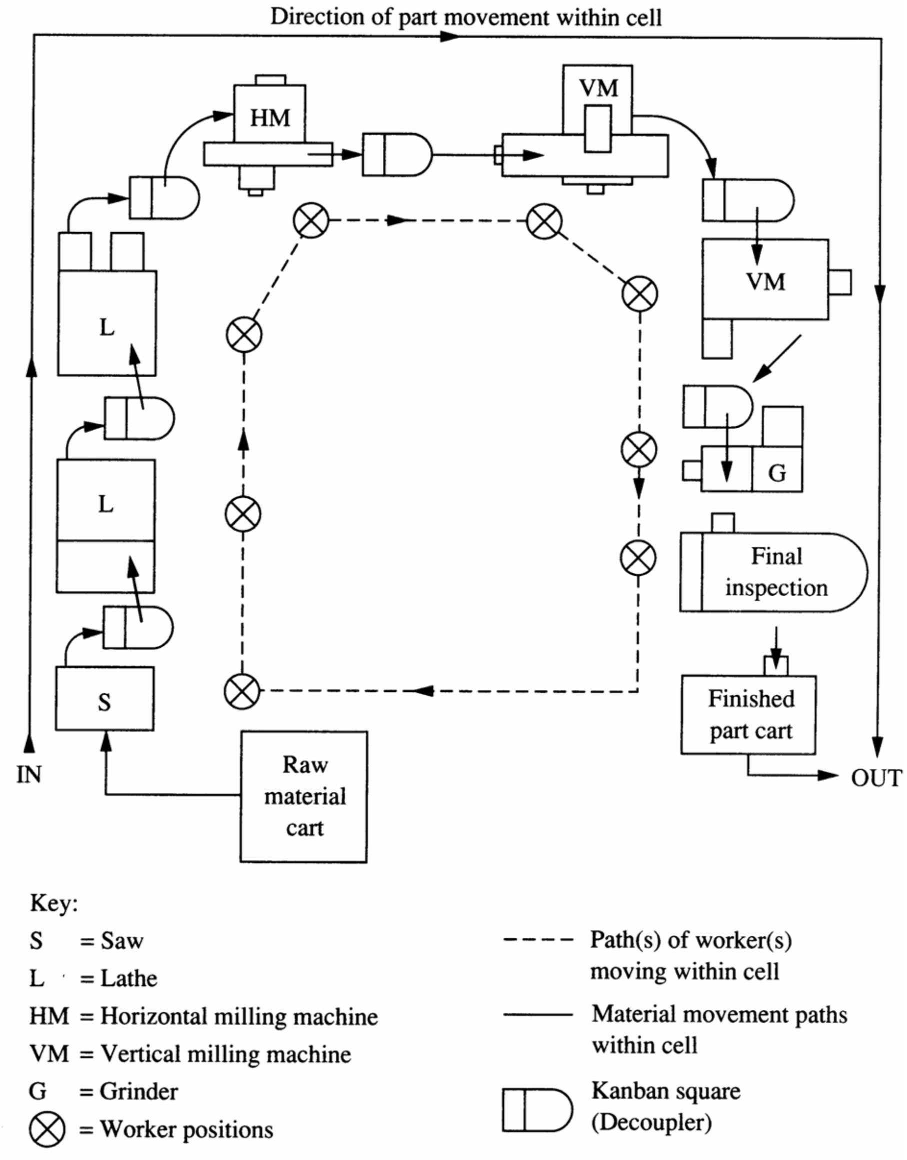
1. Form Cells

   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

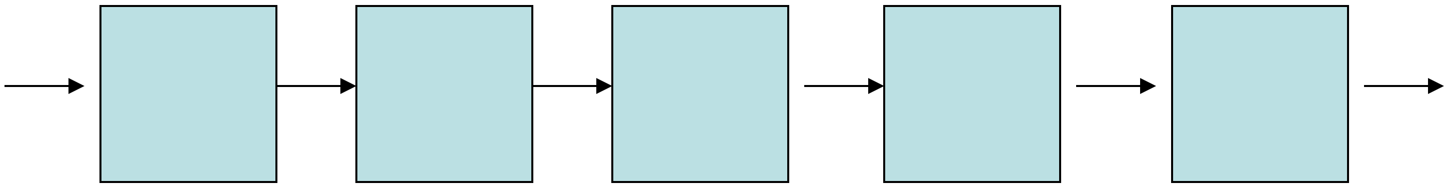
   Produce to Takt time, reduce batch sizes, smooth production flow, produce in mix to match demand

6. Link cells- Kanban

   Create “pull” system – “Supermarket” System that indicates the status of the system

Balancing and Leveling

- Balanced line: each process has the same cycle time. Match process time to assemble time, match production rate to rate of demand (Takt time)
- Leveled Line: each product is produced in the needed distribution. The process must be flexible to do this.



J T. Black – 7, 8

7. Reduce WIP

   Make system reliable, build in mechanisms to self correct

8. Build Vendor program

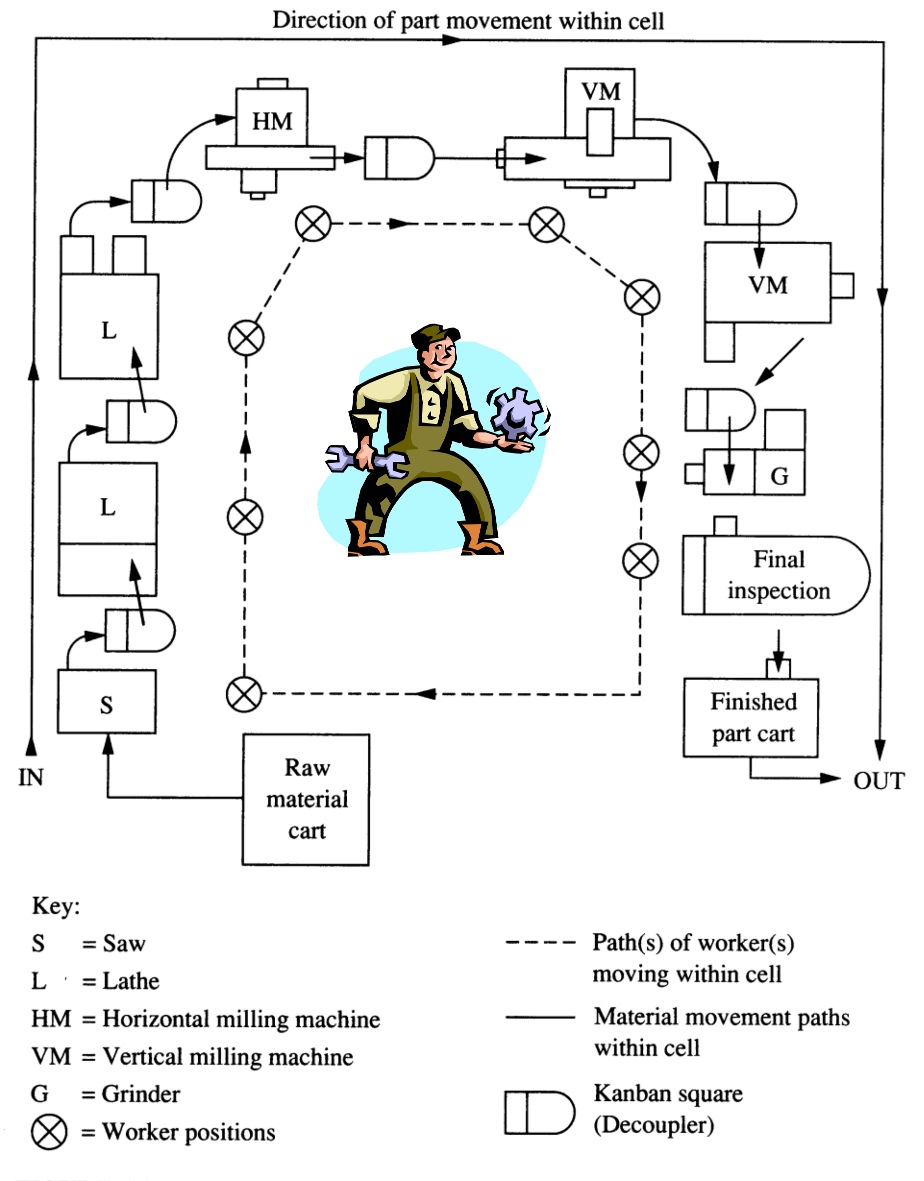
   Propagate low WIP policy to your vendors, reduce vendors, make on-time performance part of expectation

