

Introduction to Manufacturing Systems

T. Gutowski
2.810



Mfg Systems Schedule

1. Introduction
2. Additive- John Hart
3. Toyota- Jose Pacheco
4. Control- Dave Hardt
5. Time & Variability- Stan Gershwin
6. System Tools
7. Progress Reports- Your Team (Nov 6)
8. Sustainable Mfg
9. Review
10. Quiz II (Nov 20)
11. Digital Mfg- Brian Anthony

Mfg Systems Introduction

1. Basic Types: Equipment configurations

2. Inventing New Mfg Systems

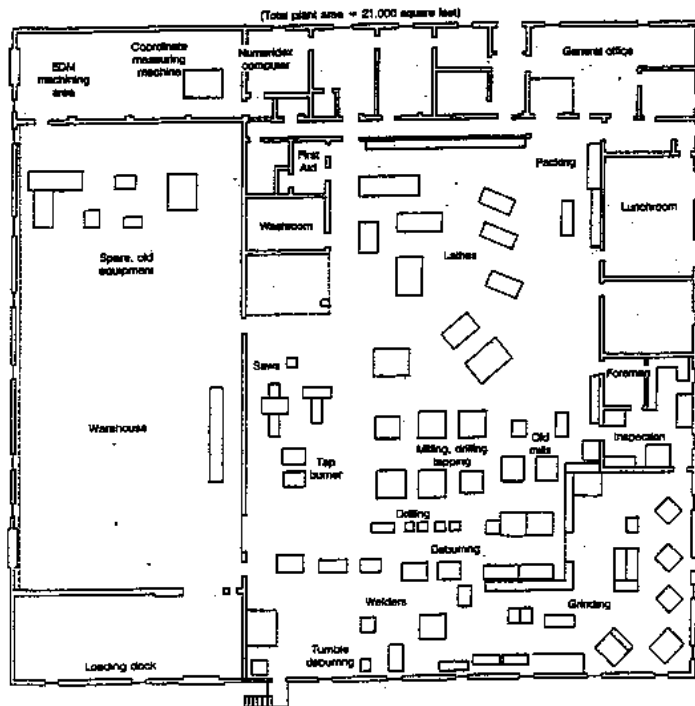
- Interchangeable parts
- Mass production
- TPS/Lean production
- Digital production

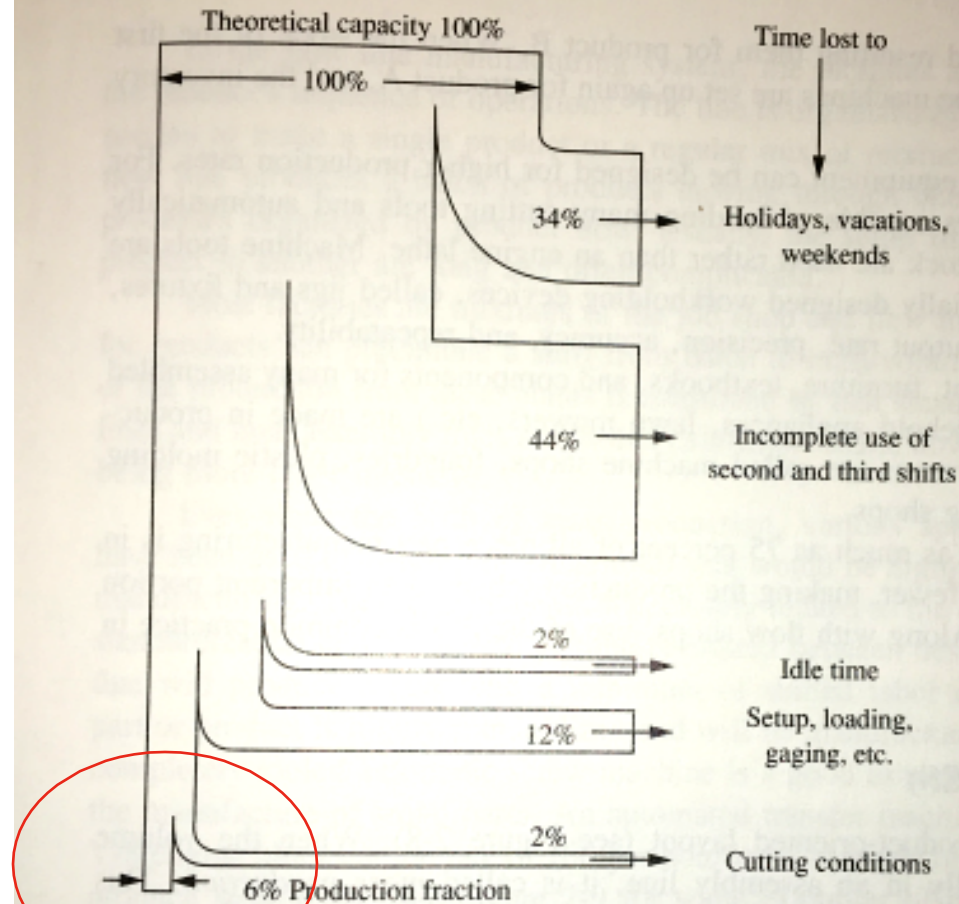
Manufacturing Systems

- **job shop** - machine arrangement by convenience
- **flow line** - dedicated resources for product(s)
- **transfer line** - automated work handling between process stations, “hardwired” flow pattern
- **flexible manufacturing system (FMS)** - flow pattern programmable
- **Toyota Production System** - production to demand
- **Toyota Cell** - One operator, multiple machines

(See J T. Black Ch 2)

Job shops - flexible, low volume

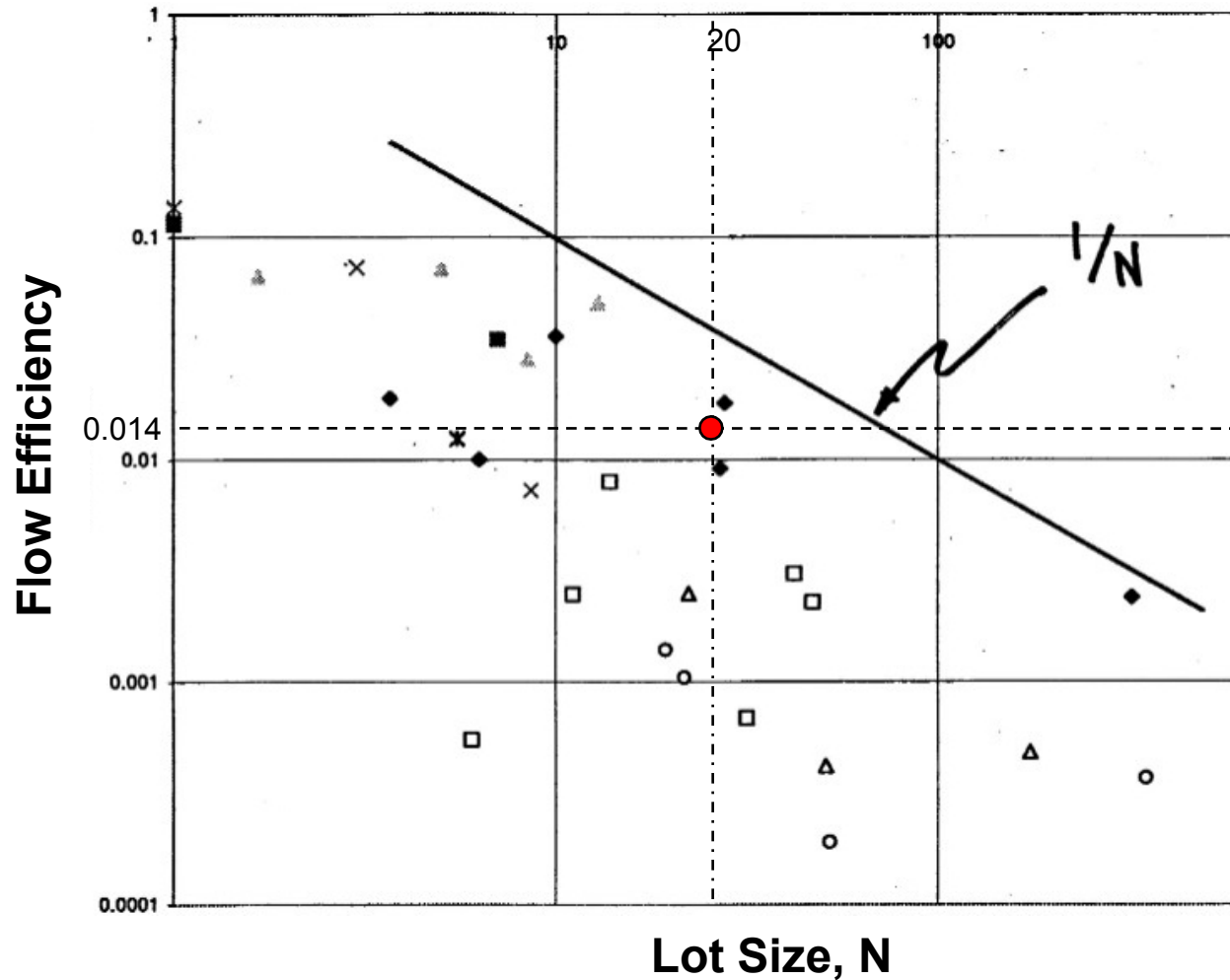


**FIGURE 2-7**

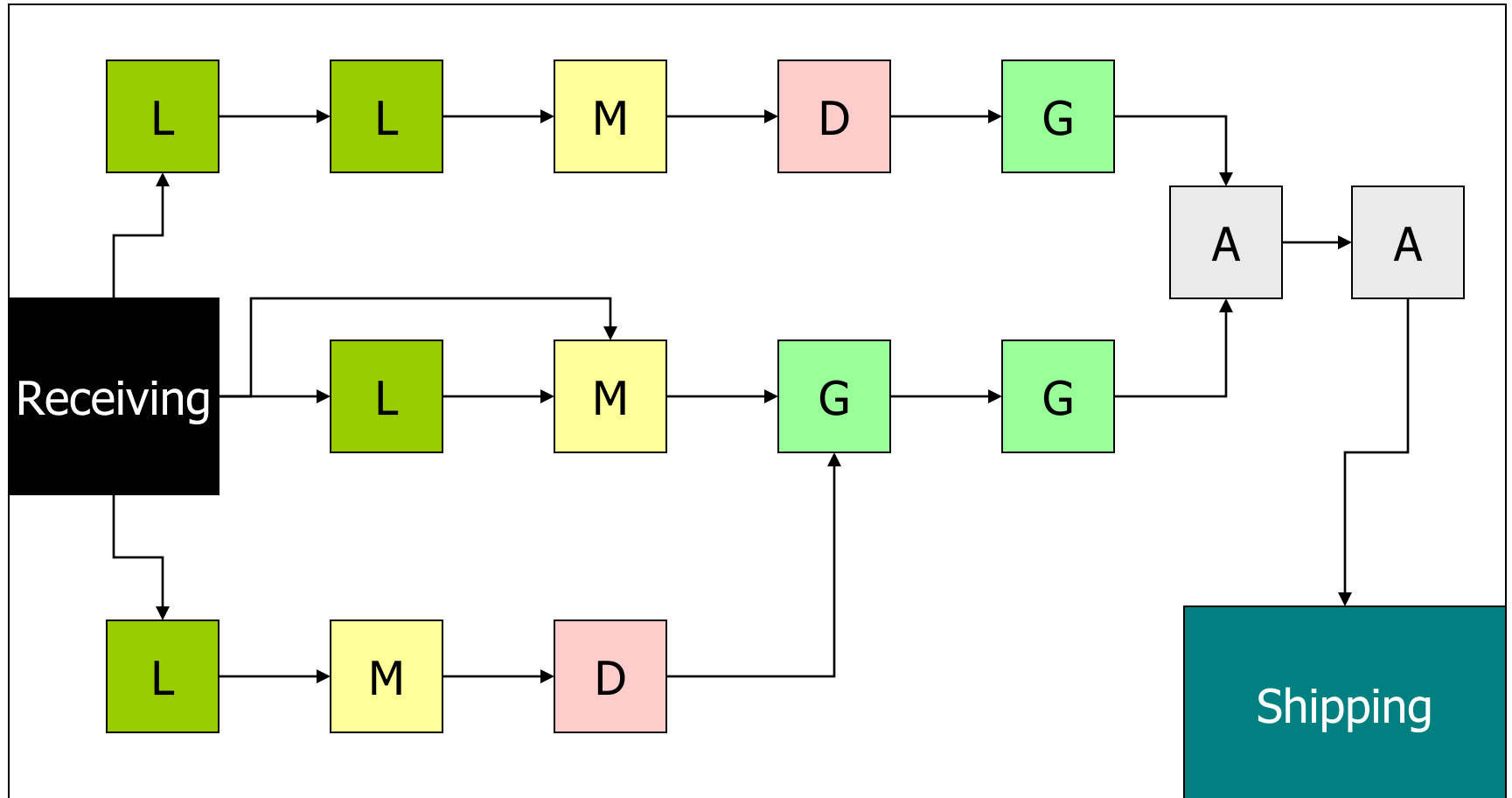
Distribution of total factory capacity of machine tools in the job shop. Typical values are shown. (Carter, C.F. *Mfg. Eng.* Aug. 82.)

Flow Efficiency versus Lot Size

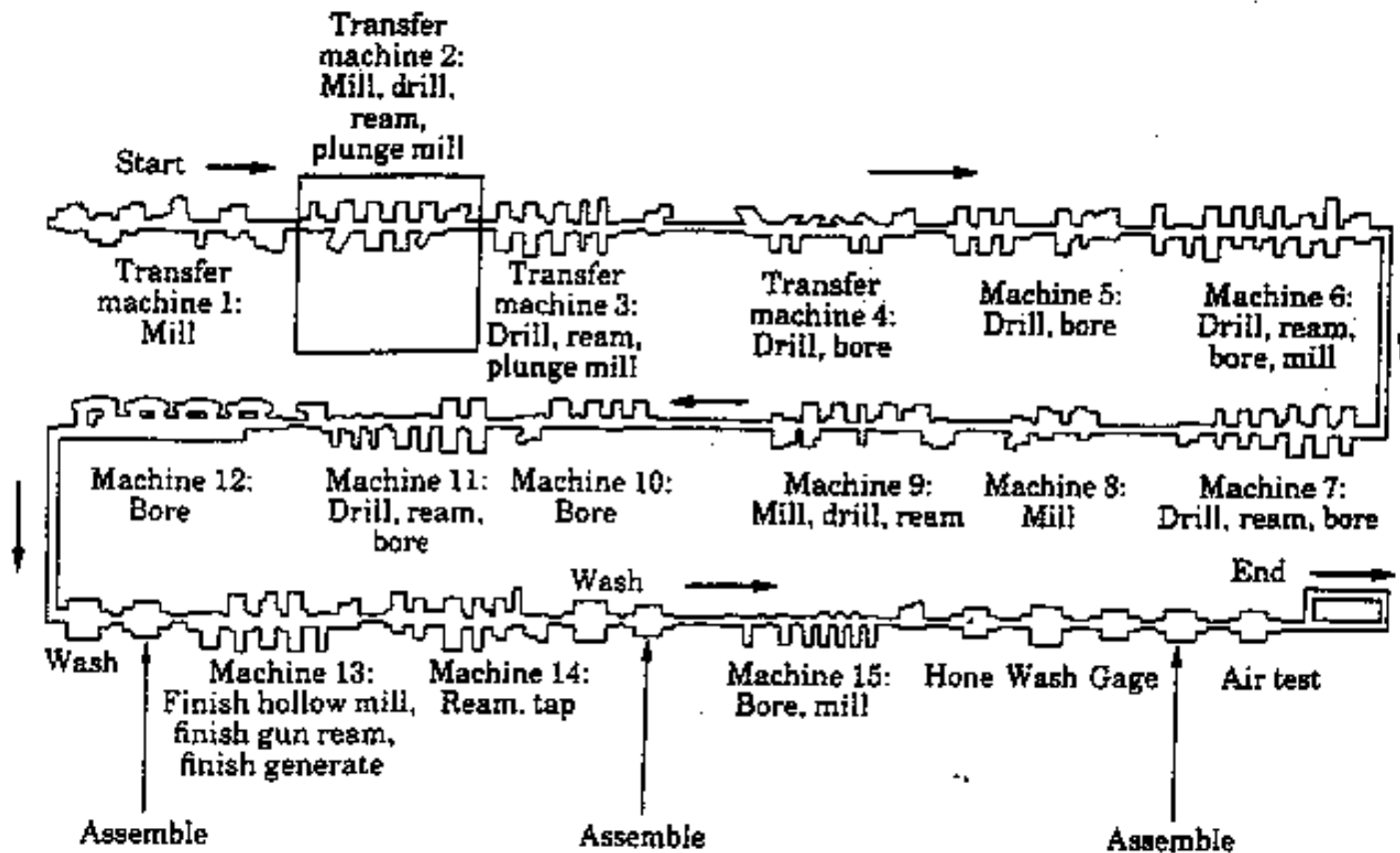
Case studies from the aerospace industry (LAI data)