TPS Cell

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

Machining Cell

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



Cell Features

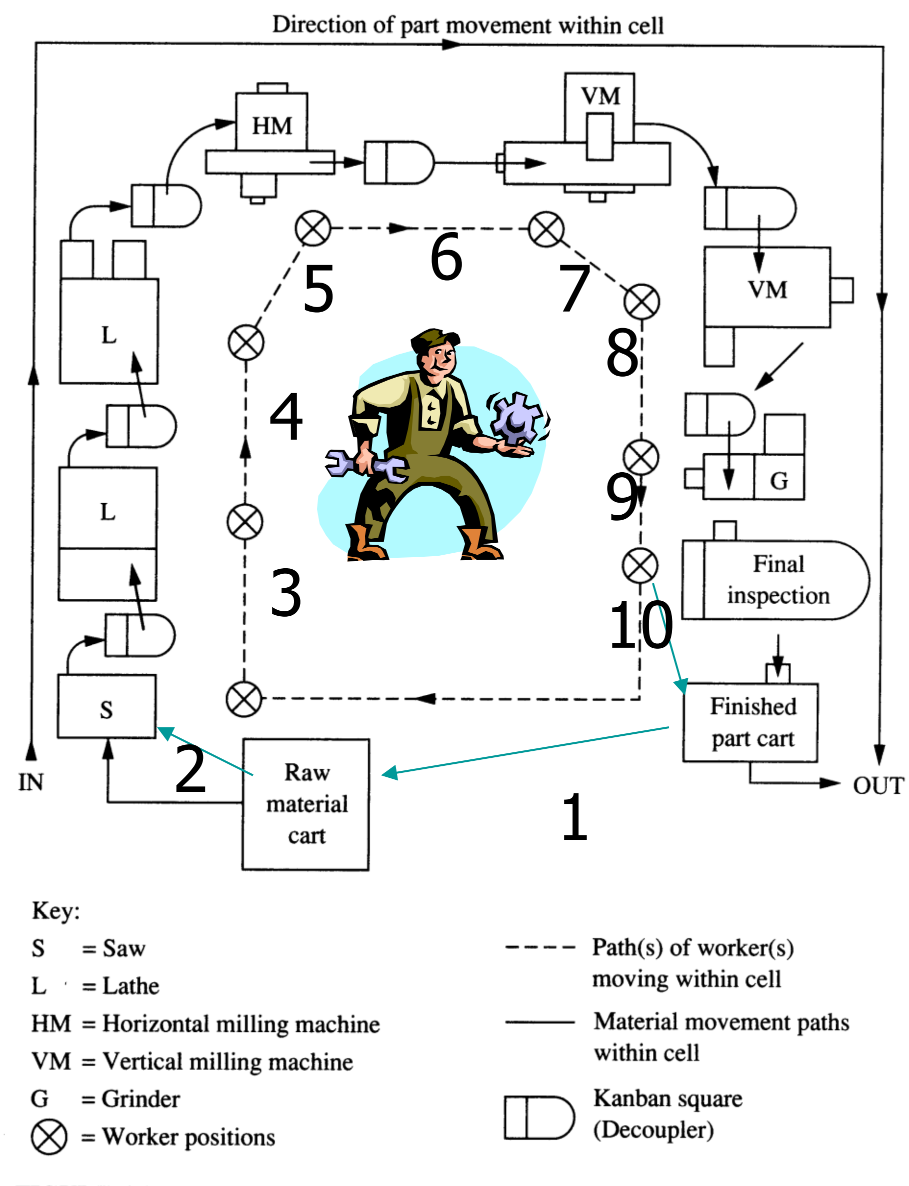
- "Synchronized", sequential production
- Operator decoupled from individual machines
- Operator integrated into all tasks
- Goal: single piece Flow
- Best with single cycle automatics, but can be done manually too

See Video

Walking segments - 10

Machining Cell

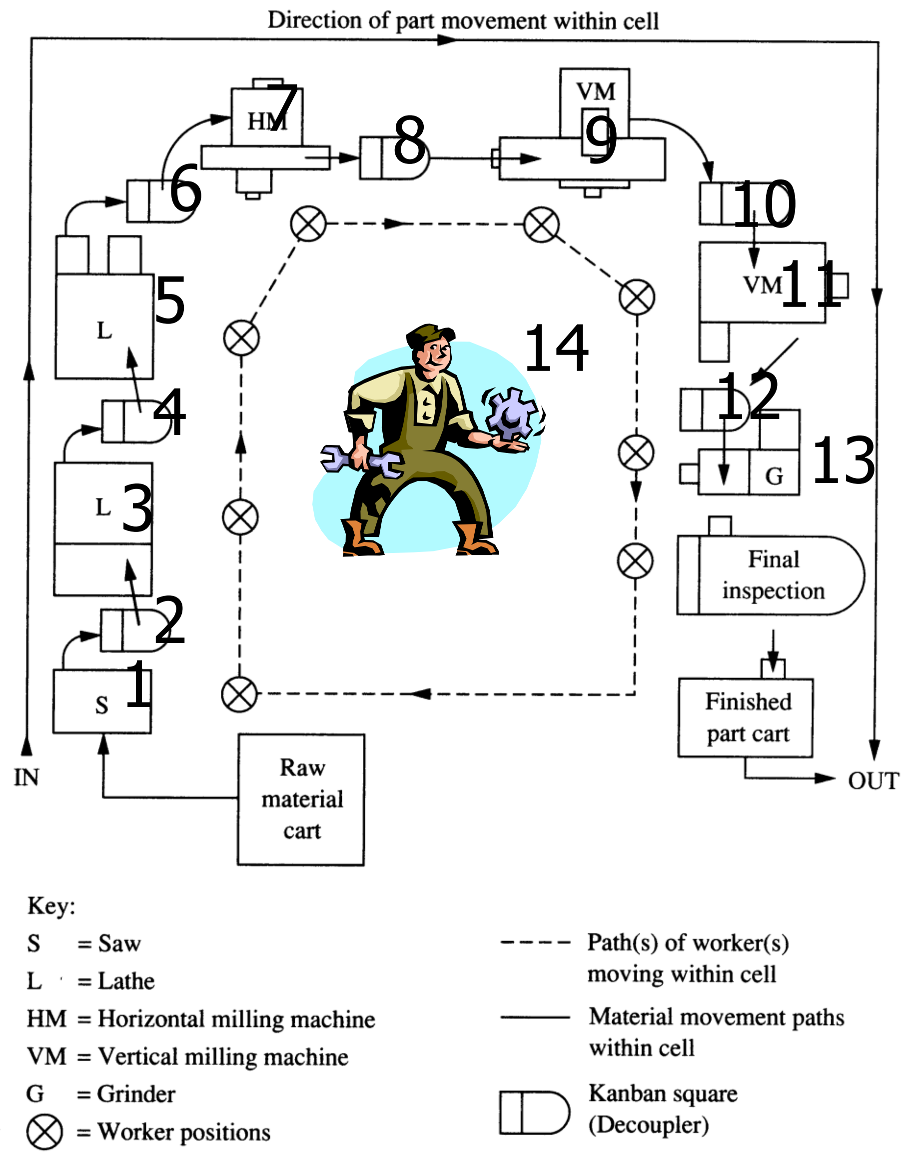
segment		Manual (Sec)	Walk to (Sec)	Machine (Sec)
1	Raw		3	
2	Saw	15	3	60
3	L1	10	3	70
4	L2	12	3	50
5	HM	12	3	120
6	VM1	20	3	70
7	VM2	20	3	60
8	G	15	3	60
9	F.I.	19	3	
10	Finish part		3	
	Totals	**M+W**	**= 153**	**490**



Parts in the cell ~ 14

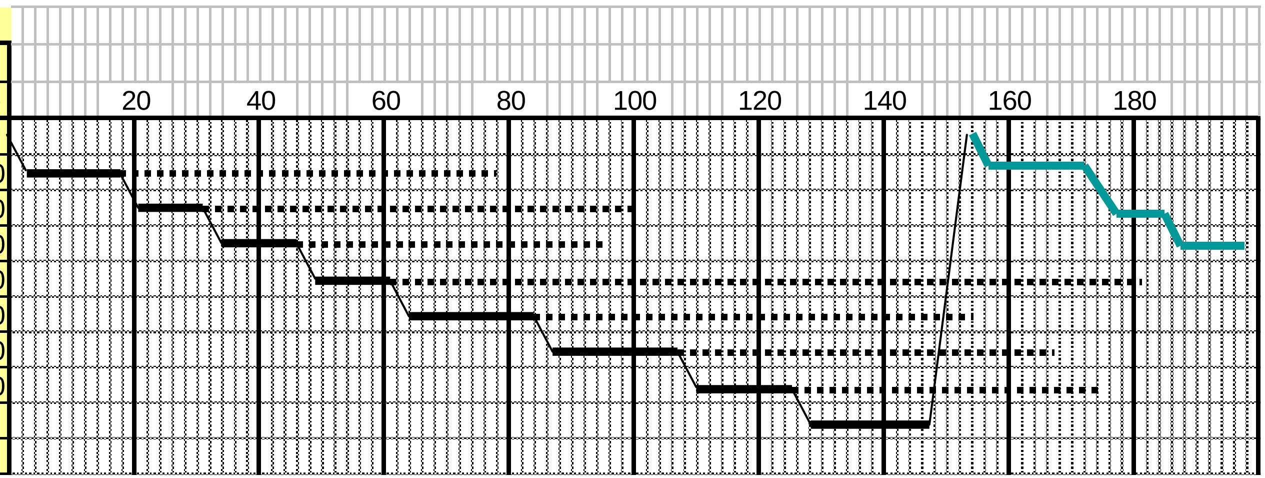
Machining Cell

	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?

TPS Cell and Little's Law

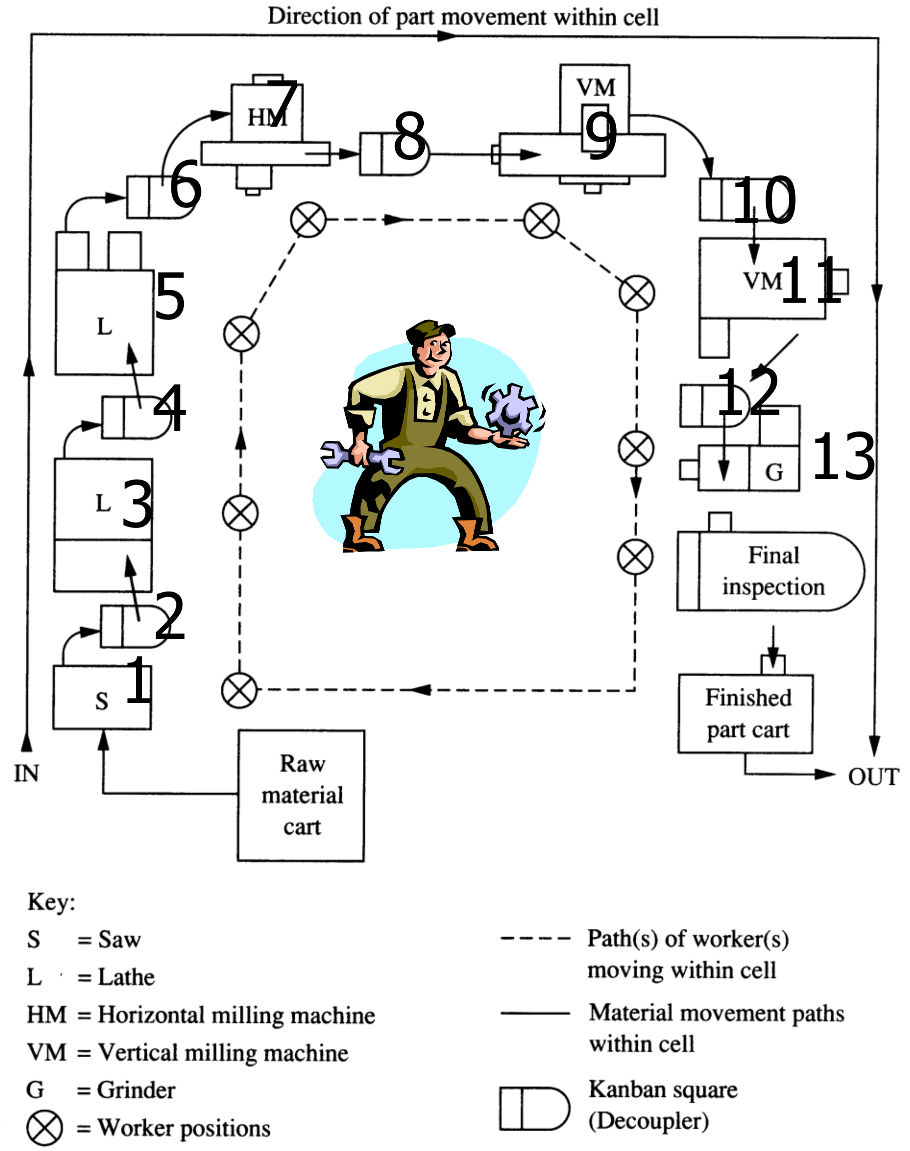
- $L = \lambda W$, we know L and λ, what is W?
- Define System Boundaries
- Follow part around the cell
- Single operator case