Flow Shop - dedicated

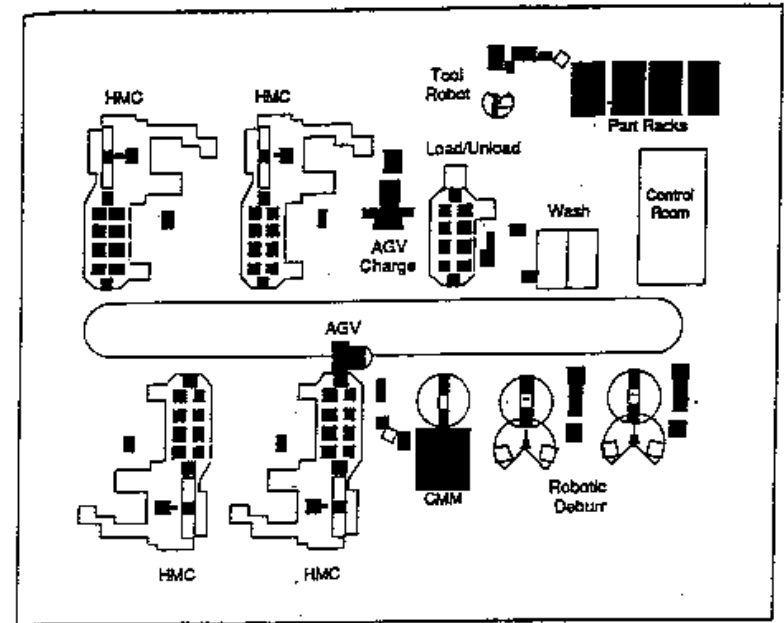
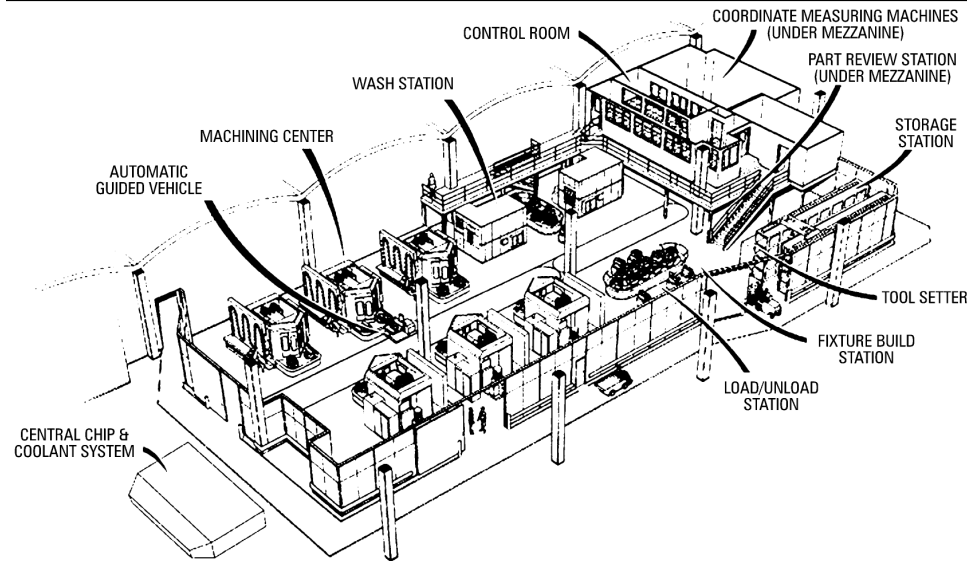


Transfer line - hardwired

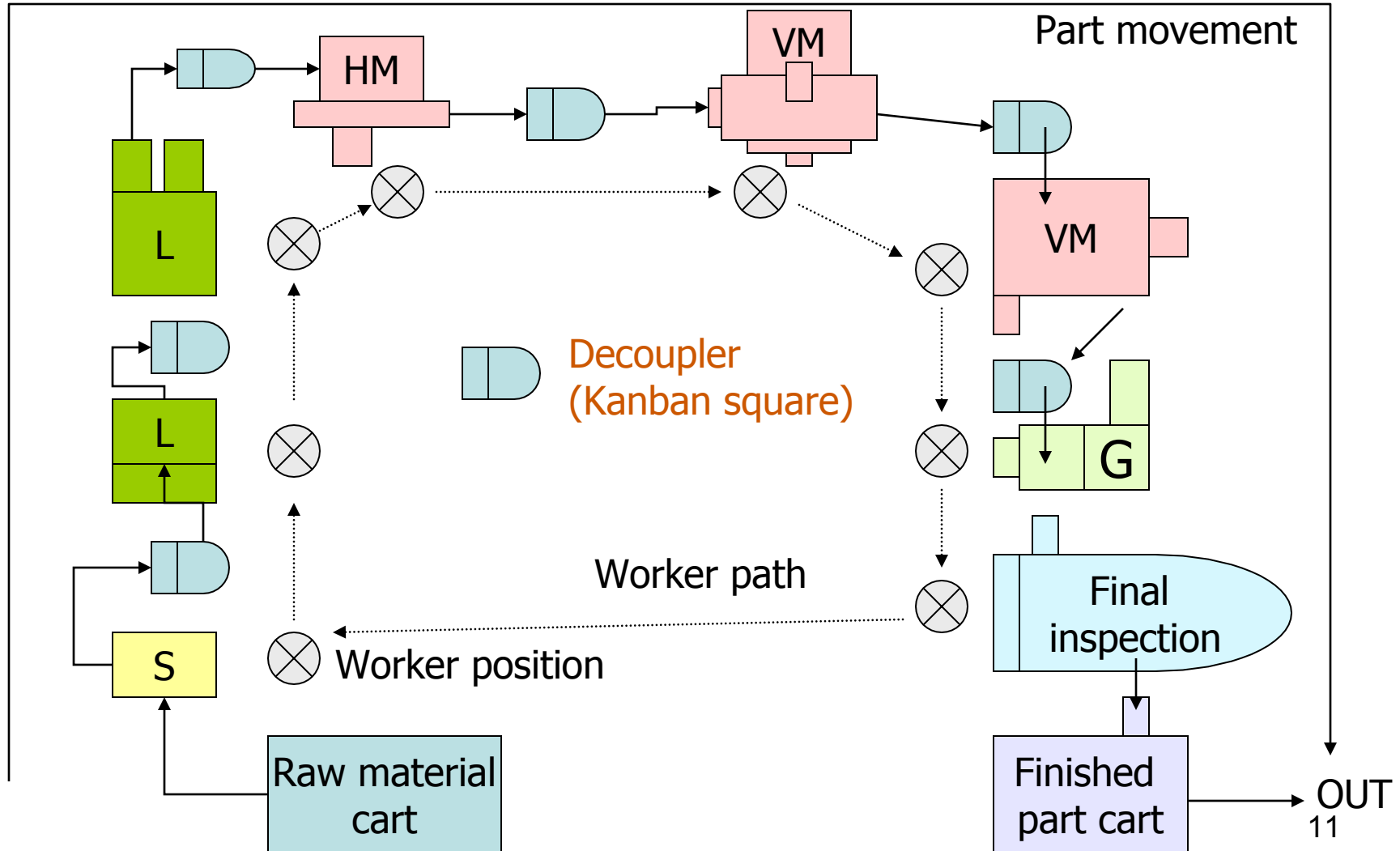


Flexible Manufacturing System (FMS)

Figure 1 AlliedSignal's flexible manufacturing system



Toyota Mfg Cell



Machining Systems Classification

46 THE DESIGN OF THE FACTORY WITH A FUTURE

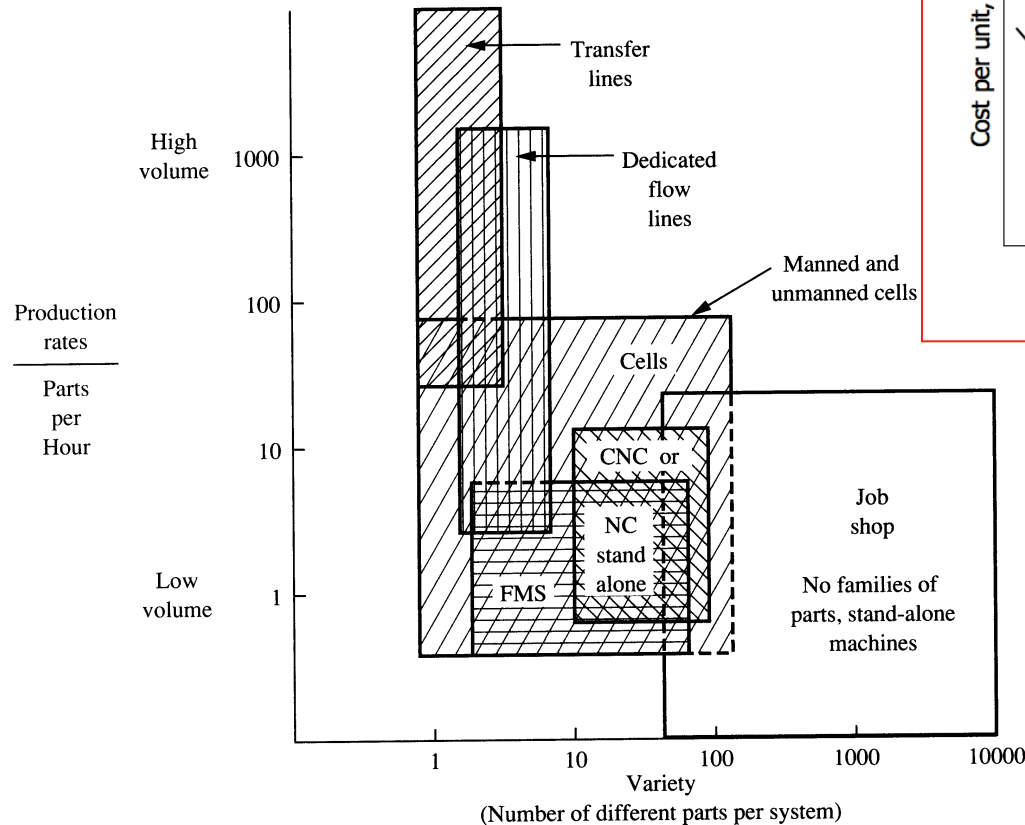
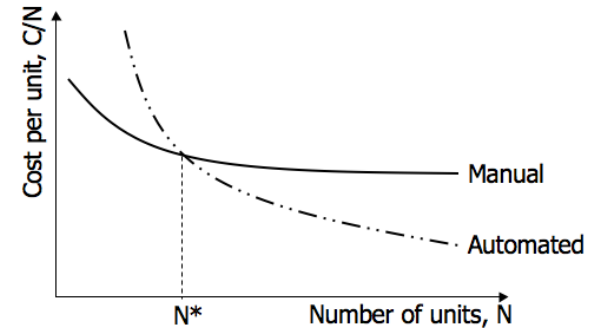


FIGURE 2-15

A comparison of different kinds of manufacturing systems with cells.

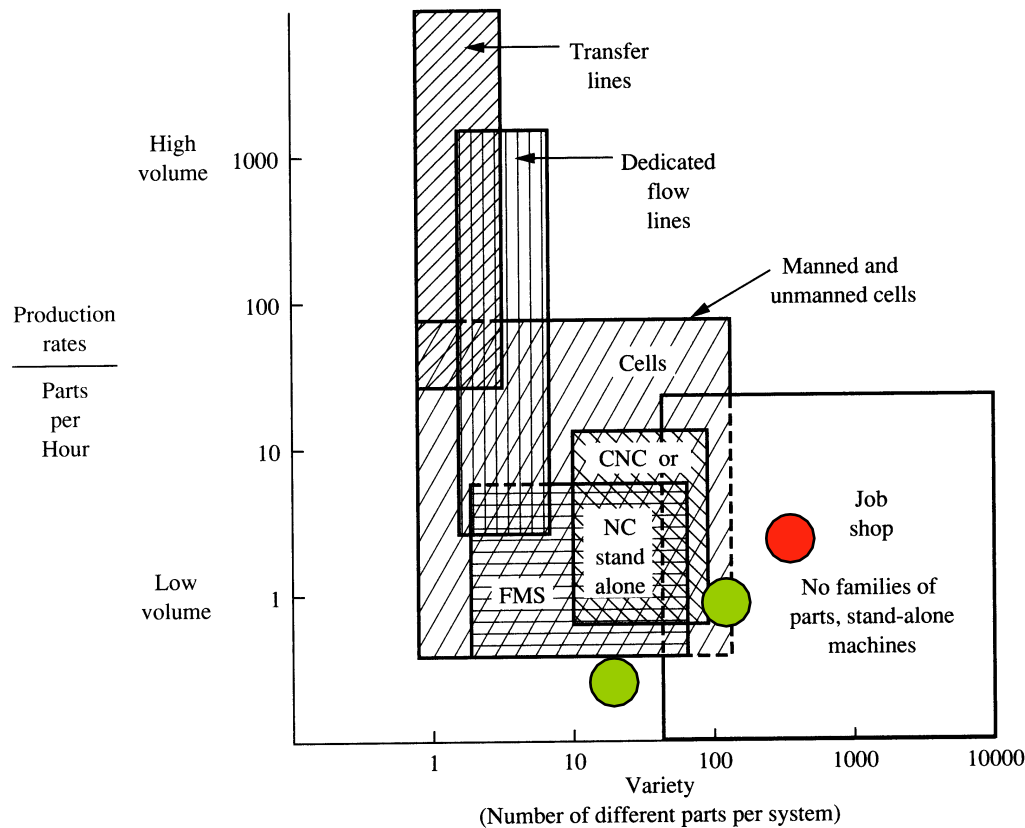


Ref J T. Black
Ch 2

Data for FMS's

Ref: J T. Black

46 THE DESIGN OF THE FACTORY WITH A FUTURE



● Company H

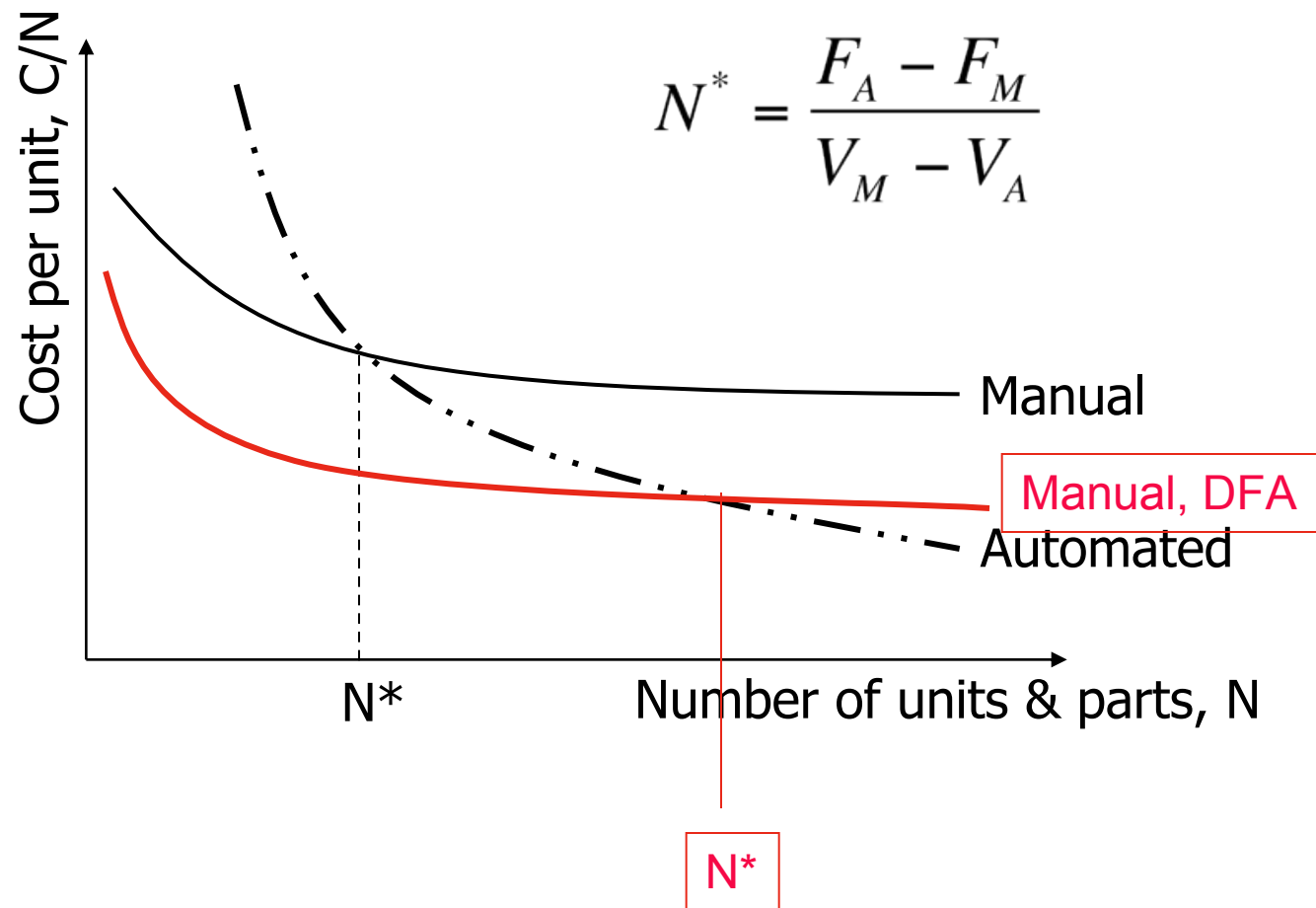
● Other systems studied that use "Maxim Cells"



FIGURE 2-15

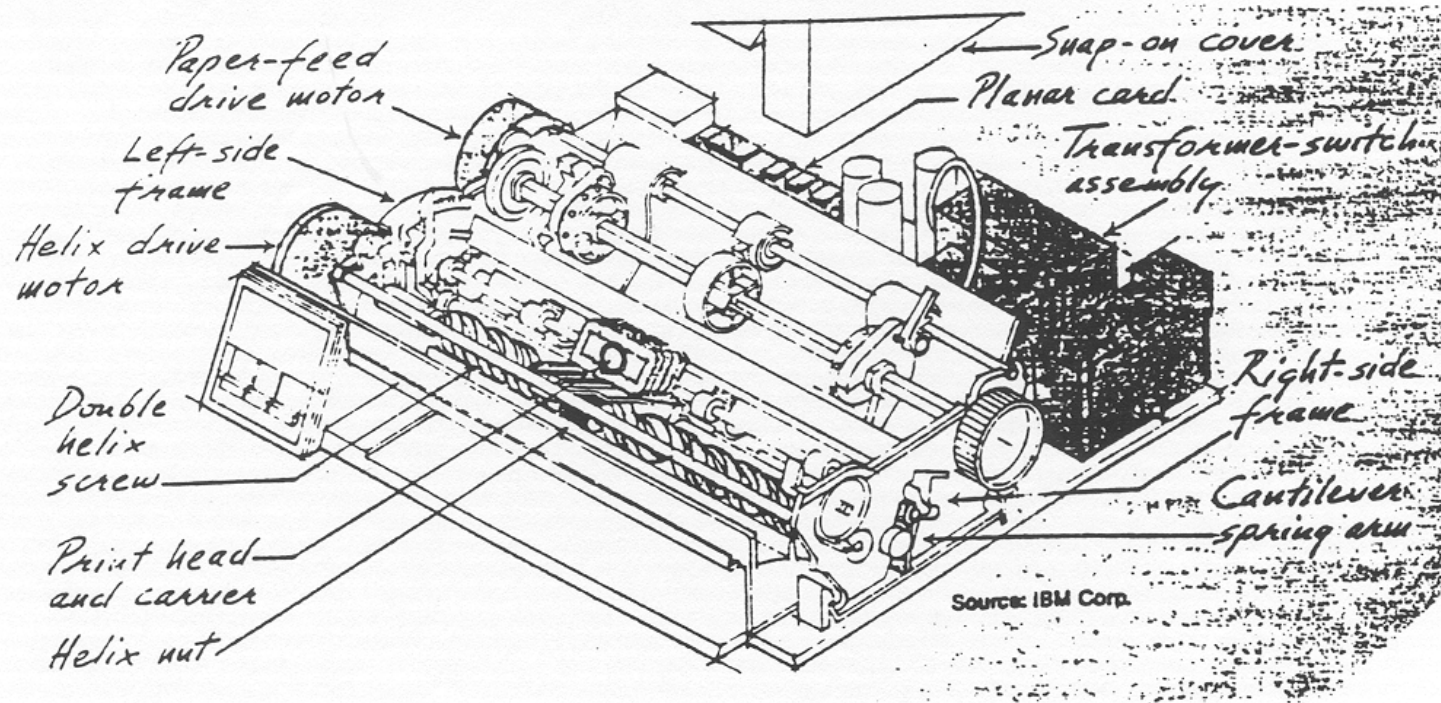
A comparison of different kinds of manufacturing systems with cells.