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

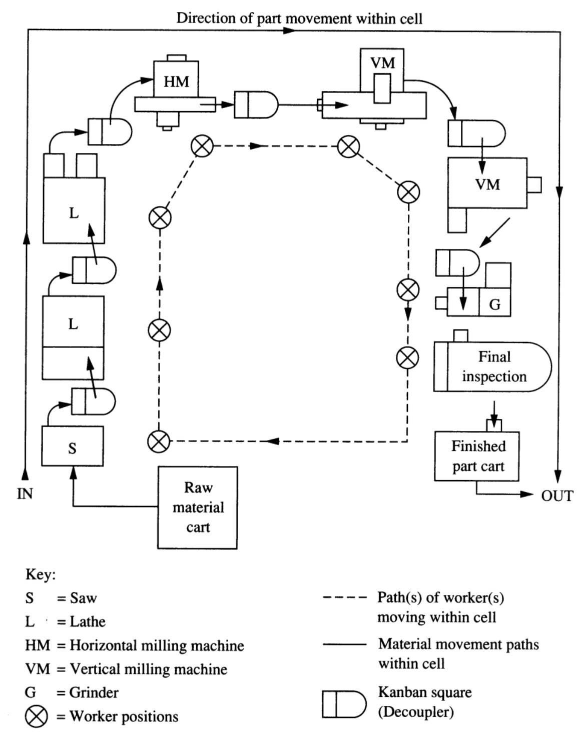


By Little's Law

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

rate, λ = 1/153 parts/second

W = 153 X 13.98 = 2139 sec



TPS Cell

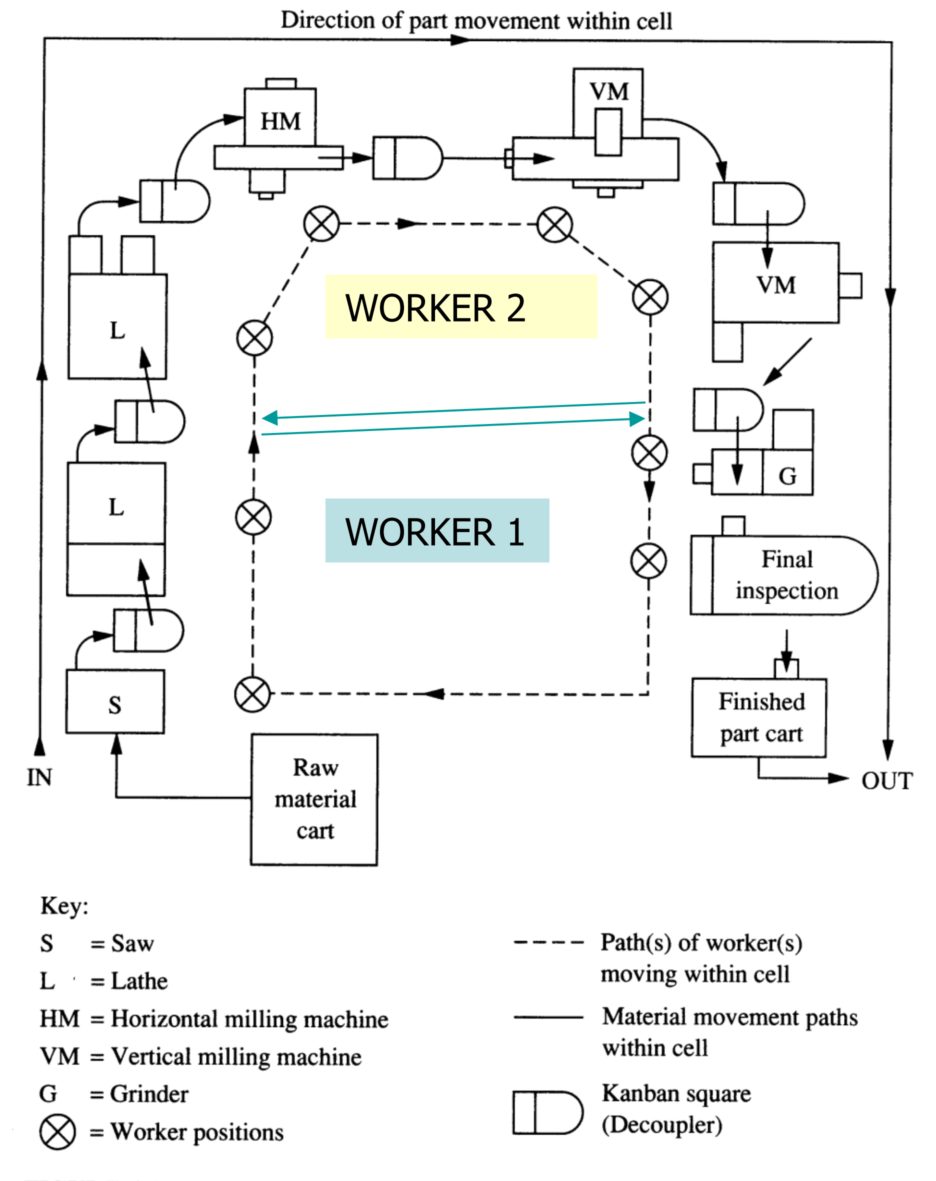
Increase production rate:

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

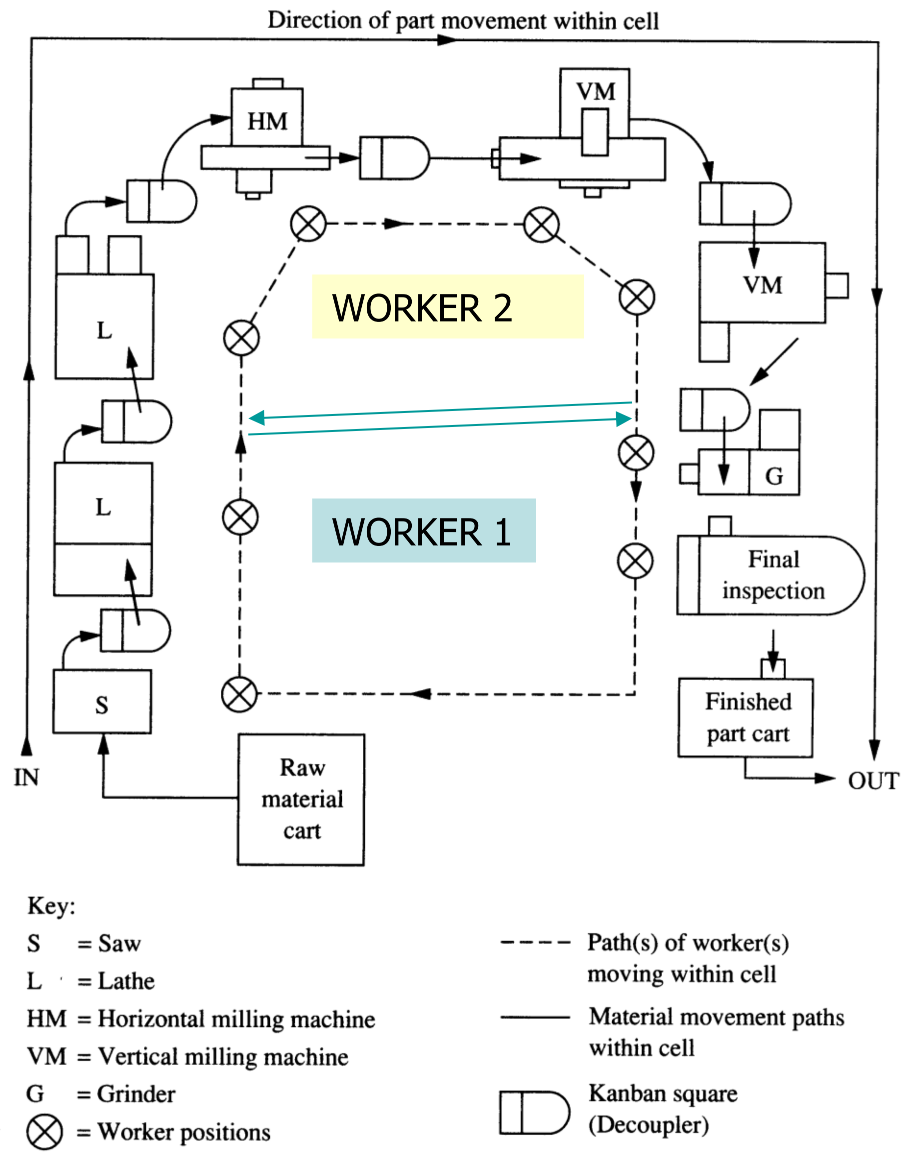
One part every 132 seconds

We are limited by the HM (horizontal mill)

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

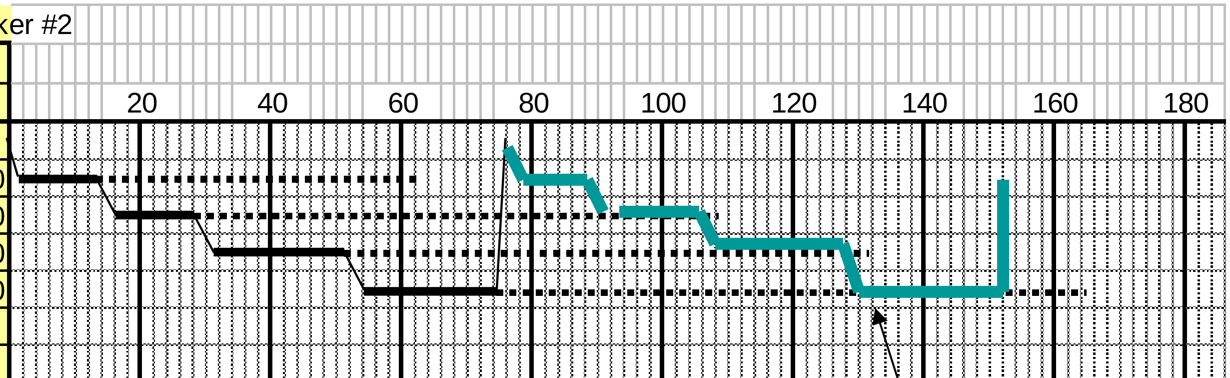
Can we shift work off of the HM to reduce the cycle time?

	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

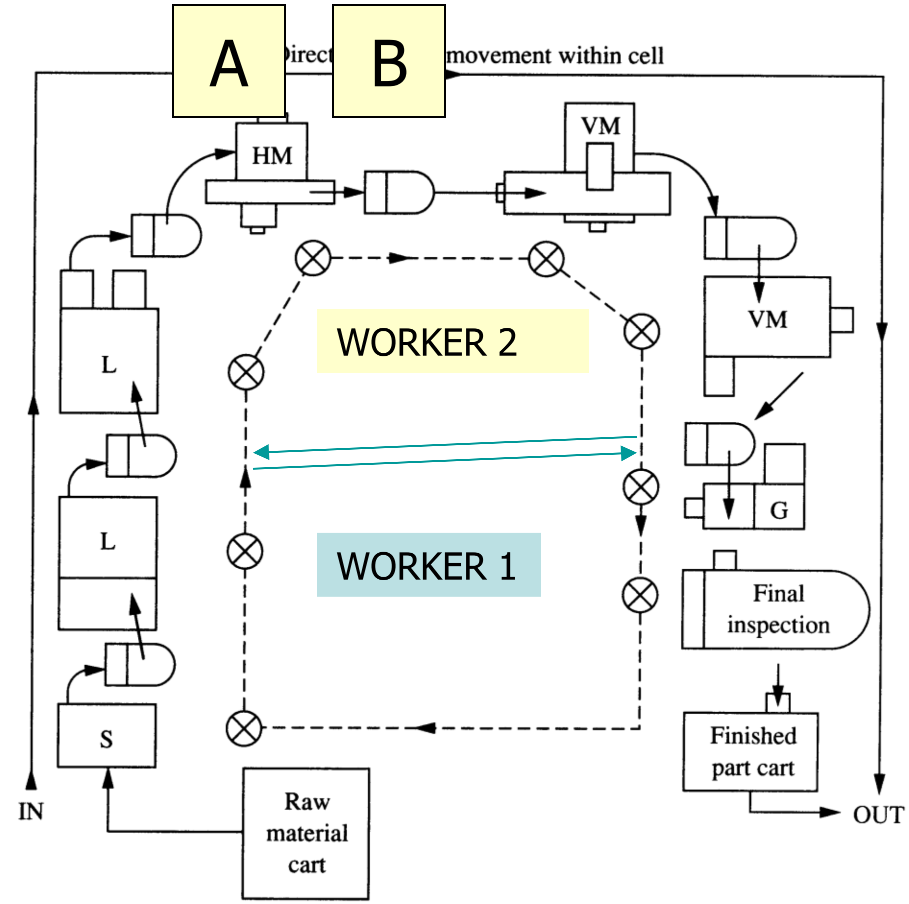
- Pro and Cons; Worker “idle”, can’t speed up by adding additional worker
- Design for flexibility make;

  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**	



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

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)

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

- 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

1. How people work
2. How people connect
3. How the production line is constructed
4. How to improve

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

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

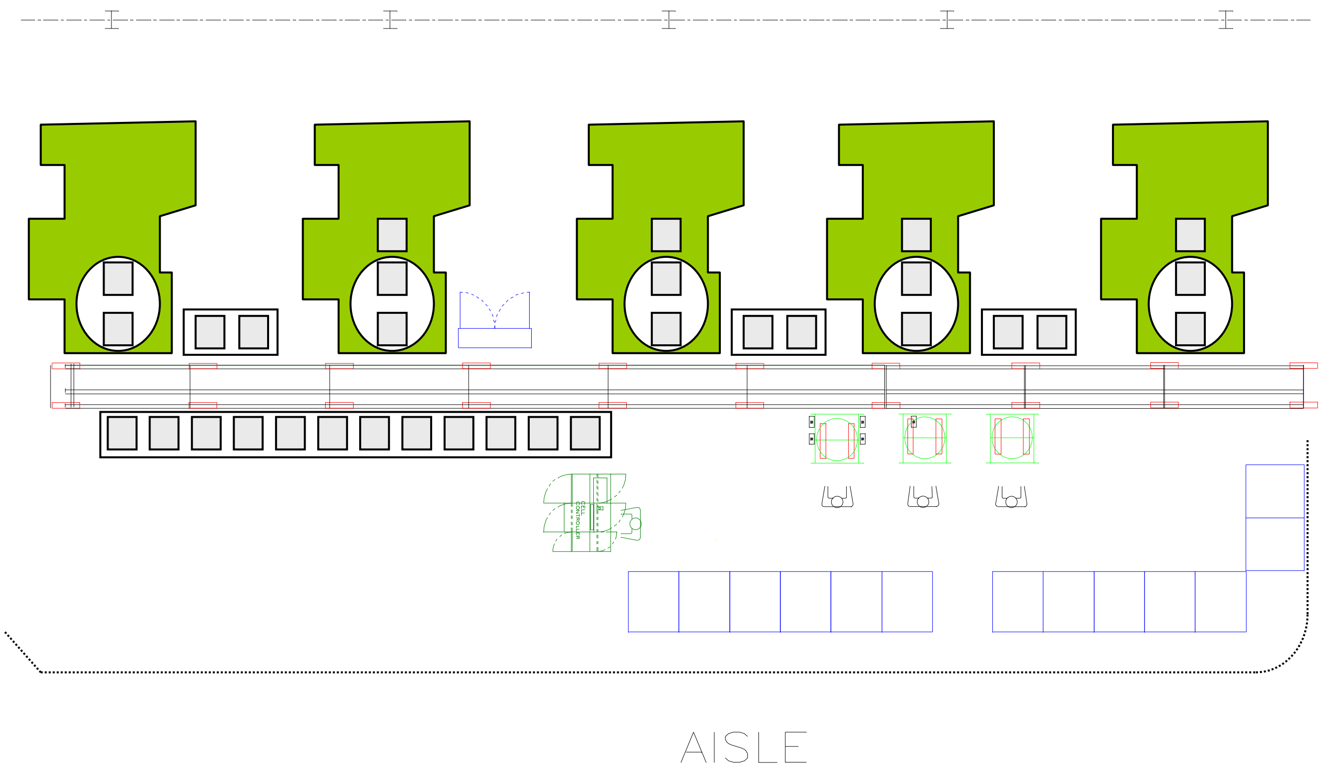
Michael Maccoby, "Is There a Best Way to Build a Car?"
HBR Nov-Dec 1997