DFA example, $C = F + V \cdot N$





IBM Proprinter



Competition from Japan - answered with robots and DFA

Economic Assessment Chart

Assembly Systems-Boothroyd/Dewhurst

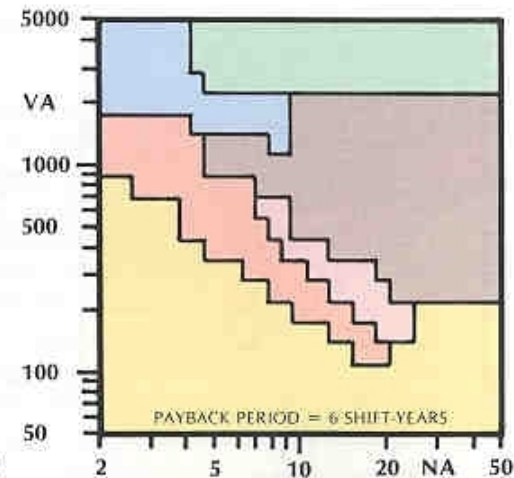
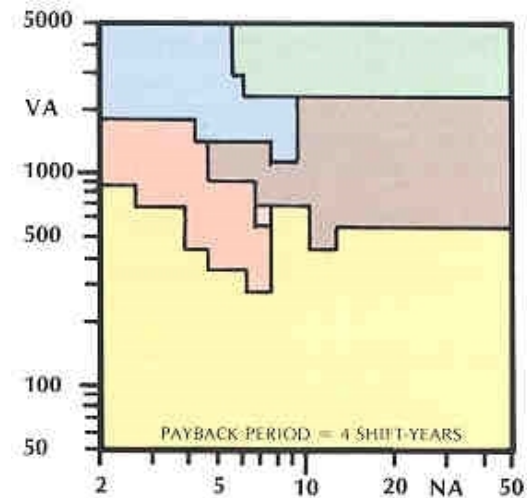
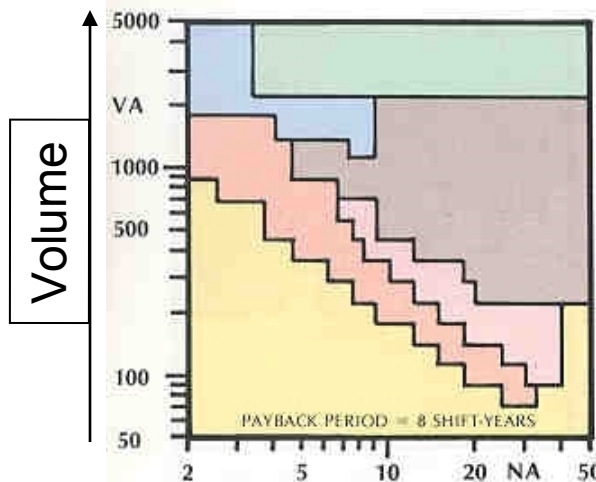
Product with only one style
(NT/NA = 1)

VA = annual production volume measured
in thousands

NA = number of parts in the assembly

NT = total number of parts from which
various product styles can be assembled

- Special-purpose indexing
- Sp.-purt. Free-transfer
- Single-st. one robot arm
- Single-st. two robot arms
- Multi-station with robots
- Manual bench assembly



What conditions lead to a revolutionary new mfg system?

1. A Need/Opportunity
2. Financing
3. Workforce
4. Enabling technology

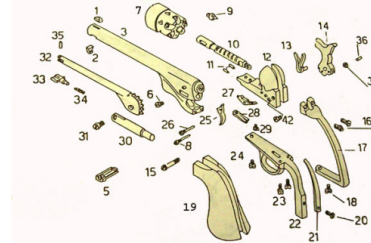
A Historical Review



Ford's Moving Assembly Line

Inventing New Mfg Systems

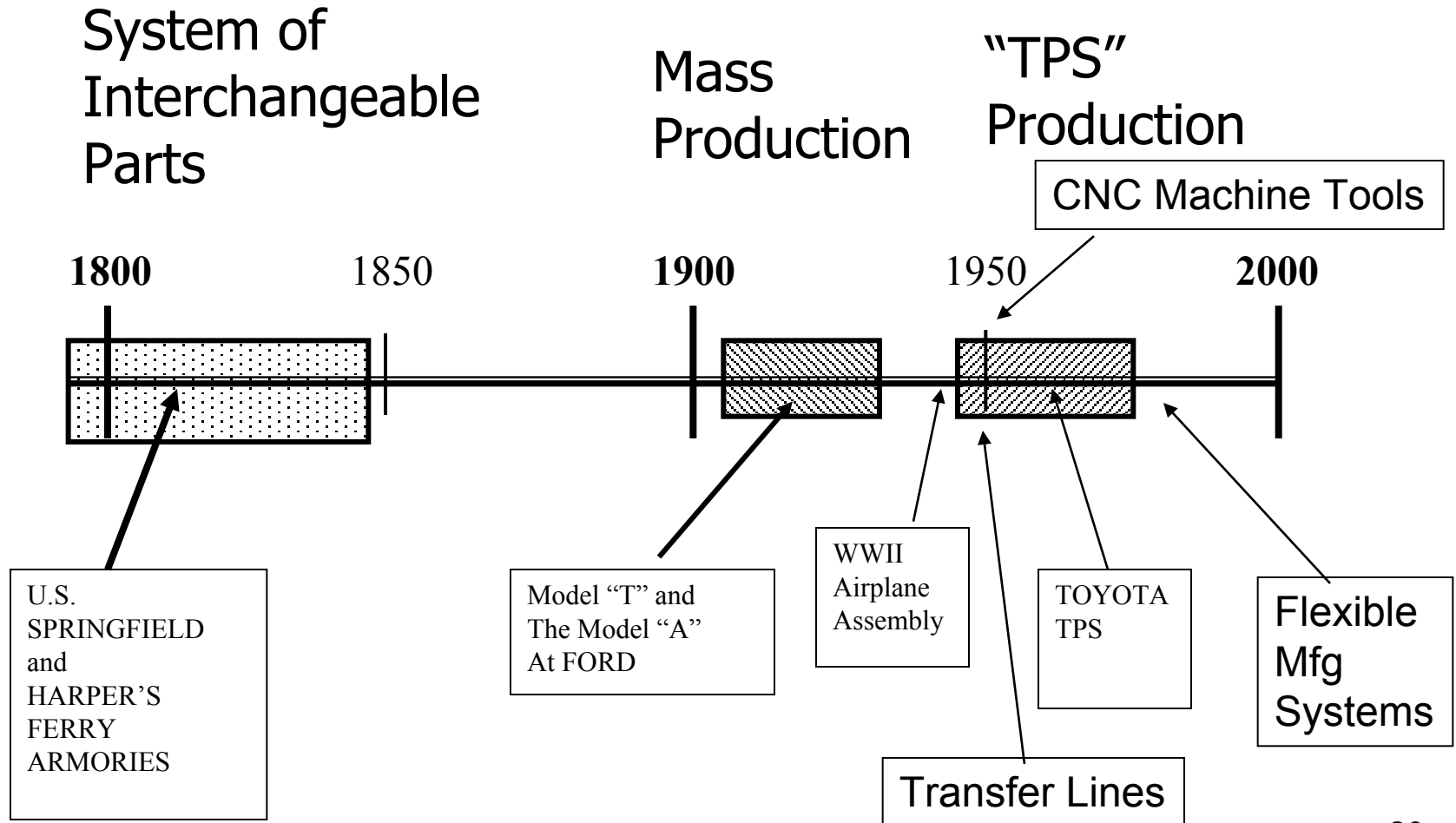
- Interchangeable Parts
 - US Armories...
- Mechanization of Production
 - Moving Assembly Line
 - Transfer Lines
- Mechanical to Digital Control
 - CNC Machines
 - Flexible Mfg Systems (FMS)
- Production to Demand
 - Toyota Production System (TPS)



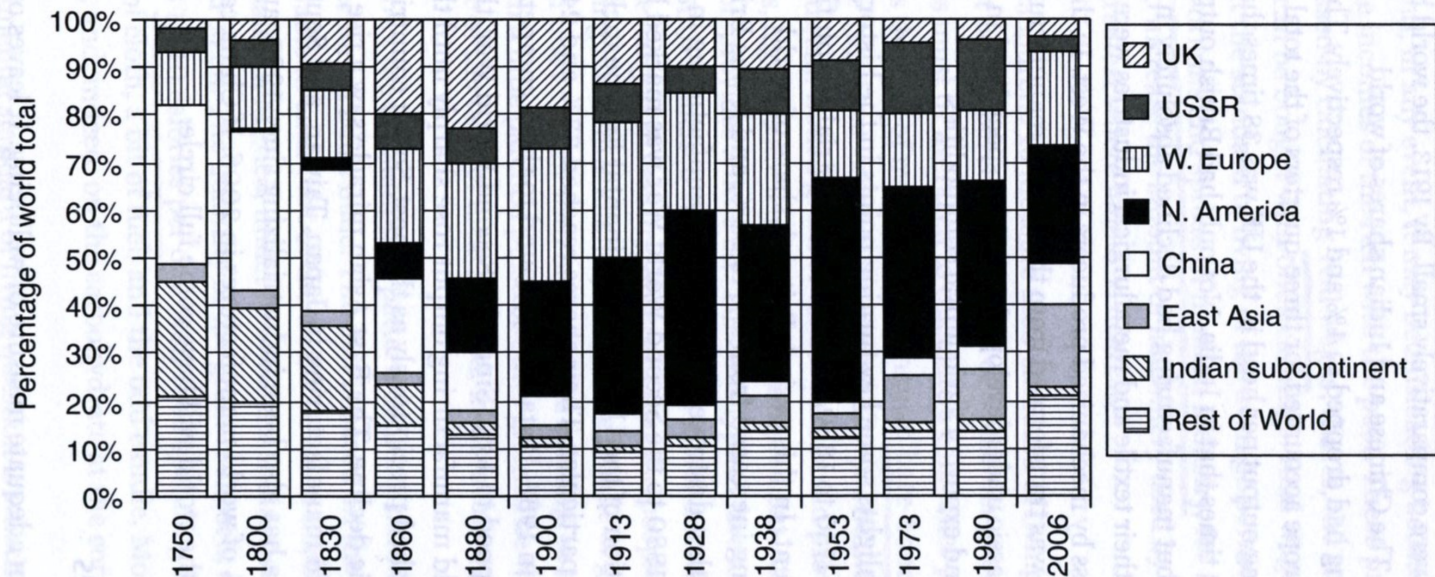
Reoccurring Issues

- Cost Effectiveness
- Social disruption
- Standardization Vs Flexibility
- Benefits and Costs of Inventory
- Work Scheduling/Control: Centralized Vs Distributed

Historical Development of Major Manufacturing Systems from ~1800 to 2000



Global Mfg Shares 1750-2006



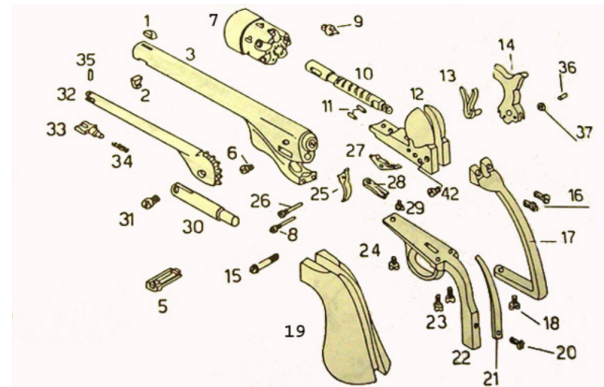
2. Distribution of world manufacturing

R.C. Allen 2011

Who developed interchangeable parts?

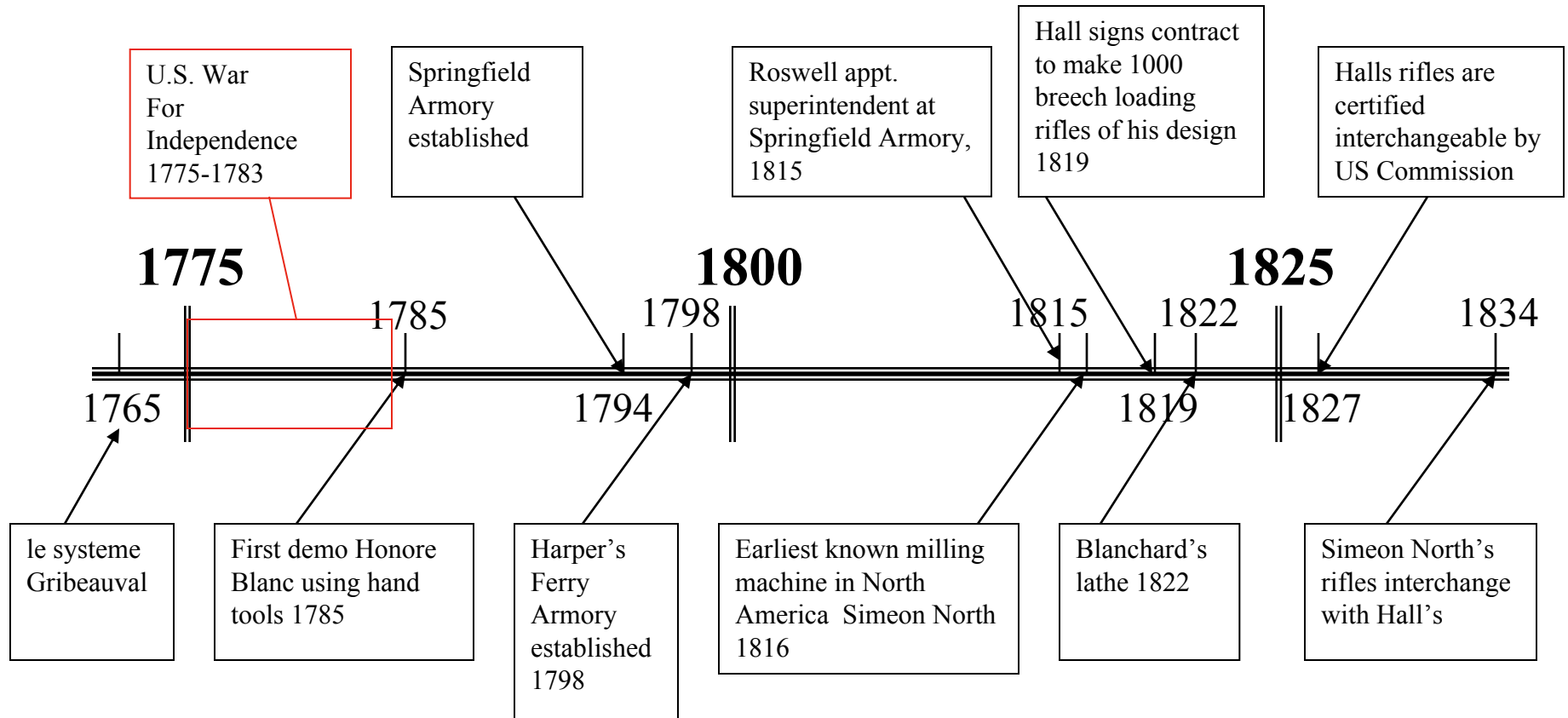


1. Eli Whitney?
2. Jean-Baptiste de Gribbeauval?
3. Samuel Colt ?
4. John H. Hall ?



Readings: David A. Hounshell, From the American System to Mass Production, 1800-1932, The John Hopkins University Press, 1984. **Introduction, Chapters 6 and 7**

Historical Developments for System of Interchangeable Parts



Refs primarily David A. Hounshell and Merritt Roe Smith

[King George III says: https://www.youtube.com/watch?v=eKFN-aqPJH8](https://www.youtube.com/watch?v=eKFN-aqPJH8) 23

Development of the System of Interchangeable Parts at the U.S. Armories



Harper's Ferry Armory

Refs:

1. Merritt Roe Smith, *Harper's Ferry Armory and the New Technology*, Cornell University Press, 1977.
2. David A. Hounshell, *From the American System to Mass Production, 1800-1932*, The John Hopkins University Press, 1984.

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1. Merritt Roe Smith, *Harper's Ferry Armory and the New Technology*, Cornell University Press, 1977.
2. David A. Hounshell, *From the American System to Mass Production, 1800-1932*, The John Hopkins University Press, 1984.