Two examples, if time

1. Know your system: VSM
2. The view from shipping

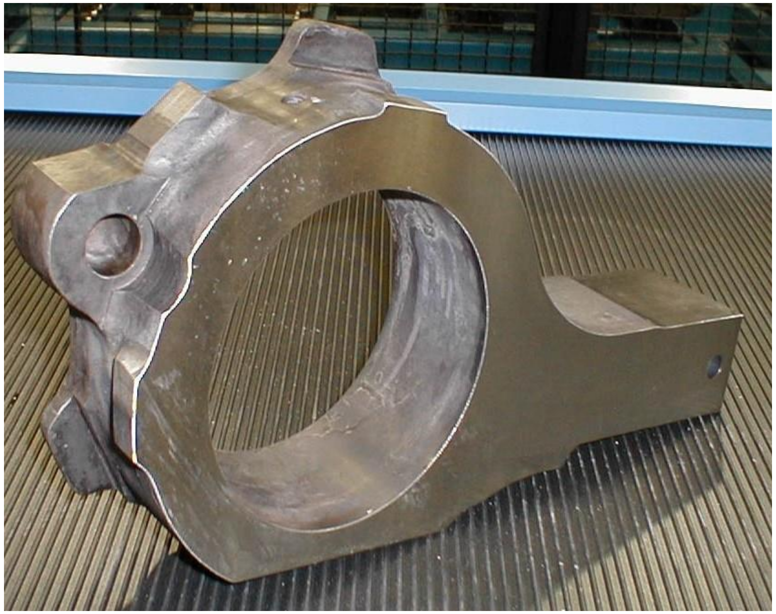
Smooth Production Flow

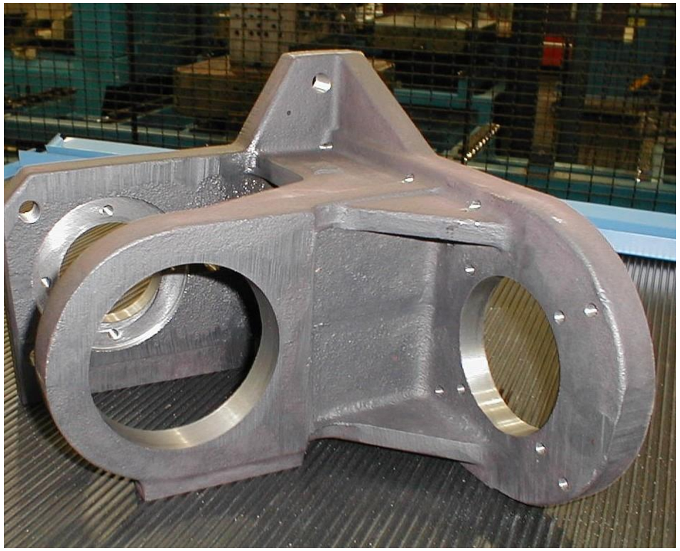
Flexible Manufacturing System



- 3 set-up stations
- 4 operators per shift
- 3 shifts
- 2,000 active part numbers
- 5 machines
- 61 programs run per shift