Springfield MA & Harper's Ferry VA US Armories

- Roswell Lee
 - Scarcity of trained gunsmiths
 - Transportation hub
 - Puritan ethics
 - Good schools
 - Rapid adoption of new technology
- James Stubblefield
 - Who's who of PA gunsmiths
 - Paternalistic society
 - Back water place
 - Poor performance
 - Poor adoption of new technology

U.S. Model 1816 Musket produced at the Springfield and Harper's Ferry Armories by craft method

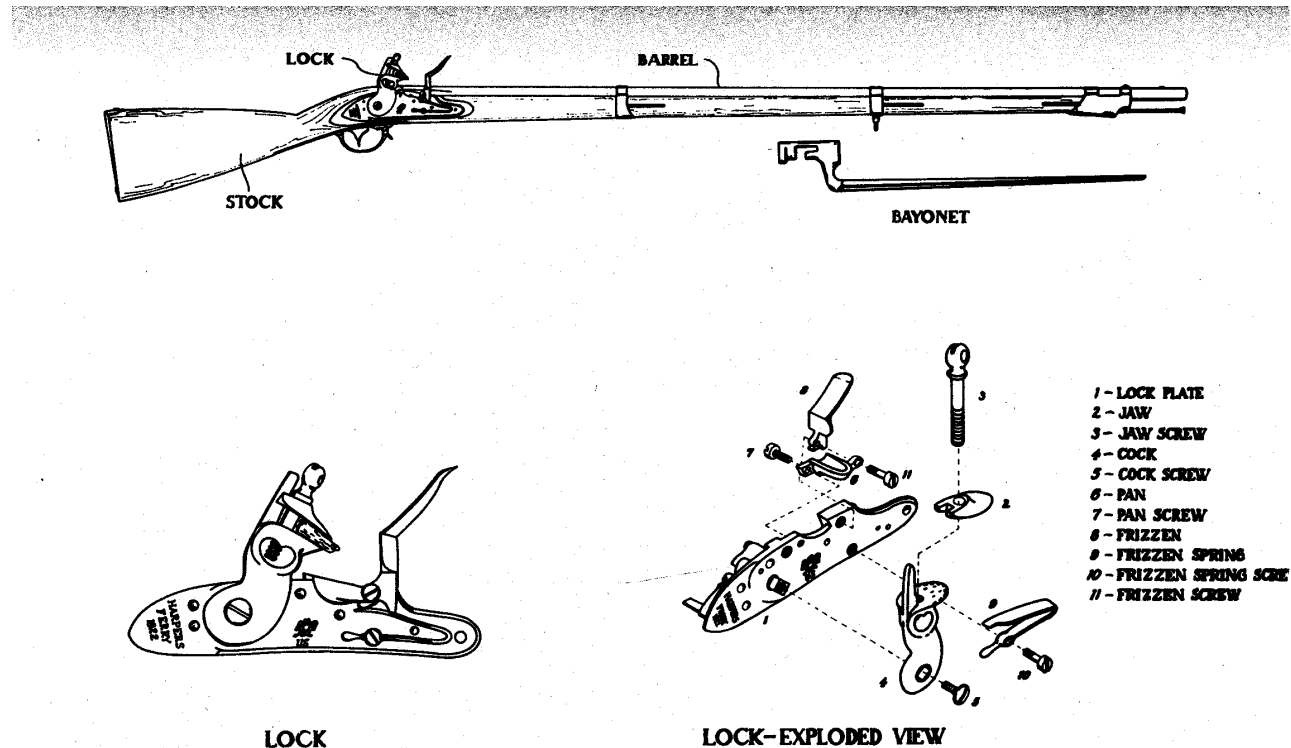


Figure 2. U.S. Model 1816 musket. For views of the tumbler, bridle, sear, and other interior parts of the lock mechanism, see Figure 14
Drawing by Steve Foutz. Photograph by Christopher Duckworth.

By employing the "European system" of division of labor
The armories could produce ~10,000 muskets/yr w/ ~250 workers

Illustration of a water driven trip hammer used for making barrels 1815 and Thomas Blanchard's eccentric lathe for turning gun stocks circa 1819

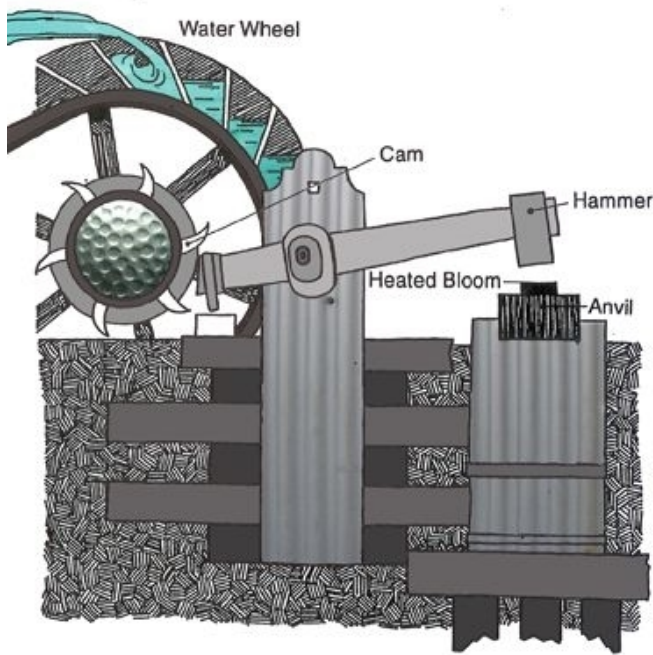
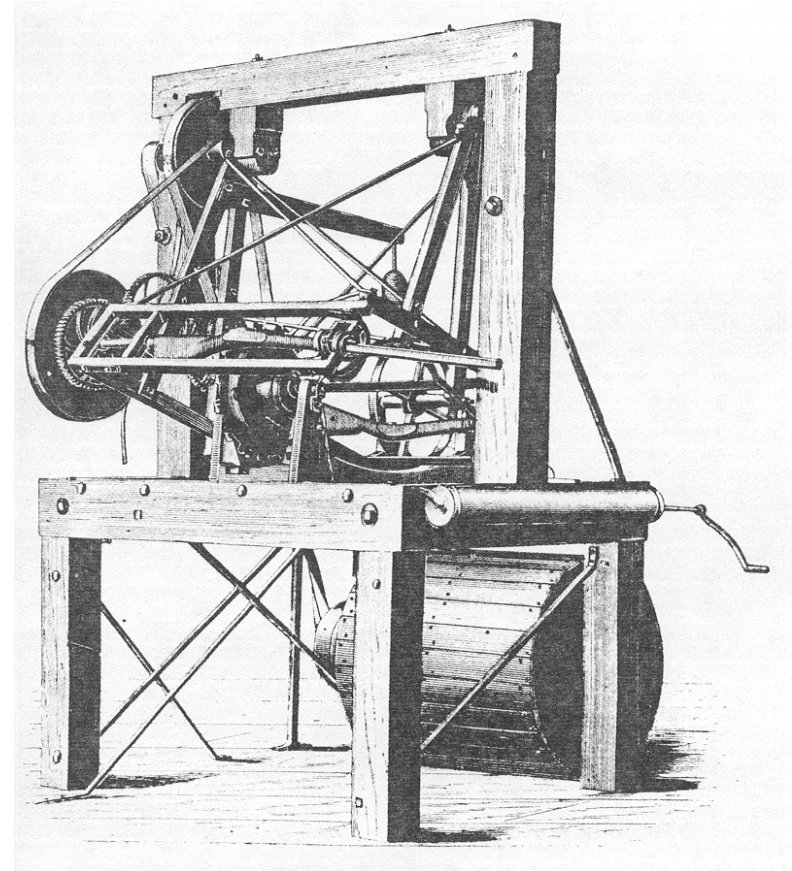
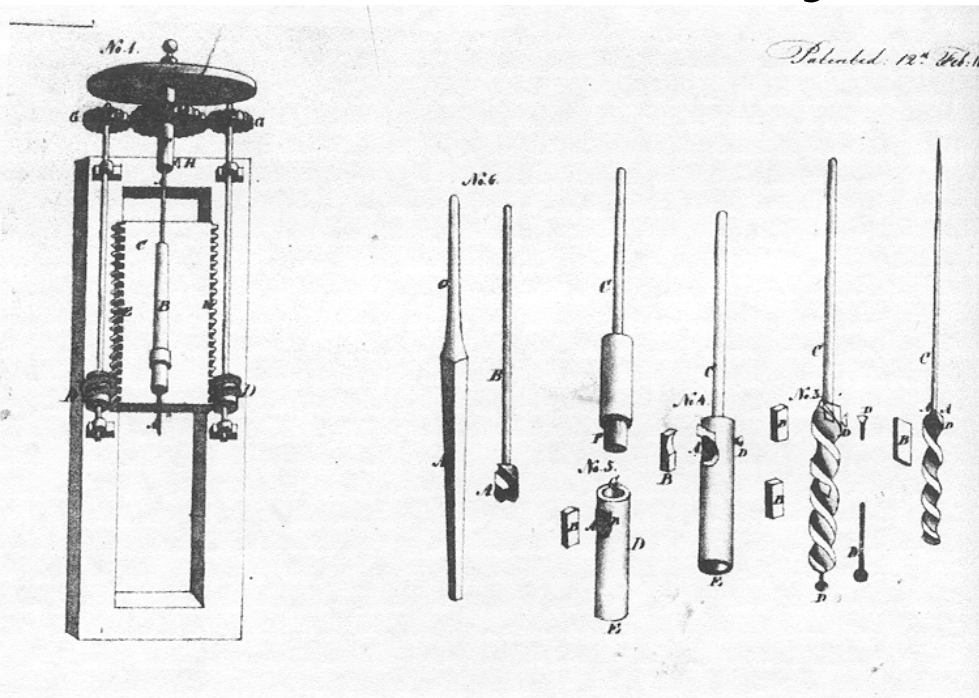


Fig. 4 Diagram of a forge trip hammer.



<https://www.youtube.com/watch?v=ITNEHqW0hyQ>

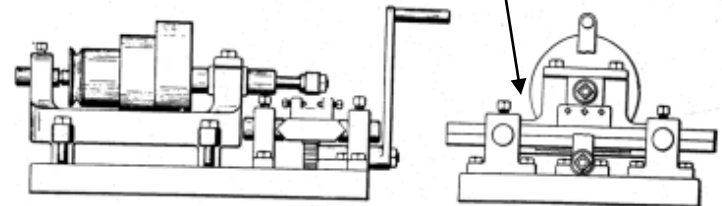
Technology development in early America



Machine for boring gun
Barrels with various
Augers from 1814 U.S. patent
application

"Earliest known milling
Machine in America"
circa 1816 by Simeon North

Ref Smith

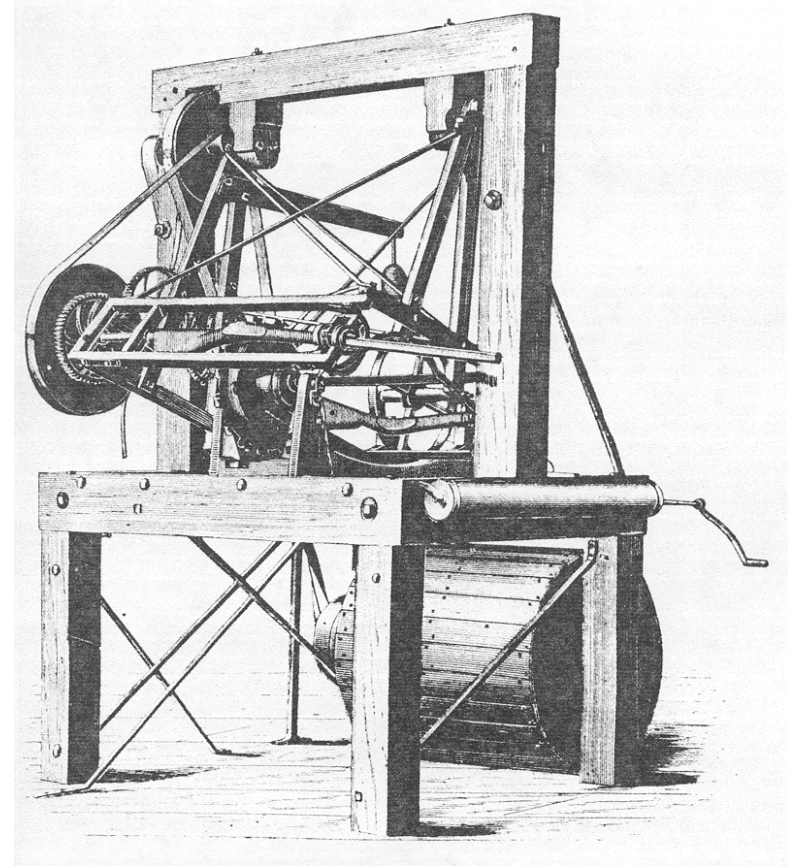
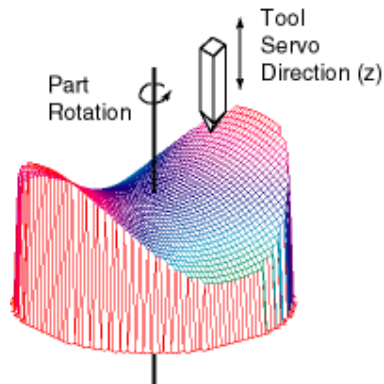
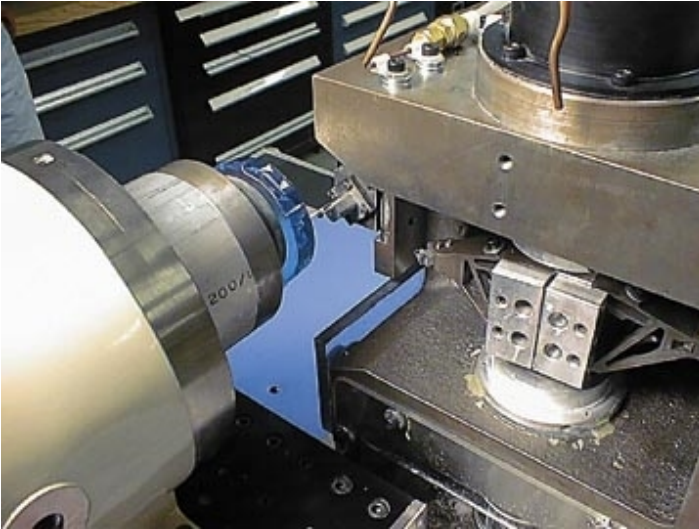


Blanchard's reply to Roswell Lee's letter of Jan 1819 requesting a demonstration of his new process at the National Armory

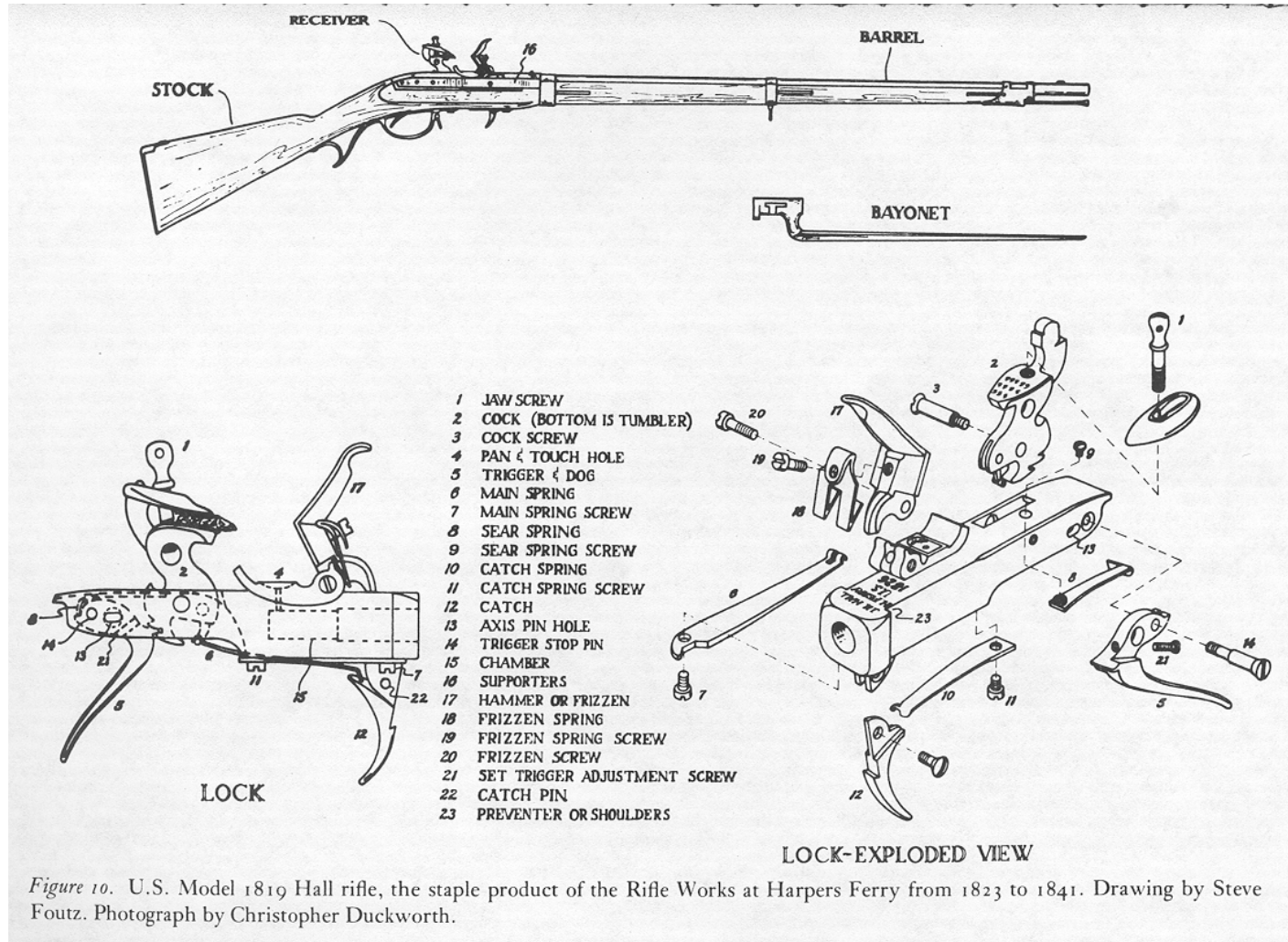
"Yours of the 21 ultame. come safe to hand – you wished me to wright you respecting macenory – I conclude you meen a machine I have recently invented for turning gun stocks and cuting in the locks and mounting. Doubtless you have heard concerning it But I would inform you that I have got a moddle built for turning stocks and cuting in the locks and mounting. I can cut a lock in by water in one minute and a half, as smooth as can be done by hand. The turning stocks is very simple in its operation and will completely imatate a stock made in proper shape. I shal bring the moddle to Springfield in the course of three weeks – I shal want your opinion of its utility."