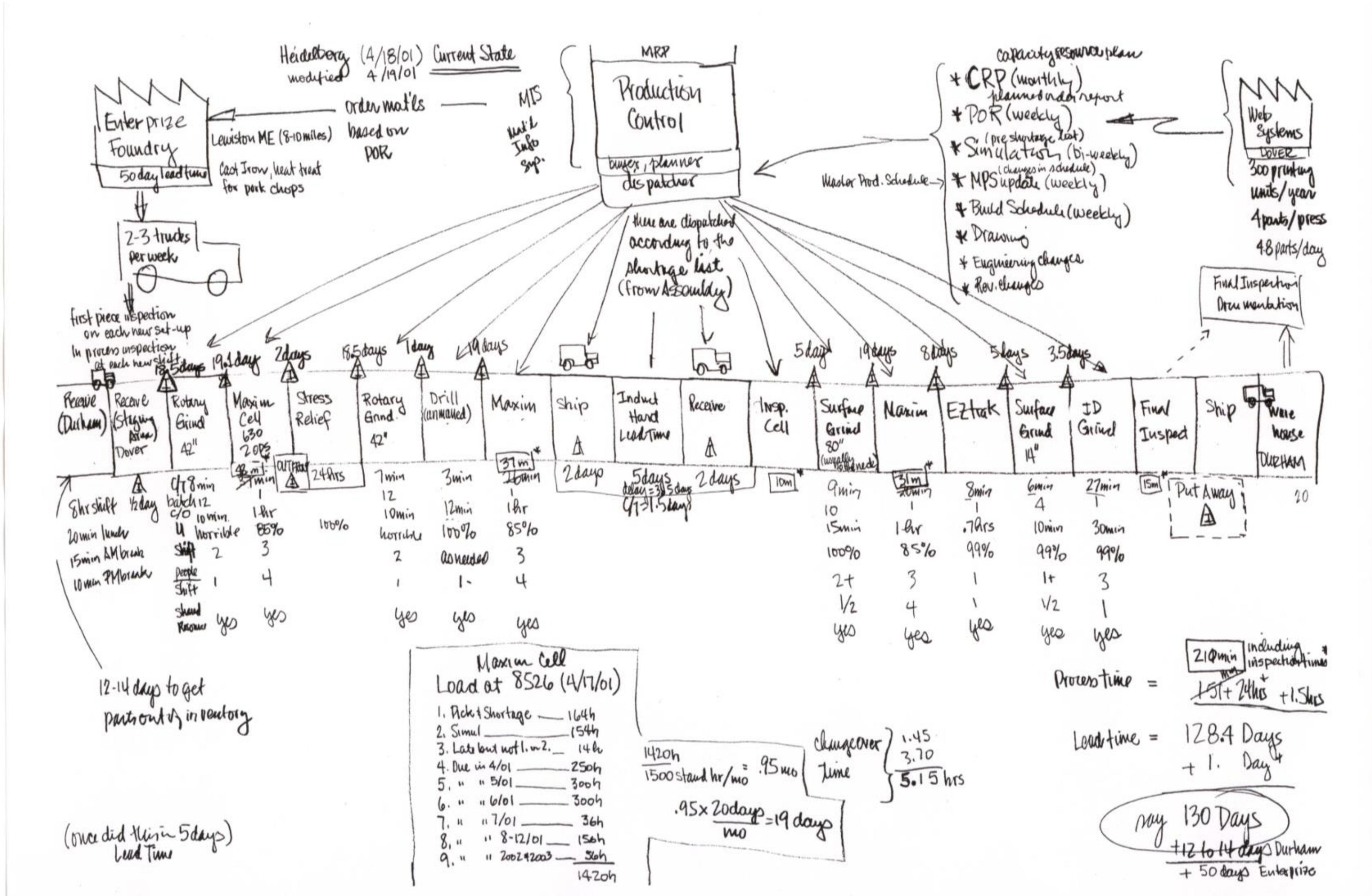
Typical Parts

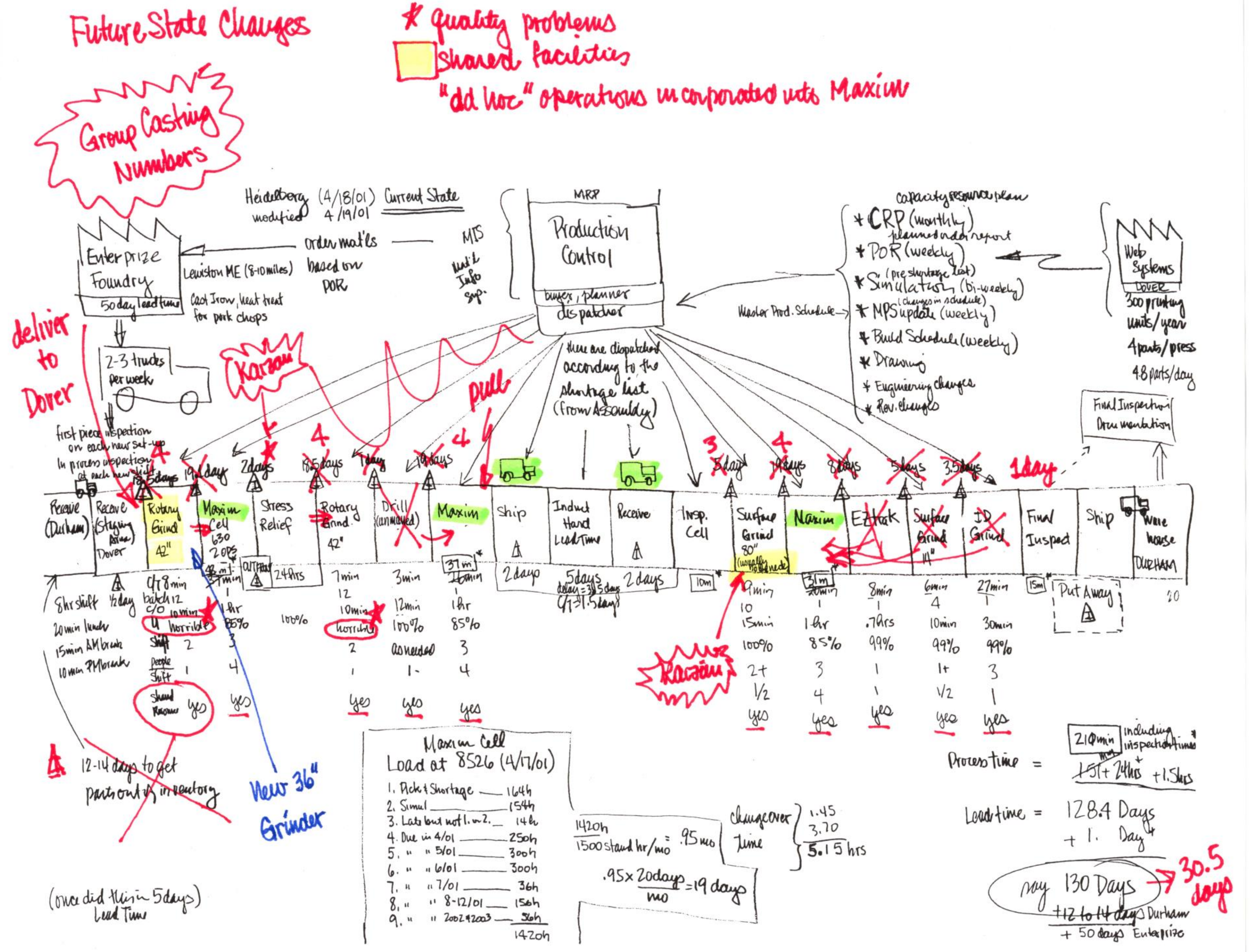




Heidelberg VSM Team

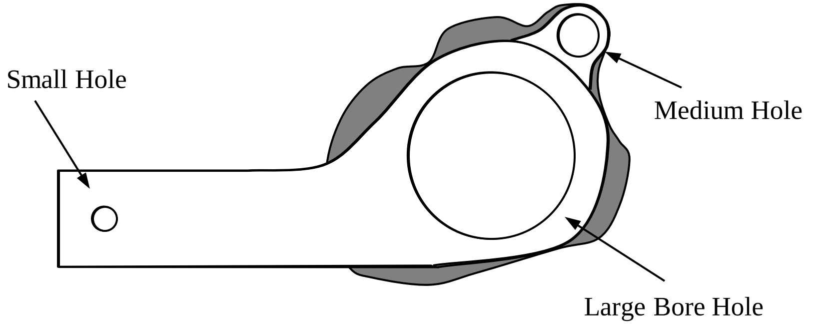
Value Steam Mapping





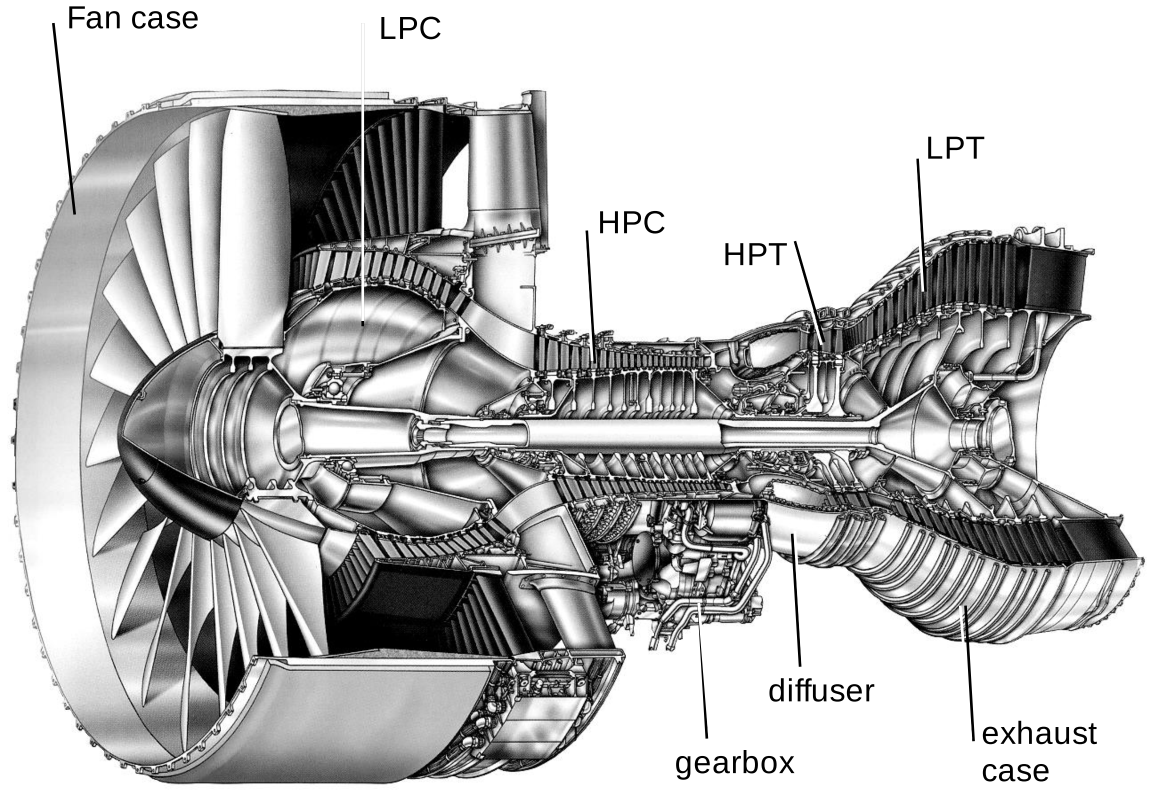
Future State Changes
* quality problems
Shared facilities
"ad hoc" operations incorporated into Maxim
Group Casting Numbers
Heidelberg (4/18/01) Current State
modified 4/19/01
Enterprize Foundry
50 day lead time
Lewiston ME (8-10 miles)
Cast Iron, heat treat for pork chops
order mat'ls based on POR
MIS
Production Control
MRP
buyer, planner
dispatcher
capacity resource plan
* CRP (monthly)
planned order report
* POR (weekly)
(pre shortage list)
* Simulation (bi-weekly)
(changes in schedule)
* MPS update (weekly)
Master Prod. Schedule
* Build Schedule (weekly)
* Drawing
* Engineering changes
* Rev. changes
Web Systems
DOVER
300 printing units/year
4 parts/press
4.8 parts/day
Final Inspection Documentation
deliver to Dover
2-3 trucks per week
Kanban
pull
there are dispatched according to the shortage list (from Assembly)
first piece inspection on each new set-up
In process inspection at each new shift
Receive (Durham)
Receive (Staging Area) Dover
Rotary Grind 42"
Maxim Cell 630 2 OPS
Stress Relief
Rotary Grind 42"
Drill (unmanned)
Maxim
Ship
Induct Hard Lead Time
Receive
Insp. Cell
Surface Grind 80" (usually not needed)
Maxim
EZ Trak
Surface Grind 11"
ID Grind
Final Inspect
Ship
Warehouse DURHAM
Put Away
1 day
8 hr shift
20 min lunch
15 min AM break
10 min PM break
horrible
Shared Resource
Kanban
New 36" Grinder
12-14 days to get parts out of inventory
(once did this in 5 days) Lead Time
Maxim Cell
Load at 8526 (4/17/01)
1. Pick & Shortage — 164h
2. Simul — 154h
3. Late but not 1. or 2. — 14h
4. Due in 4/01 — 250h
5. " " 5/01 — 300h
6. " " 6/01 — 300h
7. " " 7/01 — 36h
8. " " 8-12/01 — 156h
9. " " 2002 & 2003 — 56h
1420h
1420h / 1500 stand hr/mo = .95 mo
.95 x 20 days/mo = 19 days
Changeover time 1.45 3.70 5.15 hrs
210 min including inspection times
Process time = 151 + 24 hrs + 1.5 hrs
Lead time = 128.4 Days + 1. Day
say 130 Days
+12 to 14 days Durham
+ 50 days Enterprize
30.5 days