(ref. Merritt Roe Smith p 128)

Trumper's & Blanchard's lathes

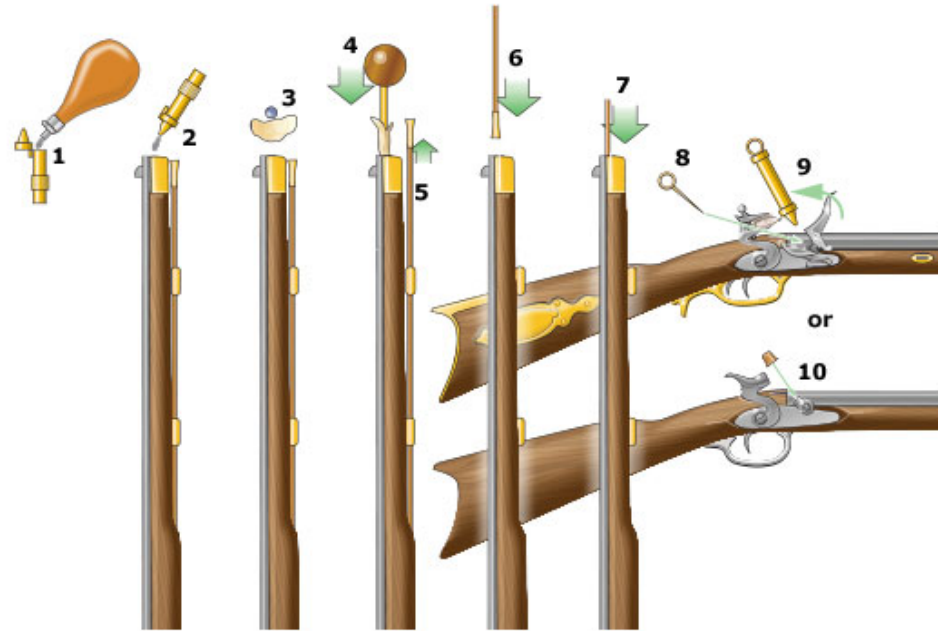


John Hall's Breech loading rifle, produced at Harper's Ferry from 1823 to 1841



Invented in 1811, certified interchangeable in 1827 by military commission

Steps for Loading a Muzzleloader



1. After you make sure the gun is unloaded and free of oil, measure powder charge into a powder measure.
2. Pour measured powder down barrel.
3. Place patch and ball on muzzle.
4. Push ball into barrel with starter.
5. Take out ramrod.
6. Ram ball down barrel.
7. Be sure ball is completely seated on the powder charge.
8. Clear vent hole with pick if necessary.
9. On a flintlock, pour powder into pan and close frizzen.
10. On a percussion lock, place cap on nipple.

John Hall's Breech loading rifle, produced at Harper's Ferry from 1823 to 1841



Invented in 1811, certified interchangeable in 1827 by military commission

Fixturing of Parts – as described by John H. Hall to the Secretary of War in 1840

“In making a part of an arm like a prescribed model, the difficulty is exactly the same, as that which occurs in making a piece of Iron exactly square. In such a case, a man would Square the 2d. side by the 1st, the 3d. by the 2d. and the 4th by the 3d., but on comparing the 4th side with the 1st, it will be found that they are not square; the cause is that in squaring each side by the preceding side, there is a slight but imperceptible variation and the comparison of the 4th with the 1st gives the sum of the variations of each side from a true square. And so in manufacturing a limb of a gun so as to conform to a model, by shifting the points, as convenience requires, from which the work is gauged & executed, the slight variations are added to each other in the progress of the work, so as to prevent uniformity. *The course which I have adopted to avoid this difficulty, was to perform & gauge every operation on a limb, from one point called a bearing so that the variation in any operation could only be the single one from that point”.*

Ref.

Merritt Roe Smith “Harper’s Ferry Armory and the New Technology”, U. Cornell Press, 1977, p. 227.

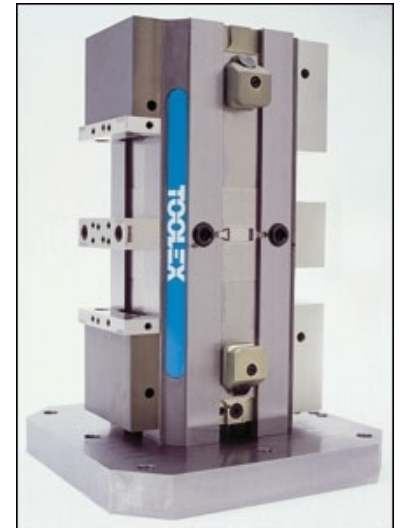
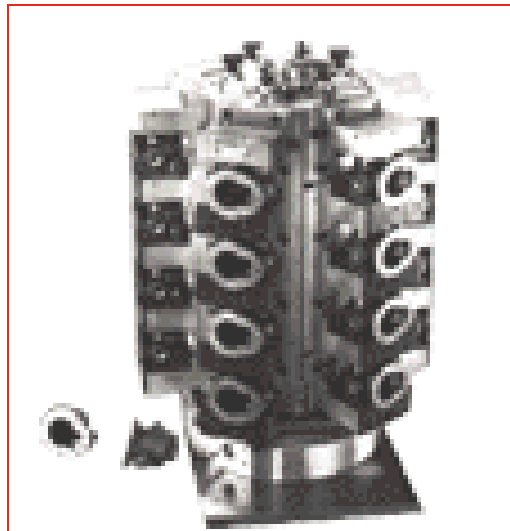
Locating feature for machining of forged crankshaft



Fixturing Principles from John Hall;

Principle: Fixture Part from a single reference or “bearing”

Corollary: Once fixtured, perform as many operations as possible.



Interchangeable Parts at U.S. Armories circa 1800-1860

Key points:

1. Military need and financing
2. Enabled by machine tool industry developments in the U.S.
3. Division of labor and piece rate accounting
4. Transition from “master” model of part to engineering drawing of part disrupts social structure in shop.
5. Maintenance of tolerance requires gauging and gauge blocks, this also disrupts social structure.
6. Cultural and leadership differences at Springfield and Harper’s Ferry Armories greatly affect rate of new technology adoption.
7. John Hall designs and builds breech loading rifle - first demonstration of interchangeable parts.
8. Cost effectiveness of new system in doubt for decades, slow and painful transition to commercial products e.g. sewing machines, harvesting machines and bicycles

The Ford Motor Co. and Mass Production



Finally after the Models A, B, C, F, K, N, R, and S came the Model “T” in 1908. Here are Henry and Edsel Ford in the last Model T produced in 1927.

Refs:

David A. Hounshell, *From the American System to Mass Production, 1800-1932*,
The John Hopkin’s University, Press, 1984.

Karl Williams, Colin Haslam and John Williams, “Ford versus “Fordism, The Beginning of Mass Production?”
appeared in *Work, Employment and Society*, December 1992.

Ford

Model T from 1908
to 1927, more than
15 million produced.
177 cu in (2.9L)
20hp, 13-21 mpg



Model A from 1927
to 1931, almost
5 million produced.
201 cu in (3.3L)
40 hp
25-30 mpg

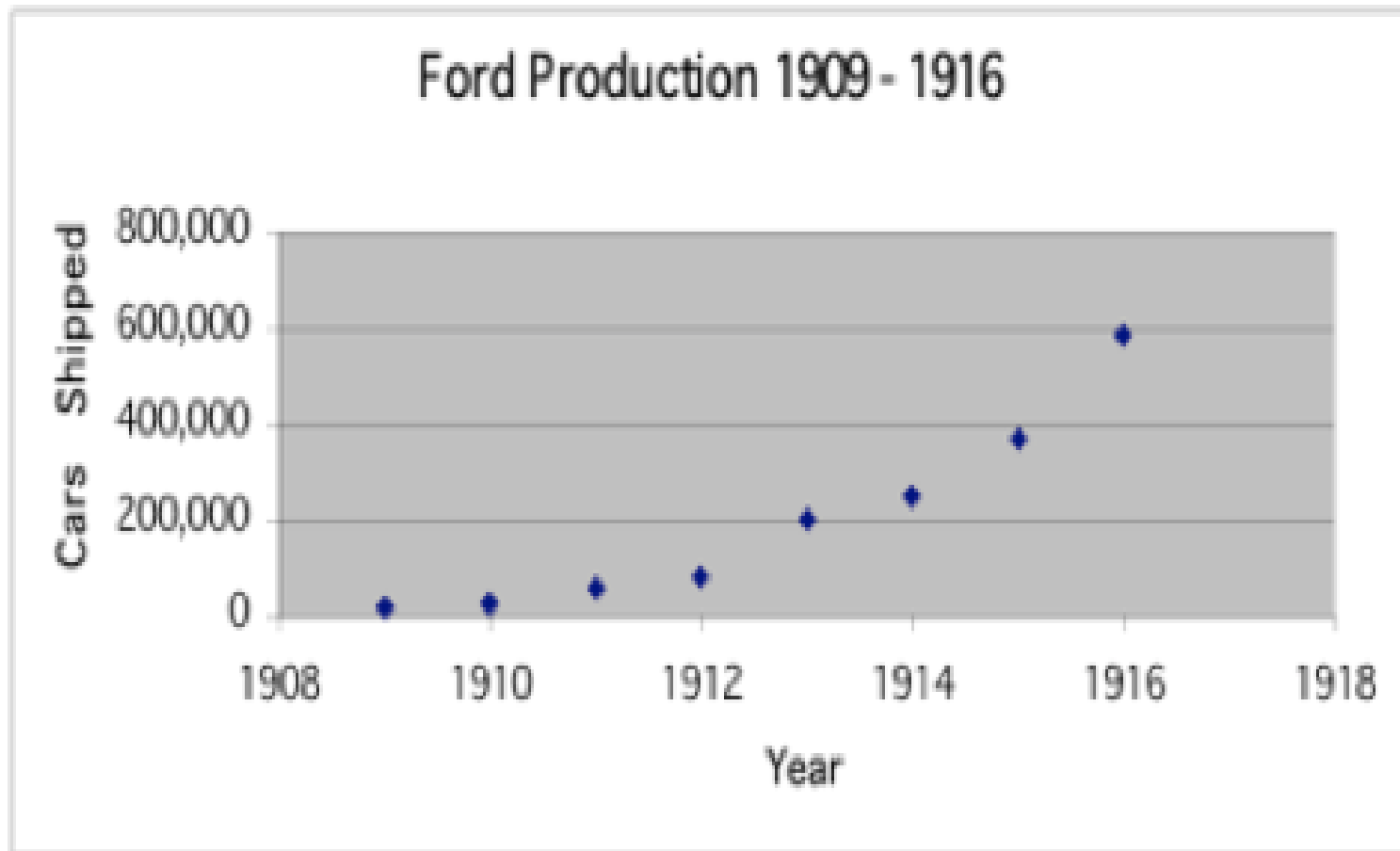
1927 Chevrolet

Best selling
car in US for
that year

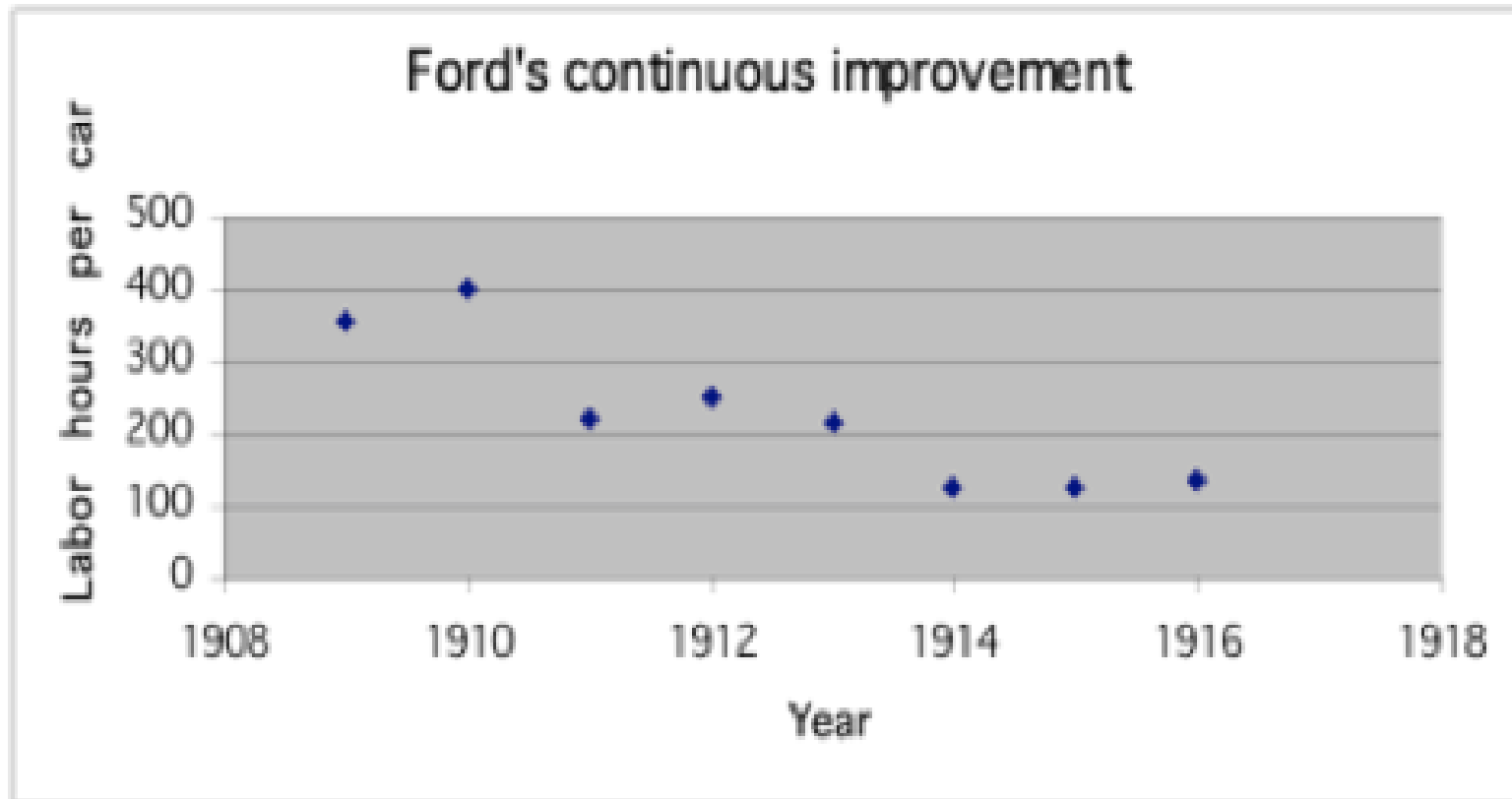


Roomy interior!
Not black!
Also inline 4
171 cu in (2.8L)
20 hp

Ford's early production was increasing as fast as he could build cars



Ford's response.....

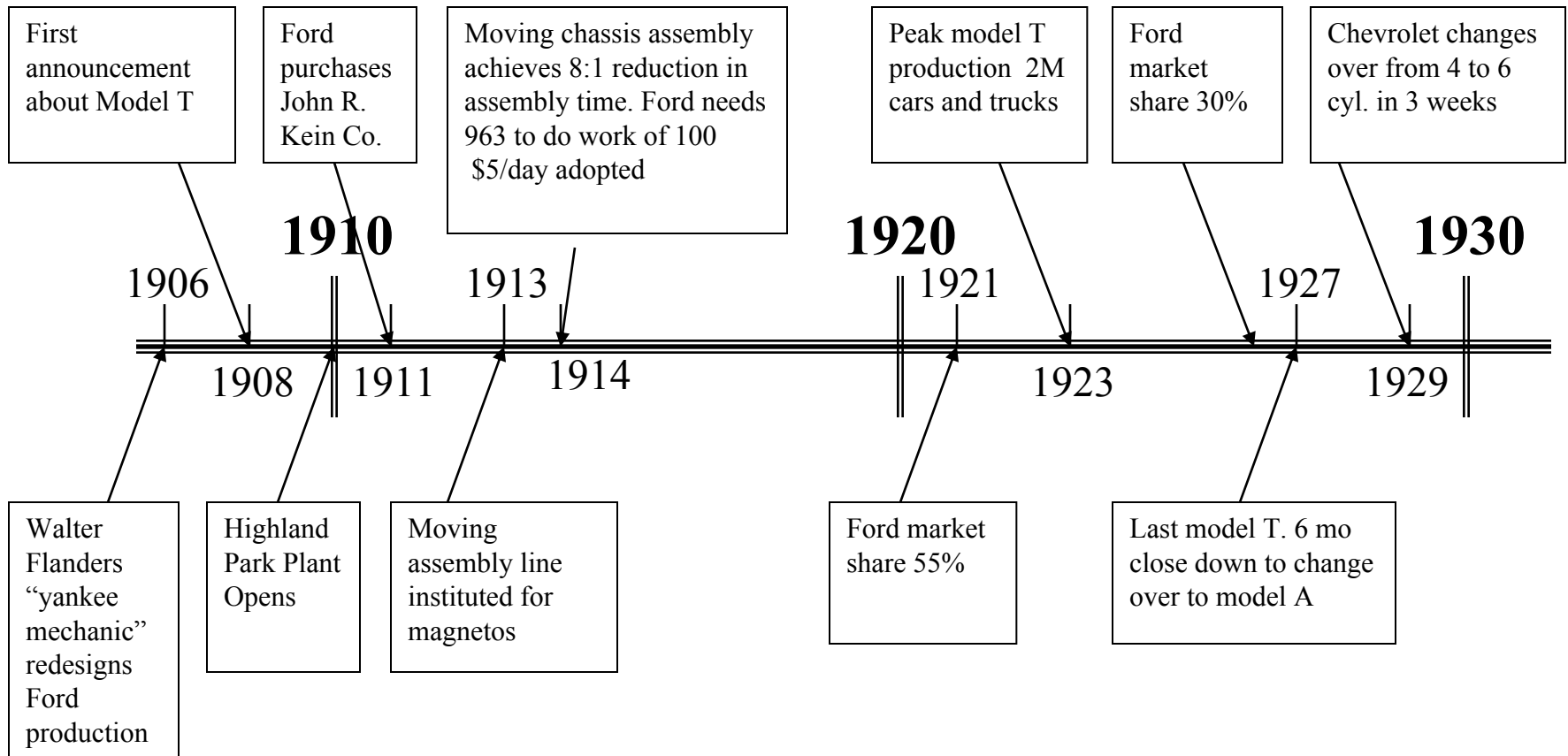


Ford's continuous improvement 1909-1916

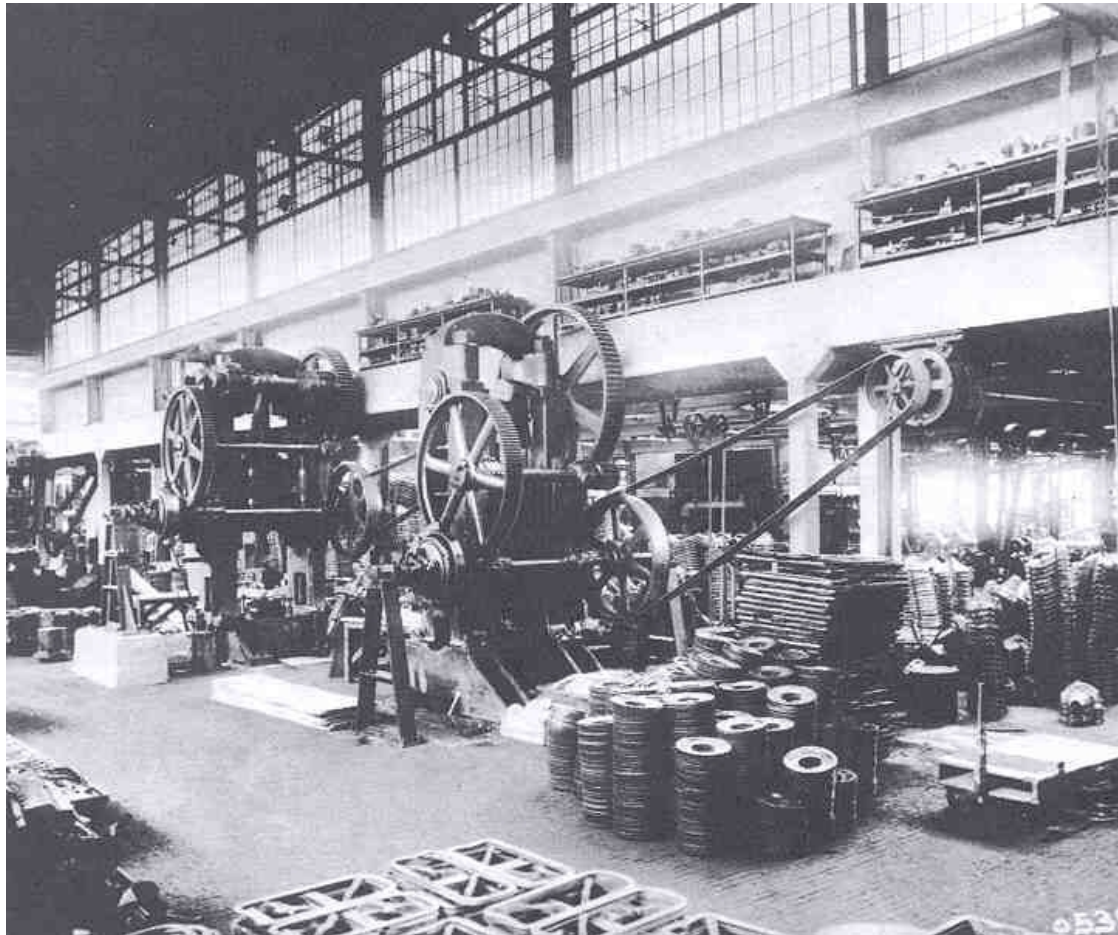
	Cars Shipped (i)	Number of employees (ii)	Cars per man year (iii)	Labor hours per car (iv)
1909	13,941	1,655	8.4	357
1910	20,738	2,773	7.5	400
1911	53,800	3,976	13.5	222
1912	82,500	6,867	12.0	250
1913	199,100	14,366	13.9	216
1914	249,700	12,880	18.8	127
1915	368,599	18,892	19.5	123
1916	585,400	32,702	17.9	134

70%
reduction

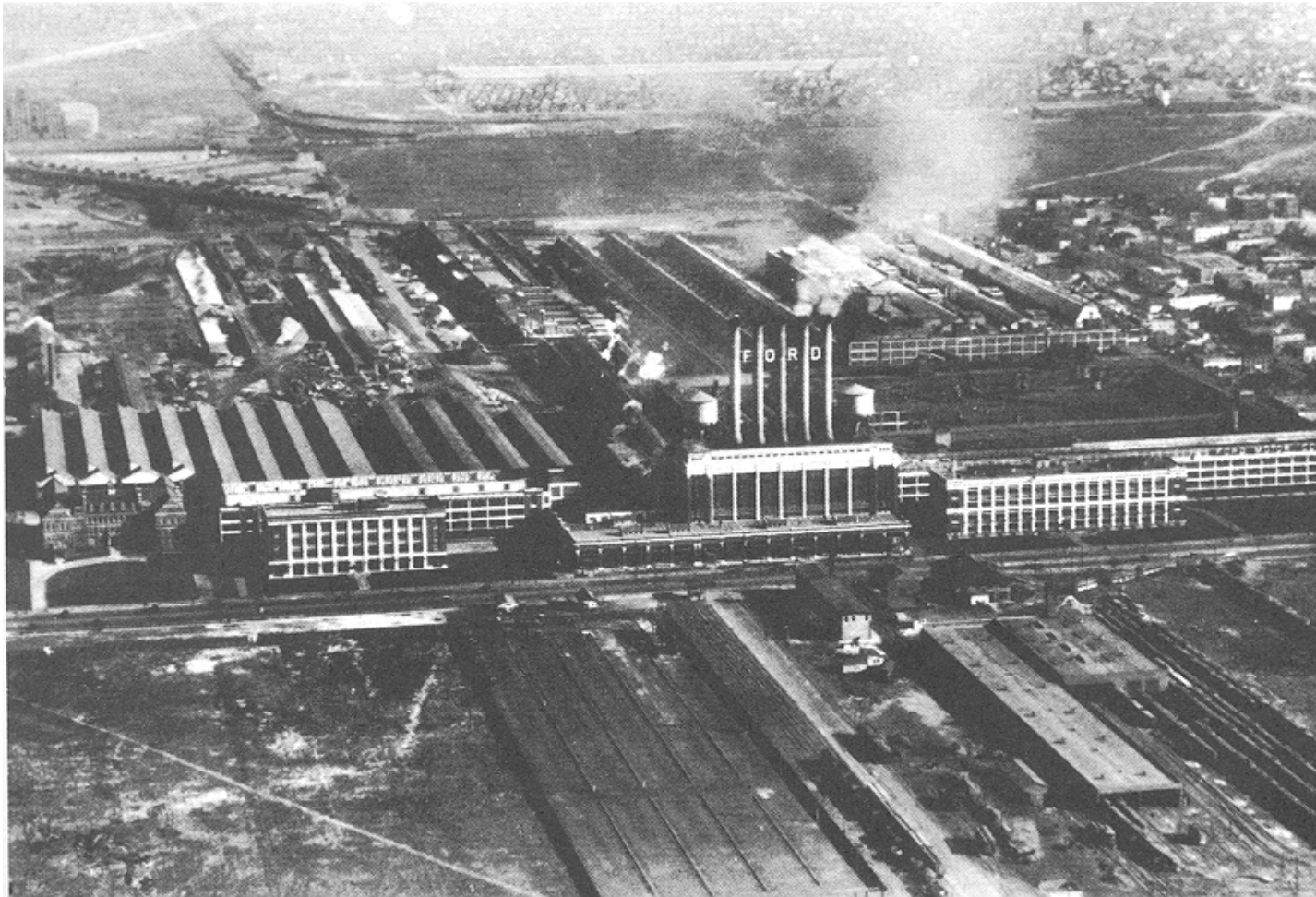
Historical Development of Mass Production at Ford.



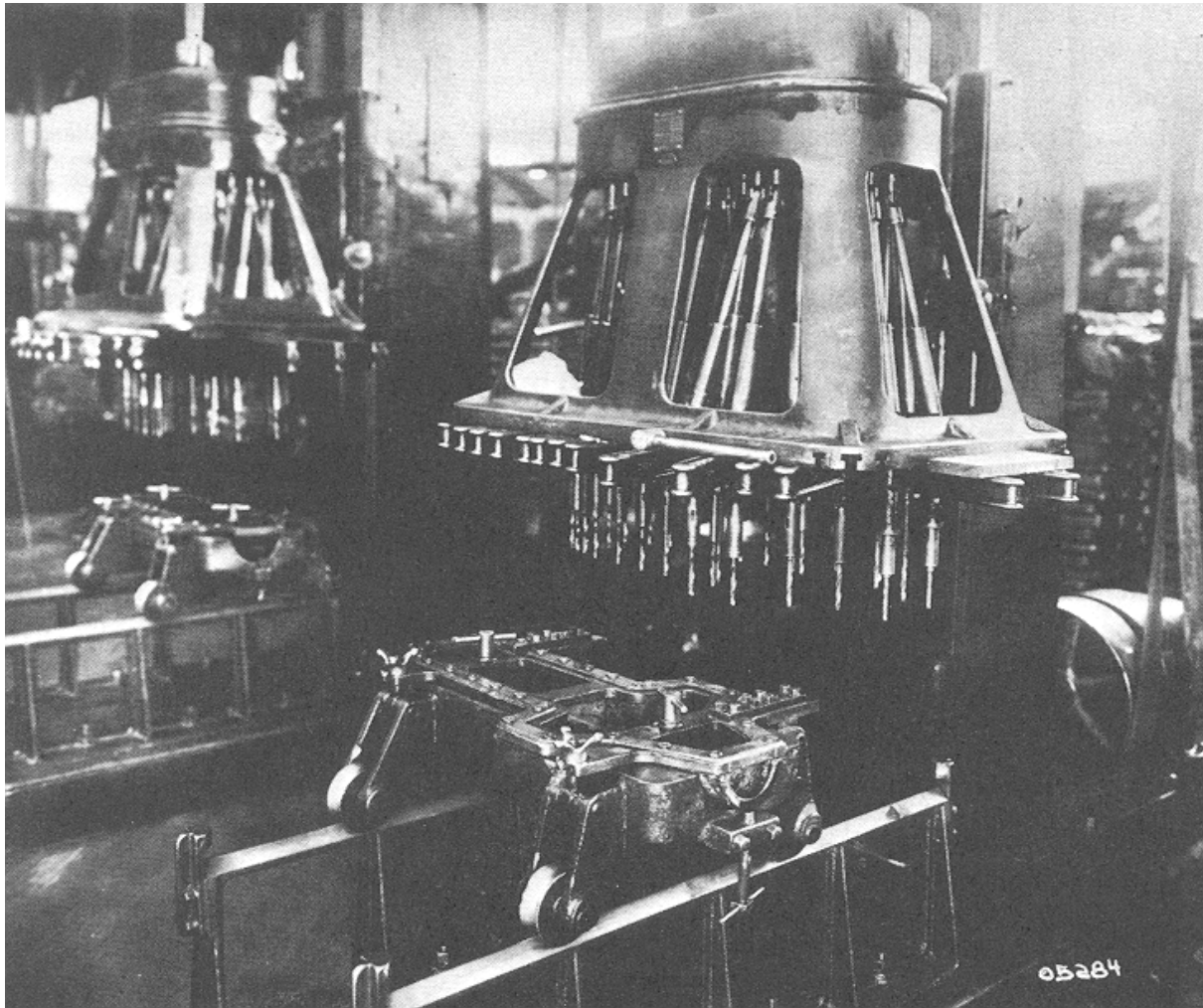
“Punch Press operations, Highland Park plant 1913
Much of Ford’s punch press machinery came from
John R. Keim Company from Buffalo, which Ford
purchased in 1911 and moved to Detroit.” Ref. Hounshell



Ford's Highland Park Plant where the moving assembly line was first developed for automobiles in 1913



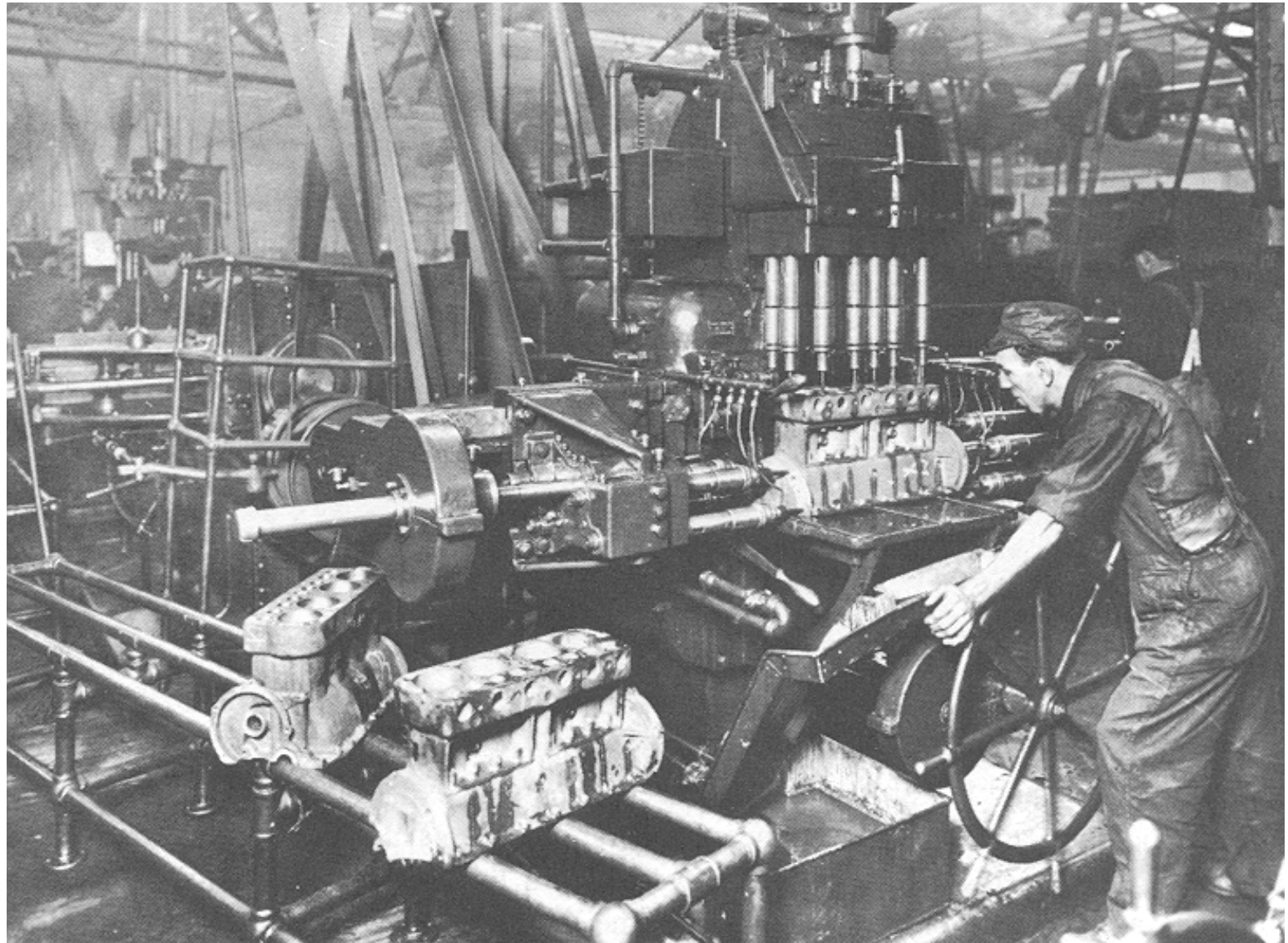
Multiple spindle drilling of the crankcase, notice the quick-change fixturing.



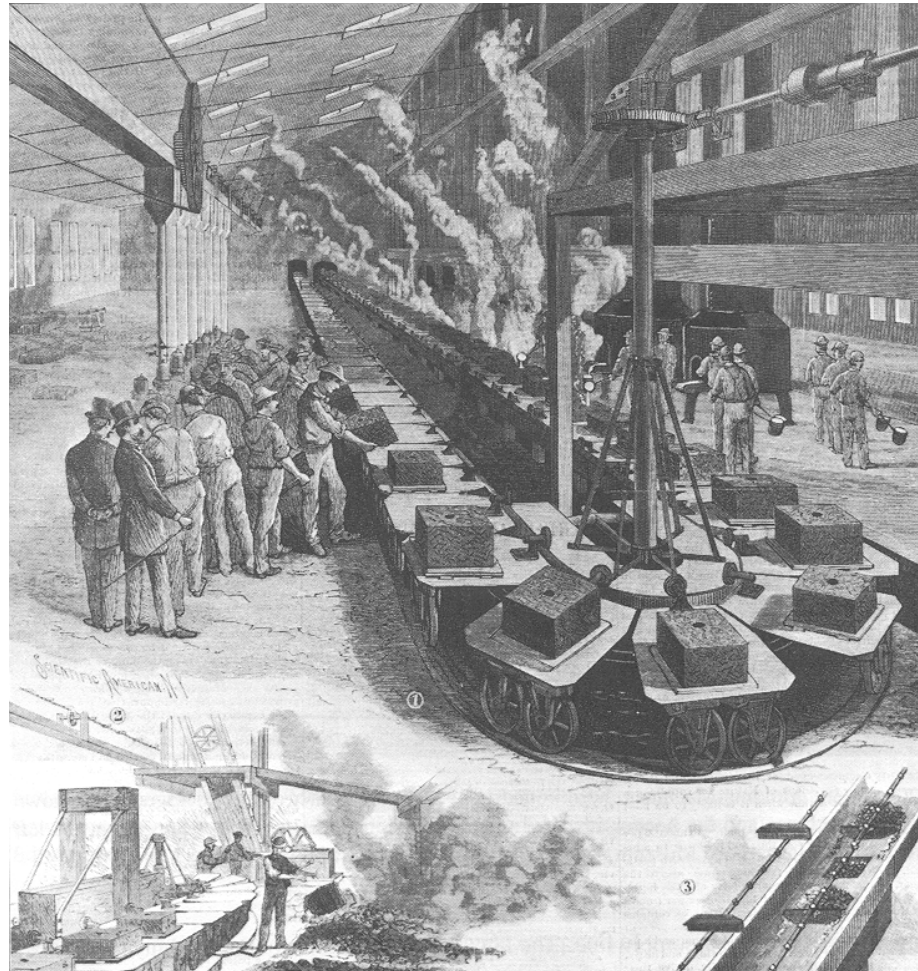
Ford Crankshaft Grinding Machines 1915



Multi-spindle drilling and reaming of engine blocks



Westinghouse Foundry in 1890
Machine made molds are moved past pourer
on conveyor system. A similar system was used at Ford