Part Families - “Pork-chops”

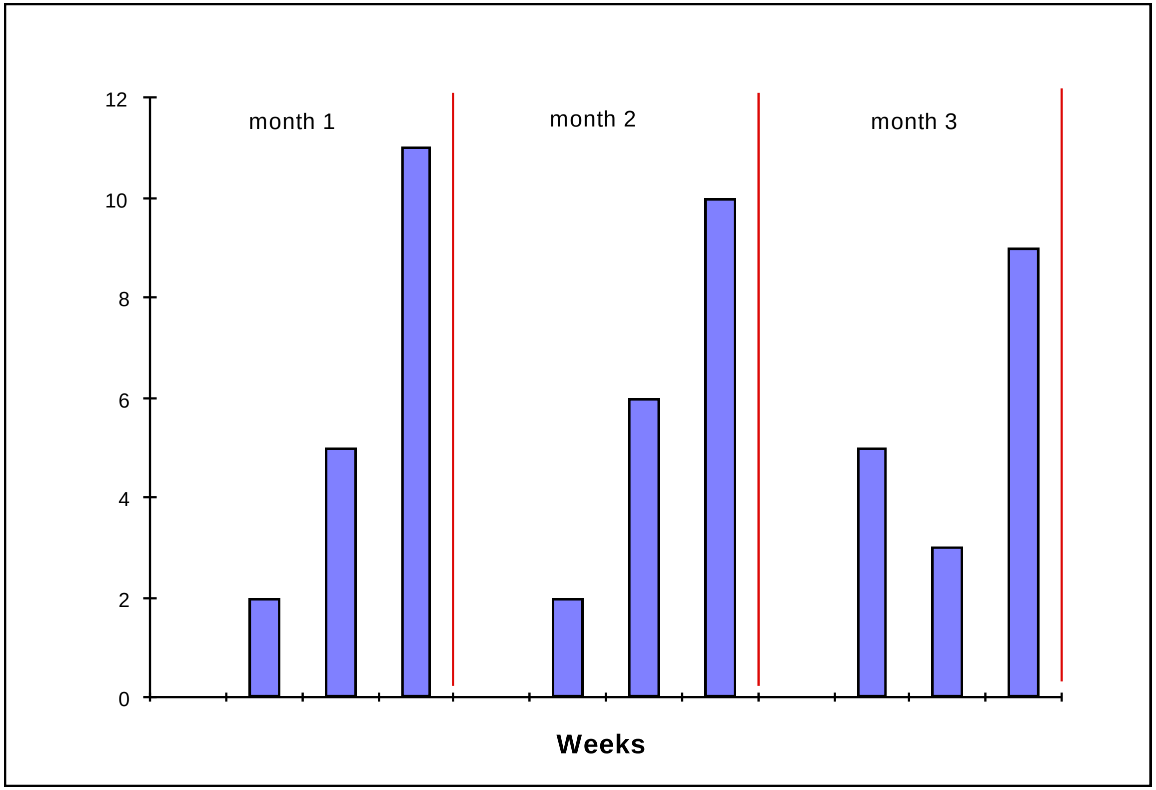


- Decrease in the number of castings from 86 to 7 (or 1)
- Lead time reduced by more than 50 days
- Cost of production of mold eliminated

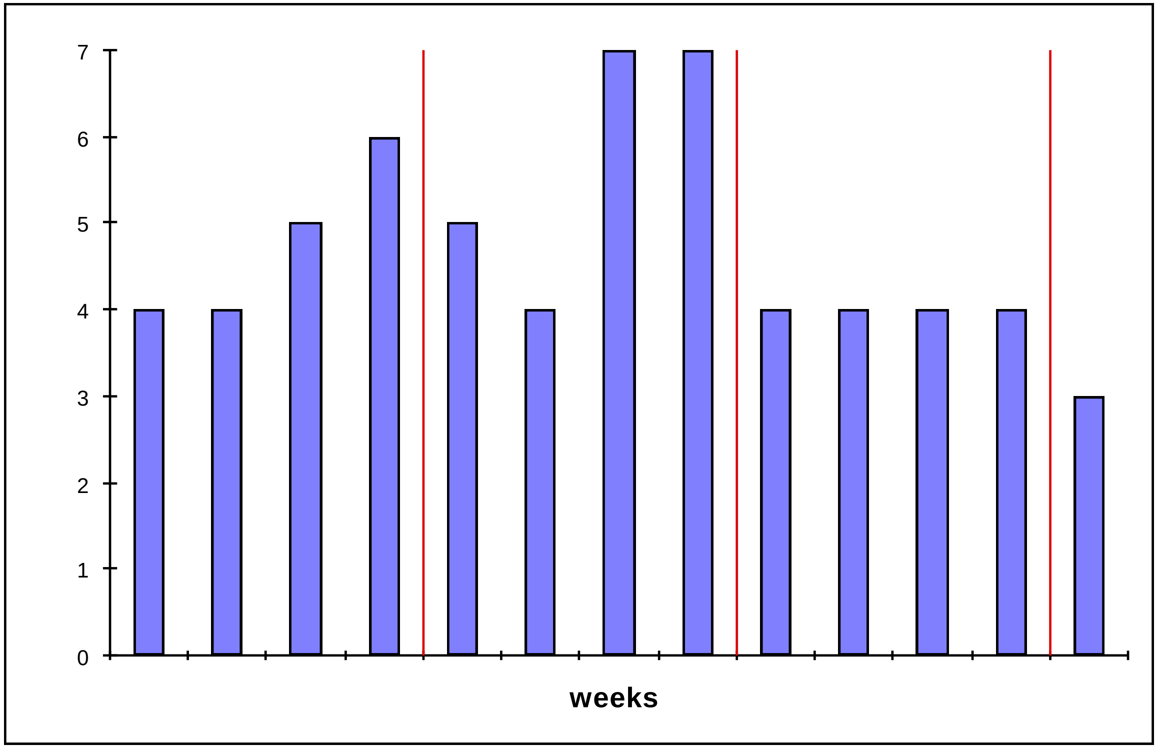
Aircraft engine case study



Engines shipped over a 3 month period at aircraft engine factory “B”



Engines shipped over a 3 month period at aircraft engine factory "C"



Late times compared to scheduled times