THE FIRST
OPERATION
TO BE
CONVERTED
TO THE
MOVING
ASSEMBLY
LINE WAS THE
MAGNETO
ASSEMBLY
IN 1913

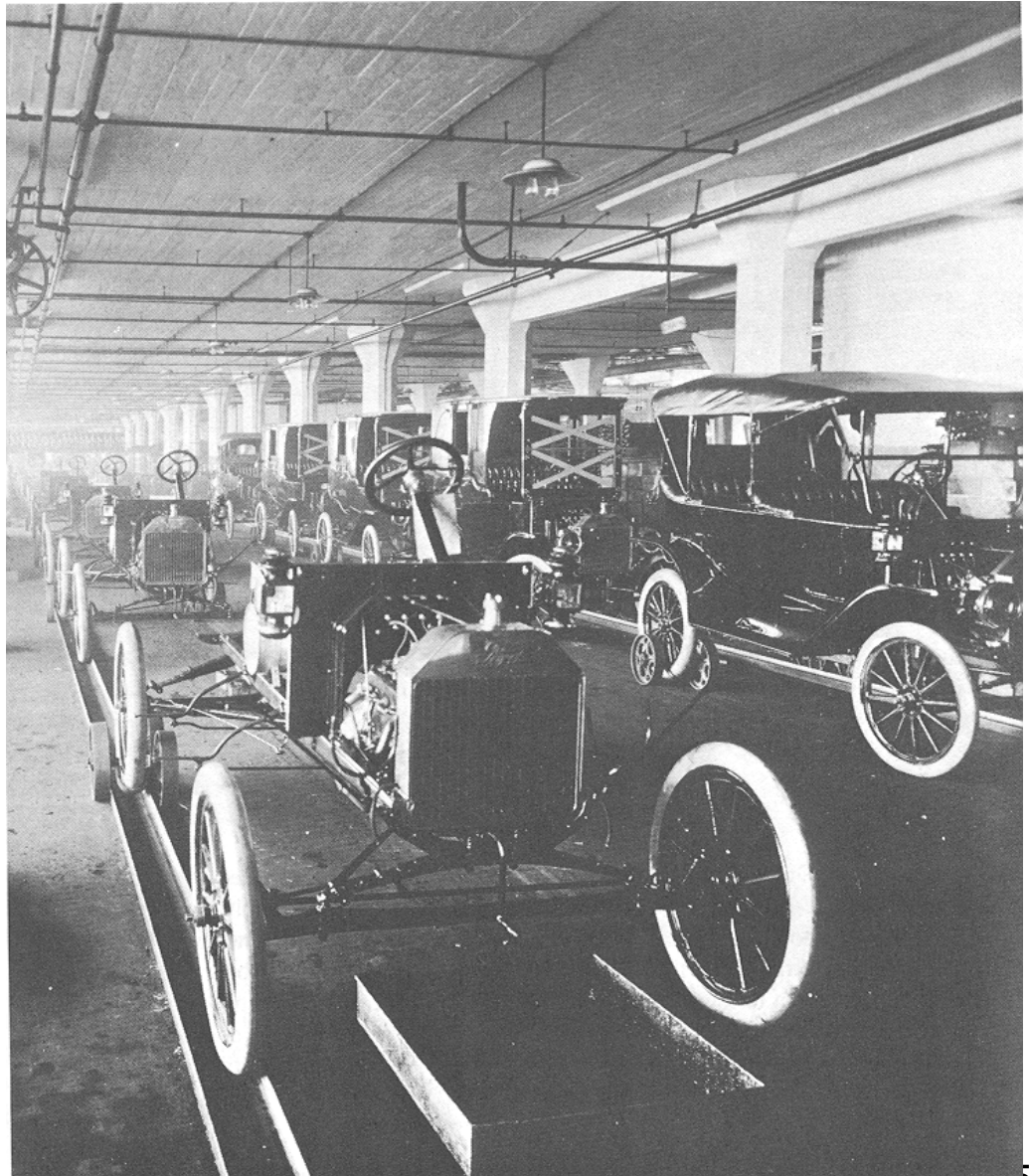


Static Assembly of the Model "N" At the Piquette Avenue Factory 1906



HIGHLAND PARK

THE CONVERSION
OF THE CHASSIS
FROM STATIC (12.5 hr)
TO MOVING (93 min)
RESULTED IN
AN **8:1 IMPROVEMENT**.
WITHIN 18 MO.
ALL ASSEMBLIES
AND SUBASSEMBLIES
WERE CONVERGED TO
MOVING ASSEMBLY.





General view of “the line” Highland Park 1914

This is the assembly line that assembled a car in 93 minutes



...However, Ford's
turnover rate
increased dramatically.
In 1914 Ford needed
To hire 963 people
To fill 100 jobs

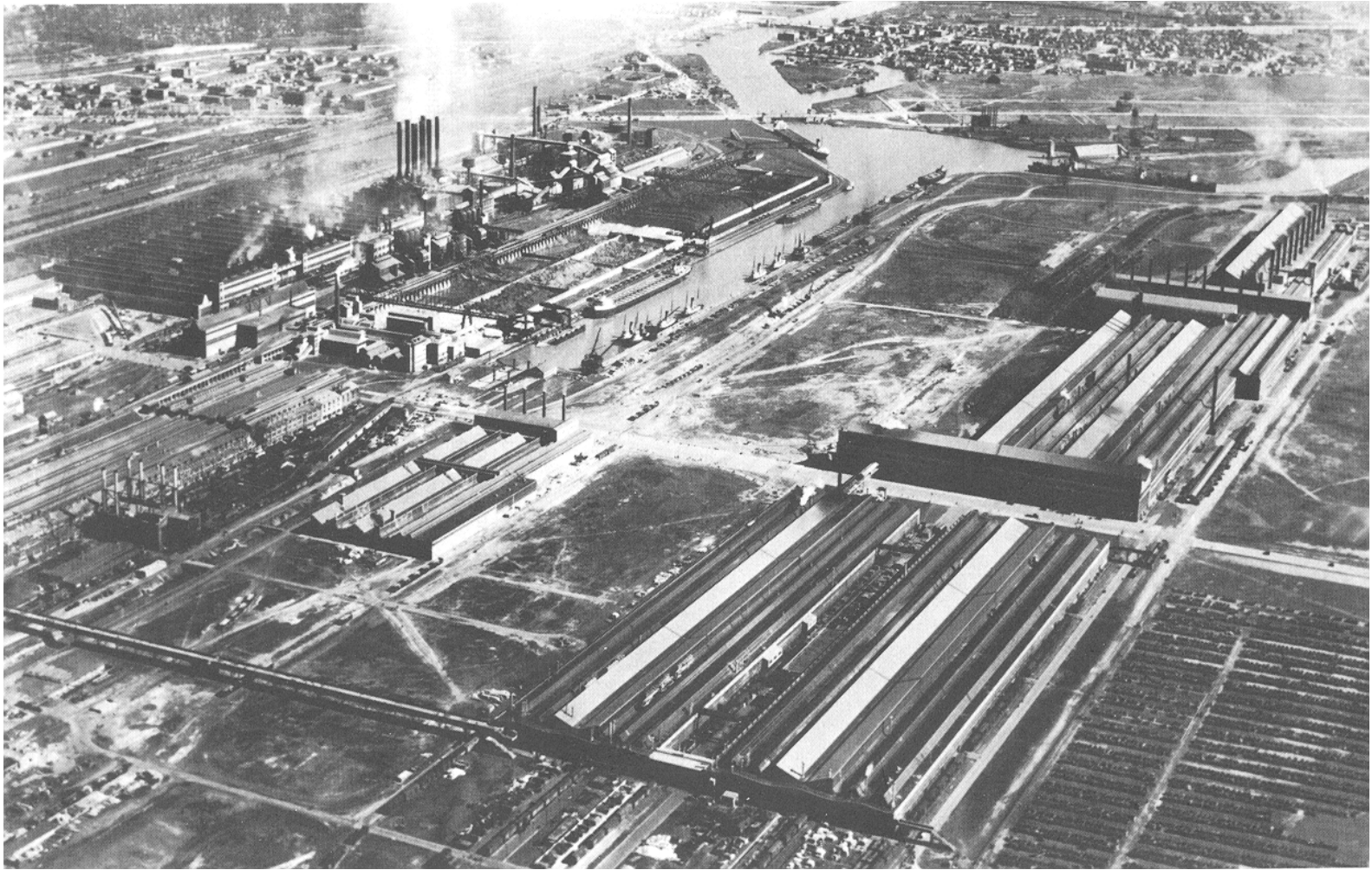
FORD MODEL T VIDEO

Crowd wanting to apply for \$5/day jobs at Ford 1914



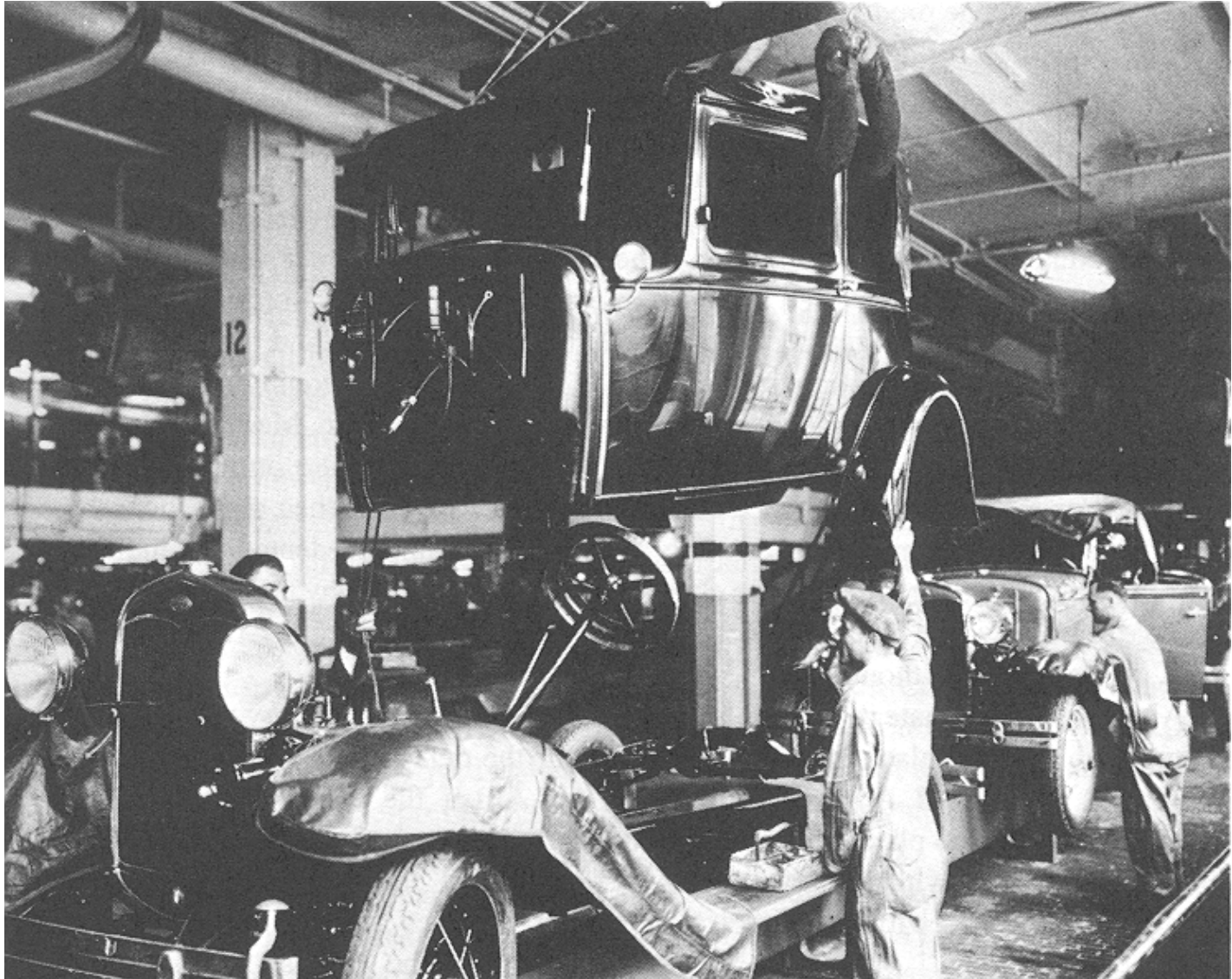
From the collections of The Henry Ford

Ford's River Rouge Plant; 27 miles of conveyor, the epitome of vertical integration.



1927 change over to model "A". 1949 strike. Now the site of Bill Ford's Heritage program.

Lowering the body onto the Model "A". Those curved lines contributed to manufacturing problems which delayed the changeover



Ford Service men in action

May 26, 1937



Harry Bennett
Head of Ford's
Security Dept.

photographer Scotty Kilpatrick, Detroit News

Labor leaders Walter Reuther and Richard Frankenstein after beatings by Harry Bennett's "service" men at the "battle of the overpass".

May 26, 1937 at the Ford River Rouge Plant.



photographer Scotty Kilpatrick, Detroit News

“The photos taken by the Detroit News photographer Scotty Kilpatrick on the overpass did not qualify for a Pulitzer Prize because there was no such category at the time. But they caused the Pulitzer committee to institute a prize for photography and in 1942 Detroit News photographer Milton (Pete) Brooks won a Pulitzer for this of a beating on a Ford picket line. Ironically, it shows picketers beating a Ford Motor Co. security man.”



Ref "Rear View Mirror"
Detroit News 62

Mass Production at Ford, 1907-1932

Keypoints:

1. “In mass production there are **no fitters**” - Henry Ford.
2. **Stamping** plays important role in providing low cost high precision parts.
3. Constant improvement, division of labor, standard work, flat organization. **Moving assembly line** (1913) comes from other examples in industry. Work pace is increased and **turnover rate** increases. In late 1913, to add 100 workers Ford needed to hire 963 people. \$5/day pay is instituted to address this problem.
4. Vertical integration is taken to limits at **River Rouge**. End of previous cost cutting strategy, conveyor system limits flexibility, labor strike moves Ford to build new plants at other locations.
5. **Conversion** from Model T **to Model A** is too late and extremely painful, occasions 6 month shut down and great upheaval.
6. **GM** introduces yearly model change 1925-1932.

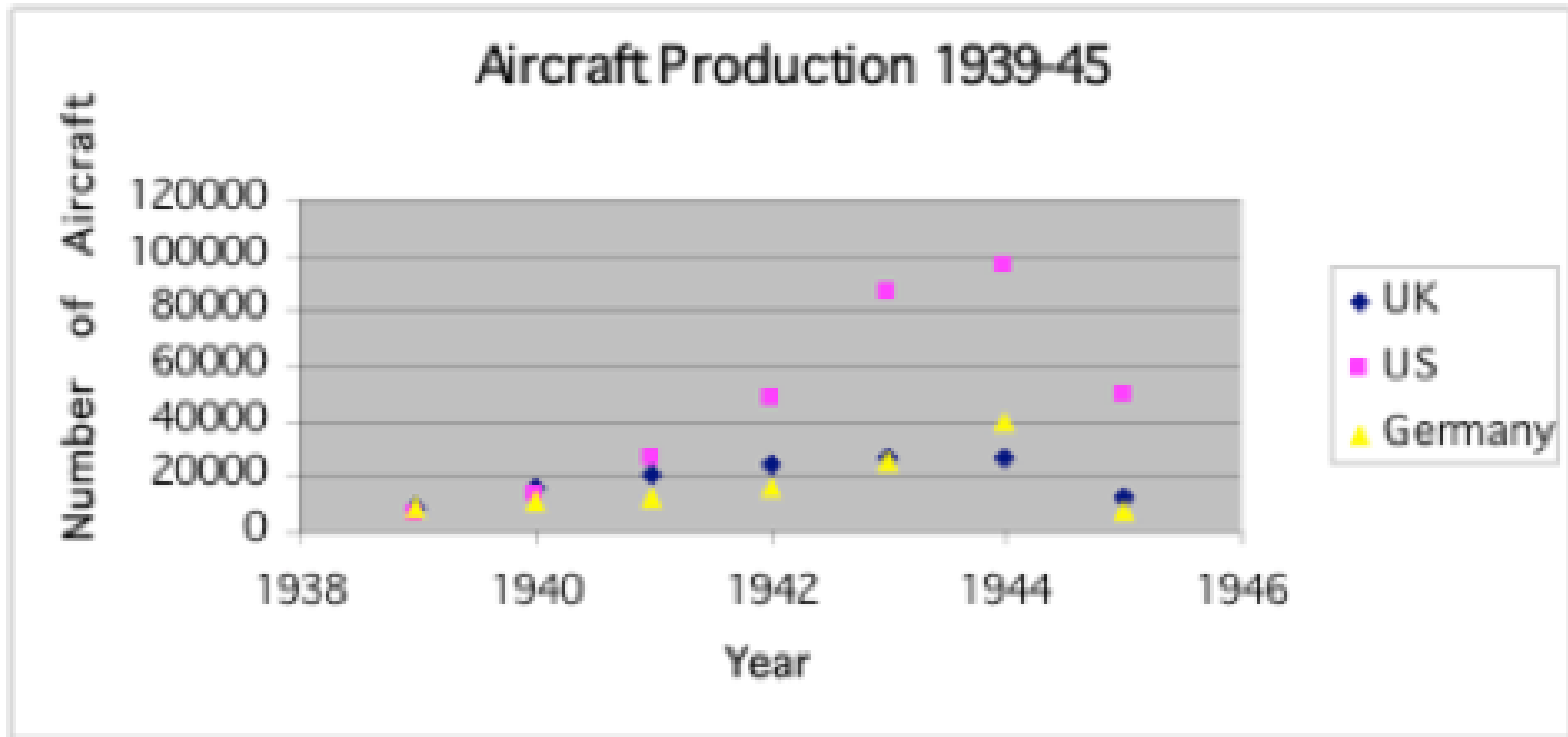
Common elements between Ford and “lean”

- Elimination of Waste
- Equipment Placed in the Sequence of Operations
- Reduced Inventory
- Production to Demand not to Stock
- Continuous Improvement
- Flat Organization

Charlie Chaplin in “Modern Times” 1936



High Volume Aircraft Production during WWII, 1939 - 1945



Refs:

1. Johnathan Zeitlin, "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the United States and Germany, 1939-1945", published in The Society for the History of Technology.
2. Don Sherman, "Willow Run", published in Air and Space, August/September 1992.
3. Joshua Stoff, "Picture History of WWII American Aircraft Production", published by Dover Publications, 1993.

How did they do it?

year	UK	US	Germany
1939	7904	5,859	8,295
1940	15,049	12,864	10,247
1941	20,094	26,277	11,776
1942	23,672	47,836	15,049
1943	26,263	85,898	24,809
1944	26,461	96,318	39,807
1945	12,070	49,761	7,540



16:1 !!!

- Division of labor
- Auto Vs Aircraft Methods
- Pre-fabrication strategy
- Moving assembly line
- Modification Centers

B-24 Assembly line in Ft. Worth



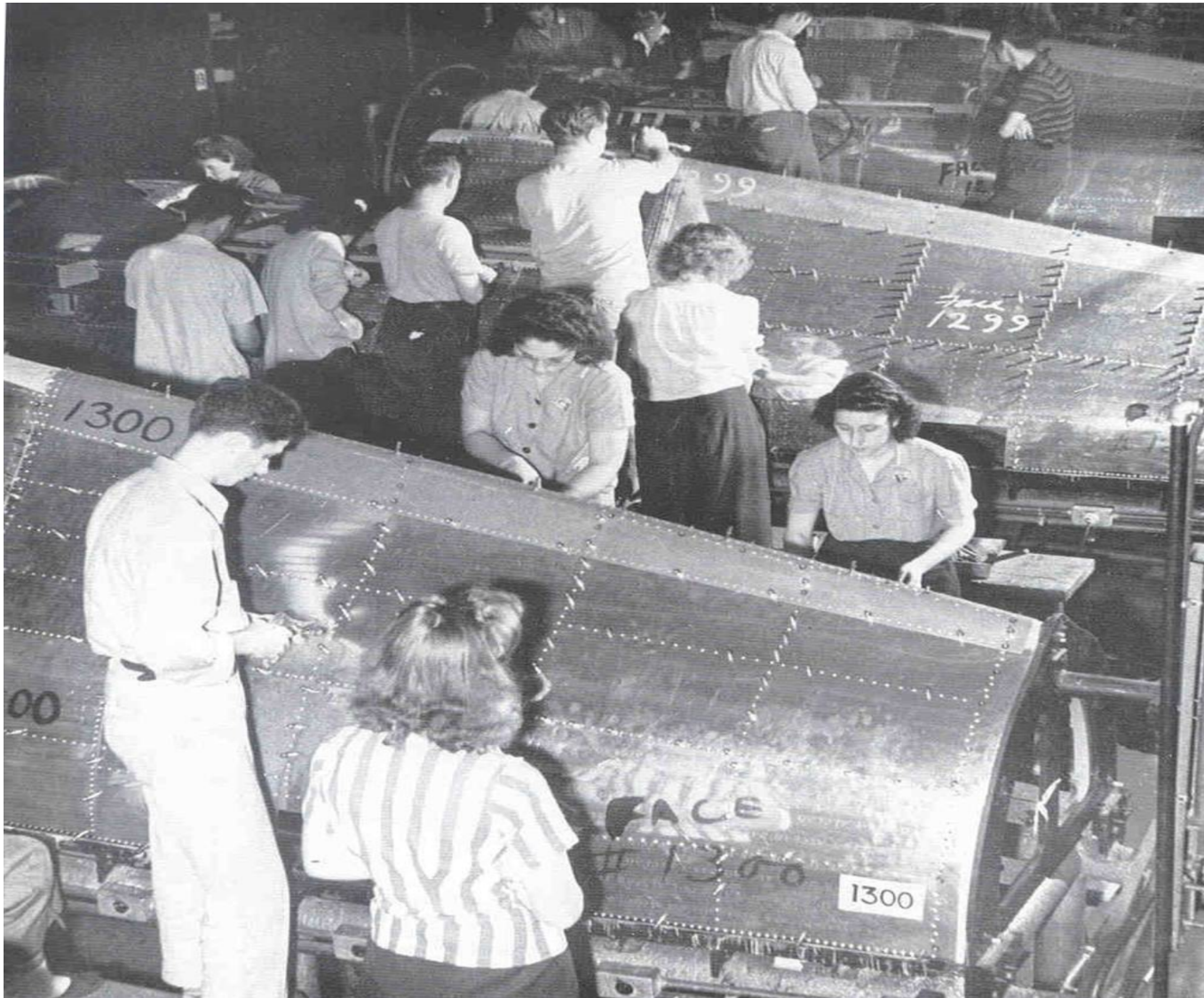
Consolidated, later General Dynamics, 4000 ft long

C-47 (DC-3) line in Long Beach 1944



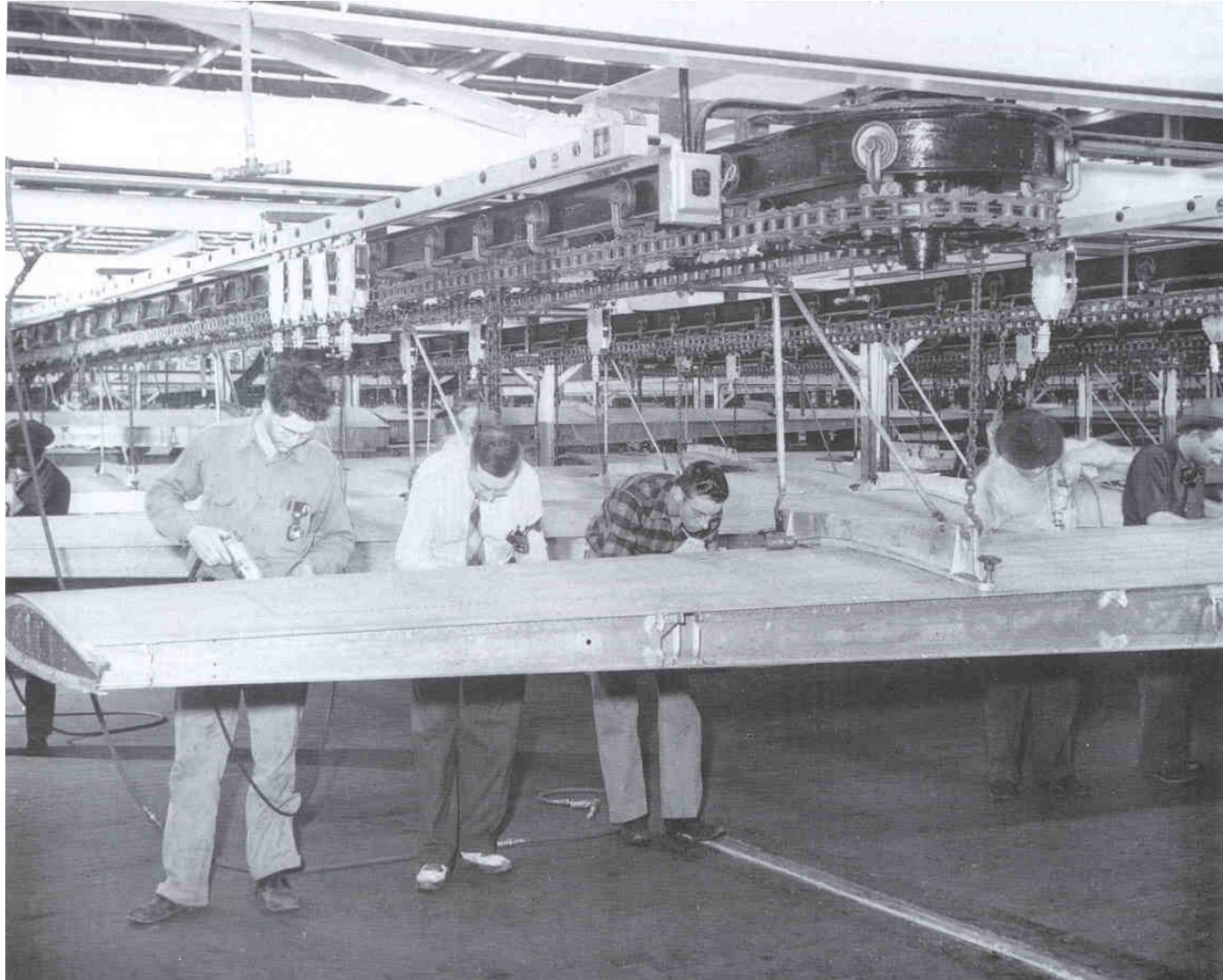
Moved every 5 minutes

P-47 fuselage riveting



Division of Labor

B-24 (skin riveting) assembly line in San Diego

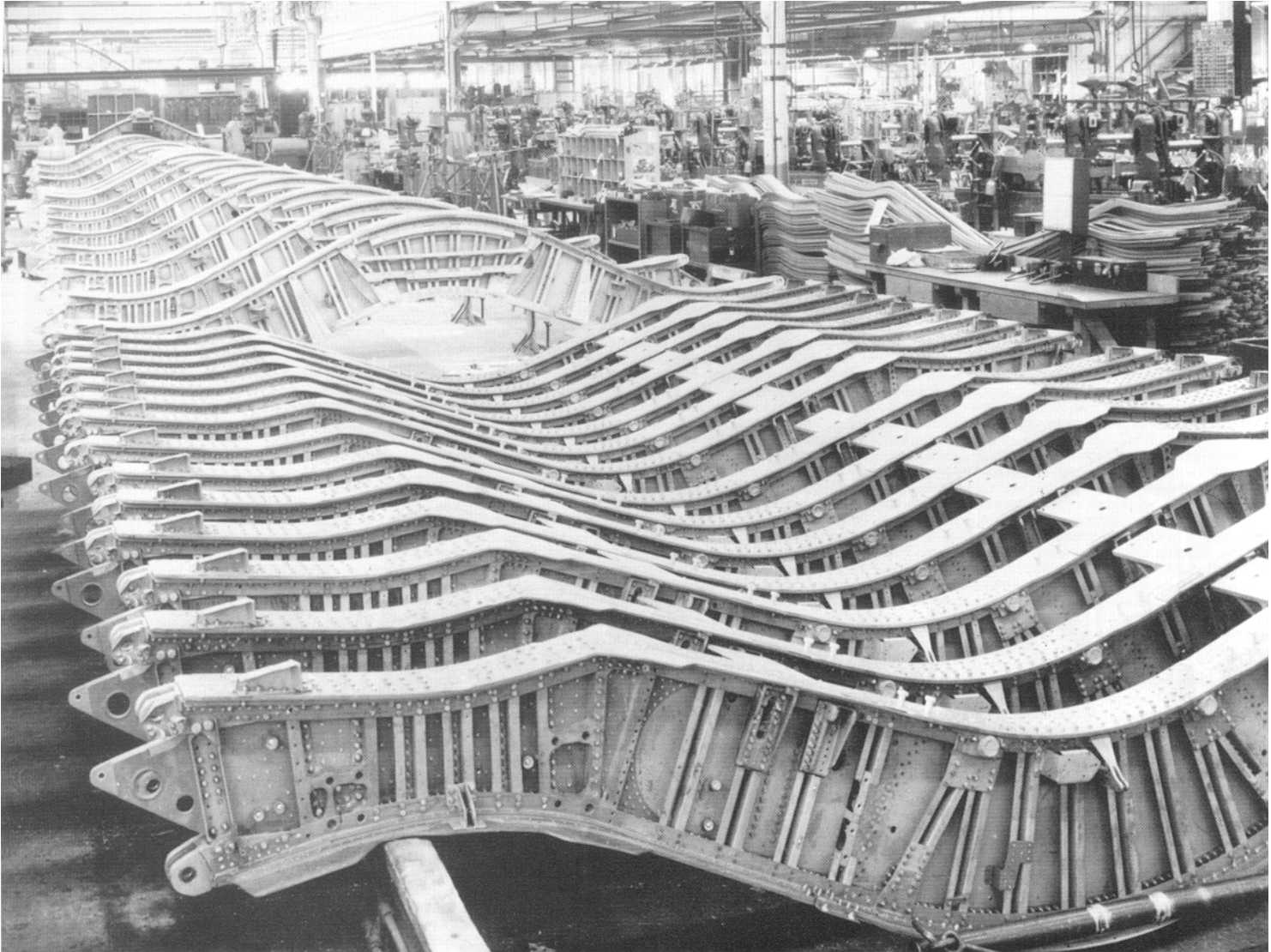


B-17 "precompletes" for Boeing's "multiline" production



Saves room, improves access to interior

Vought F4U "Corsair" main spars for wing center sections



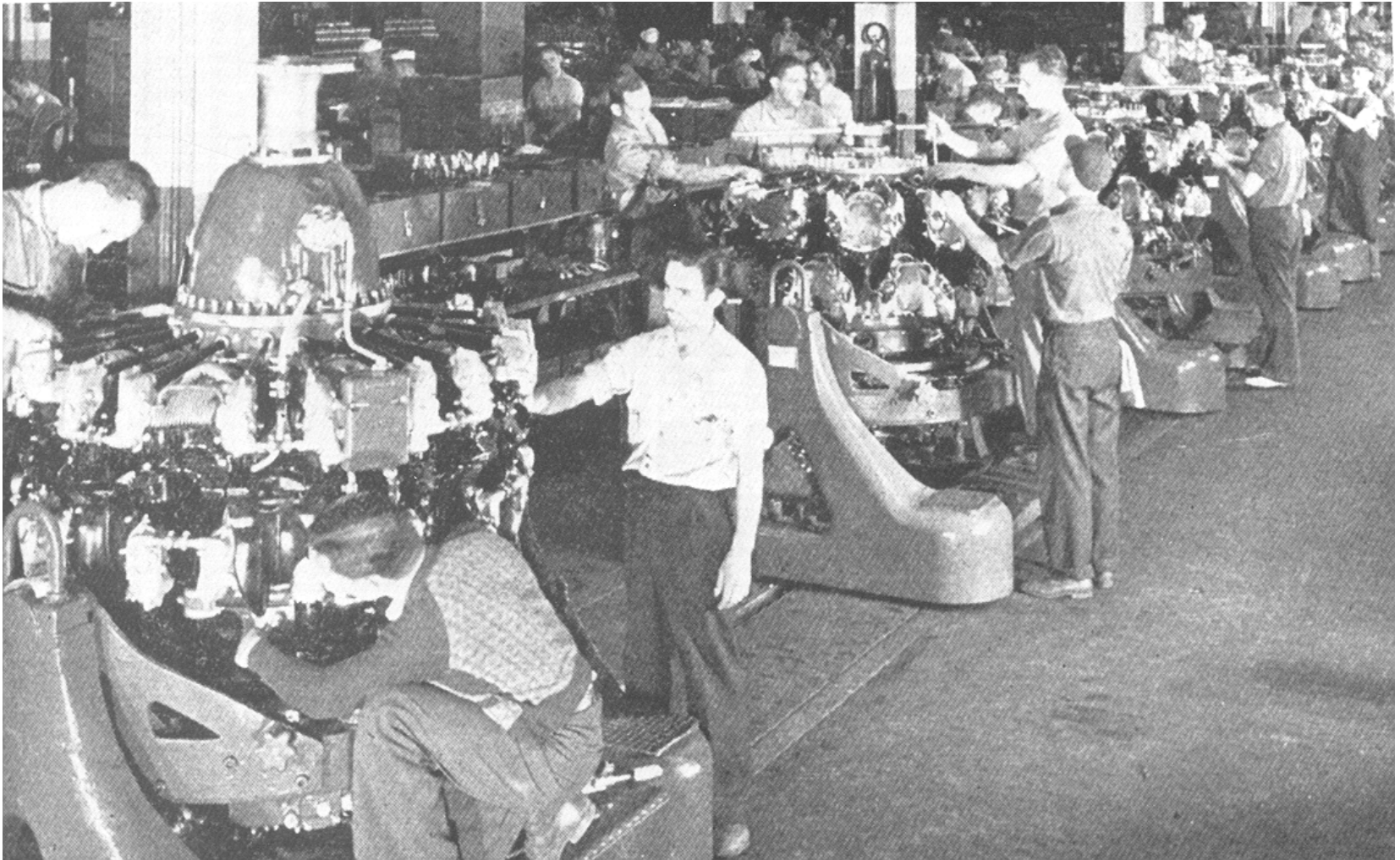
13 ft propeller, 2000 hp engine

Vought F4U "Corsair" main spars for wing center sections



13 ft propeller, 2000 hp engine

Assembly of Pratt and Whitney R-2800 (2000hp, 2800 cu in) Engine at the Ford Dearborn Plant in 1944



Willow Run - “Will it run”?



Ford's Willow Run plant - 10 mo delay, but in 1944 produced 453 airplanes in 468 hrs

High Volume Aircraft Production during WWII, 1939 - 1945

Keypoints:

1. **Mass production** techniques applied to military products including; division of labor, redesign for casting and forging, interchangeable parts, and moving assembly line.
2. **Ford's Willow Run** plant called “will it run?” due to long startup delay. Many of Ford's tools not used, “retrospective” modification required at separate plant.
3. Experience with automotive and **aircraft companies** with military aircraft production shows aircraft companies better suited to introduce new system in both U.S. and England.
4. **“multiline”** production developed at Boeing.
5. Continuous learning and the **learning curve** documented.
6. Strategy to introduce design changes; U.S. & U.K.

What conditions lead to a revolutionary new mfg system?

	Interchangable parts	Mass Production	TPS/Lean (Page numbers from Machine that Changed the World)
Where/when	US Armories 1794-1827 Springfield to certification	Ford 1908-1927 Model T start to finish	Toyota 1945-1975 Ohno
Need	Military field repairs	Mobility alternative	Re-build after WWII
Financing	U.S. Gov'n	Ford reinvests	Tokyo banks/ Keiretsu p 194
Workforce	Scace Yankees	Yankee mechanics, immigrants	Unions/ p 54 lifetime employment
Enabling Technology	Mechanization of machining	Interchange-able parts, moving assembly & stamping	Work organization

Reoccurring Issues-Summary

Issue	US Armories	Ford	Toyota
Cost Effectiveness	Doubtful for long time	immediate	Long time
Social disruption	Two armories	\$5/day & Harry Bennett	Avoid strike
Standardization & flexibility	standardization	More standardization	Still more...
Benefits & costs of inventory	Not mentioned	Vertical integration & low inventories	JIT, low inventories...
Work Scheduling/ control	Central	Centralized control	Push Vs pull - some local control

Readings (1-4)

1. David A. Hounshell, From the American System to Mass Production, 1800-1932, The John Hopkins University Press, 1984. **Introduction, Chapters 6 and 7**
 2. J T. Black The Factory with a Future **Ch 2 & 4**
 3. James Womack, Daniel T. Jones and Daniel Roos, The Machine that Changed the World, 1990, **Ch 3 and 4**
 4. J T. Black, Design Rules for Implementing the Toyoda Production System, IJPR 2007
- Michael Maccoby, “Is There a Best Way to Build a Car?” HBR Nov-Dec 1997
 - Steven Spear and H. Kent Bowen, “Decodong the DNA of the Toyota Production System” HBR, Sept-Oct 1999

Additional References

1. Merritt Roe Smith, *Harper's Ferry Armory and the New Technology*, Cornell University Press, 1977
2. Johnathan Zeitlin, "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the United States and Germany, 1939-1945", published in *The Society for the History of Technology*, 1995.
2. Don Sherman, "Willow Run", published in *Air and Space*, August/September 1992.
3. Joshua Stoff, "Picture History of WWII American Aircraft Production", published by Dover Publications, 1993
4. Kenneth N. MaKay, *The Evolution of Manufacturing Control - What Has Been, What will Be*. Working paper 2001