

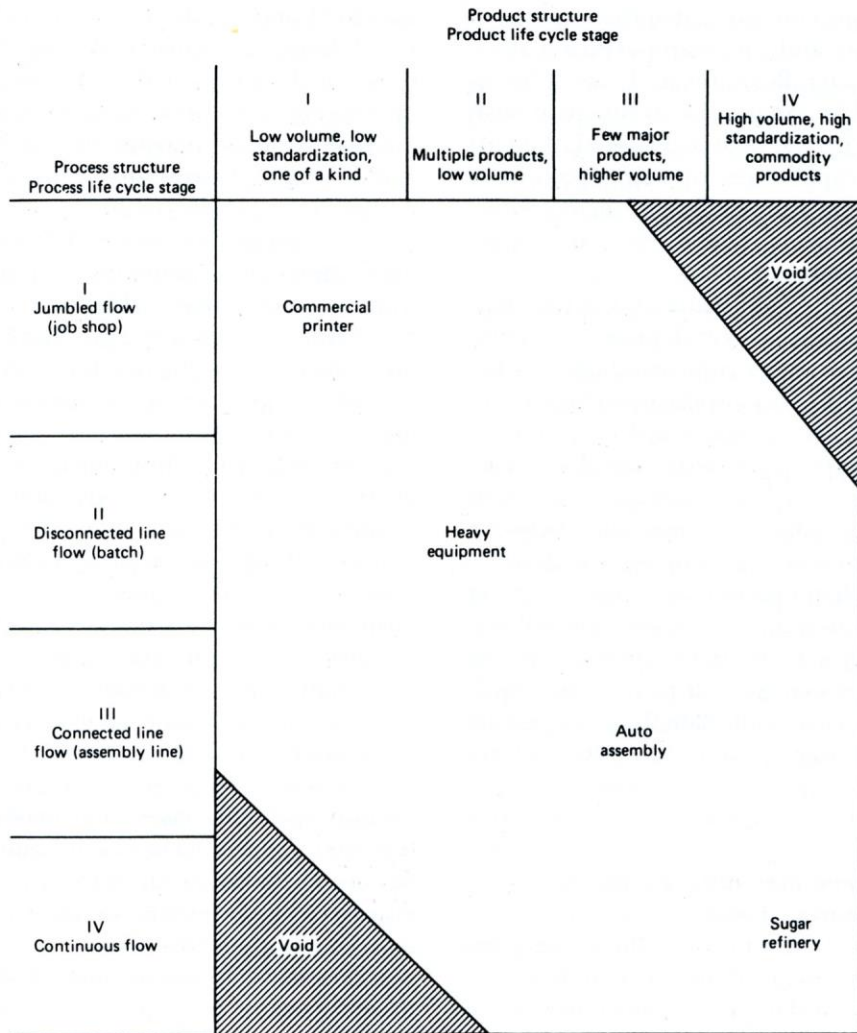
# Introduction to Manufacturing Systems

*T. Gutowski*  
*2.810*



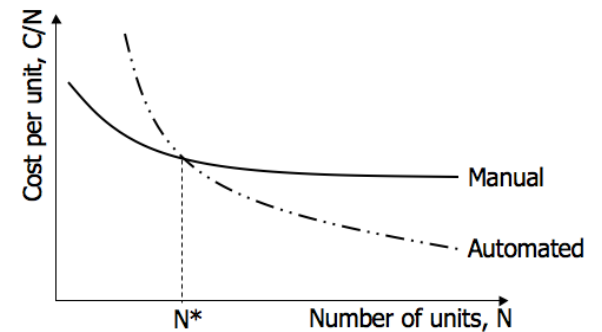
# Outline

1. Matching manufacturing system to production objectives
2. Relationship between product design and manufacturing system
3. Inventing new manufacturing systems



## Major Issues:

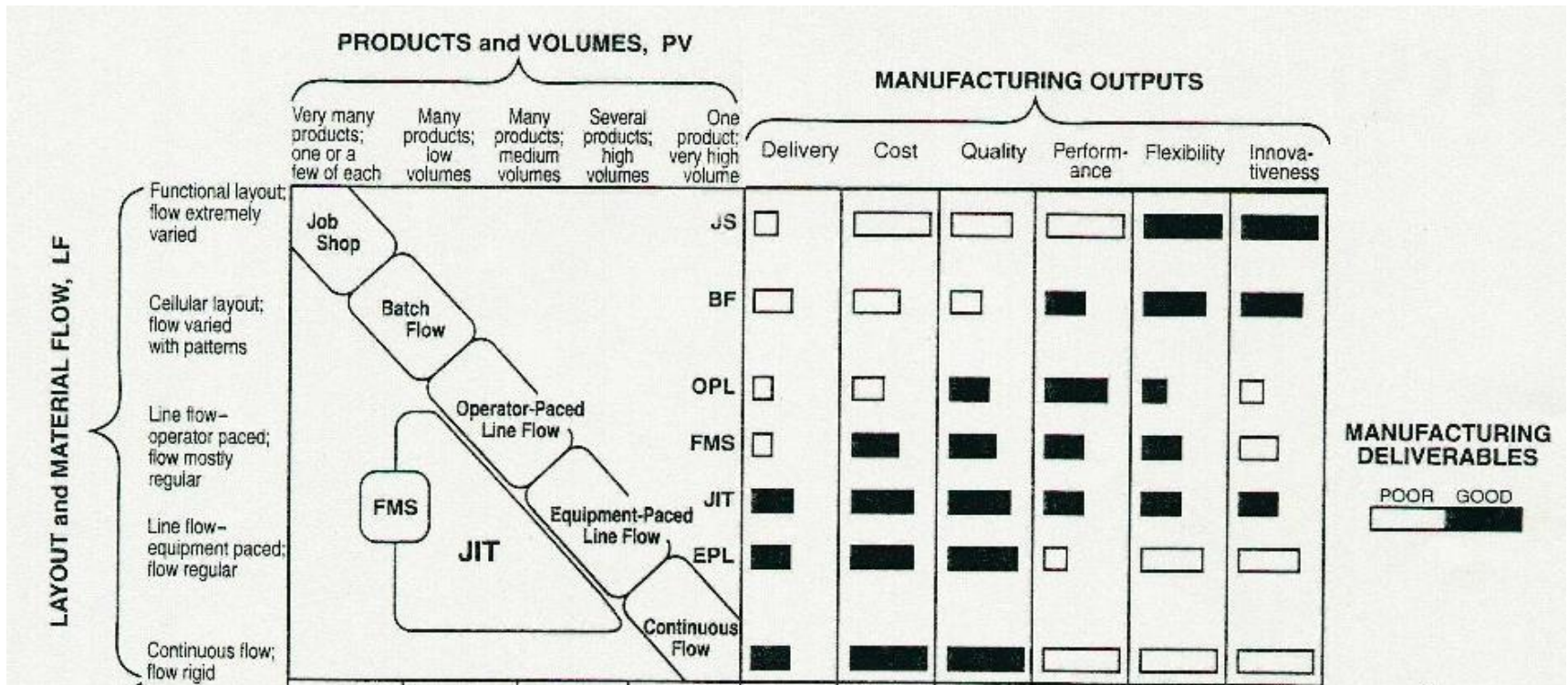
- Volume
- Variety
- Standardization
- Investment in Hardware



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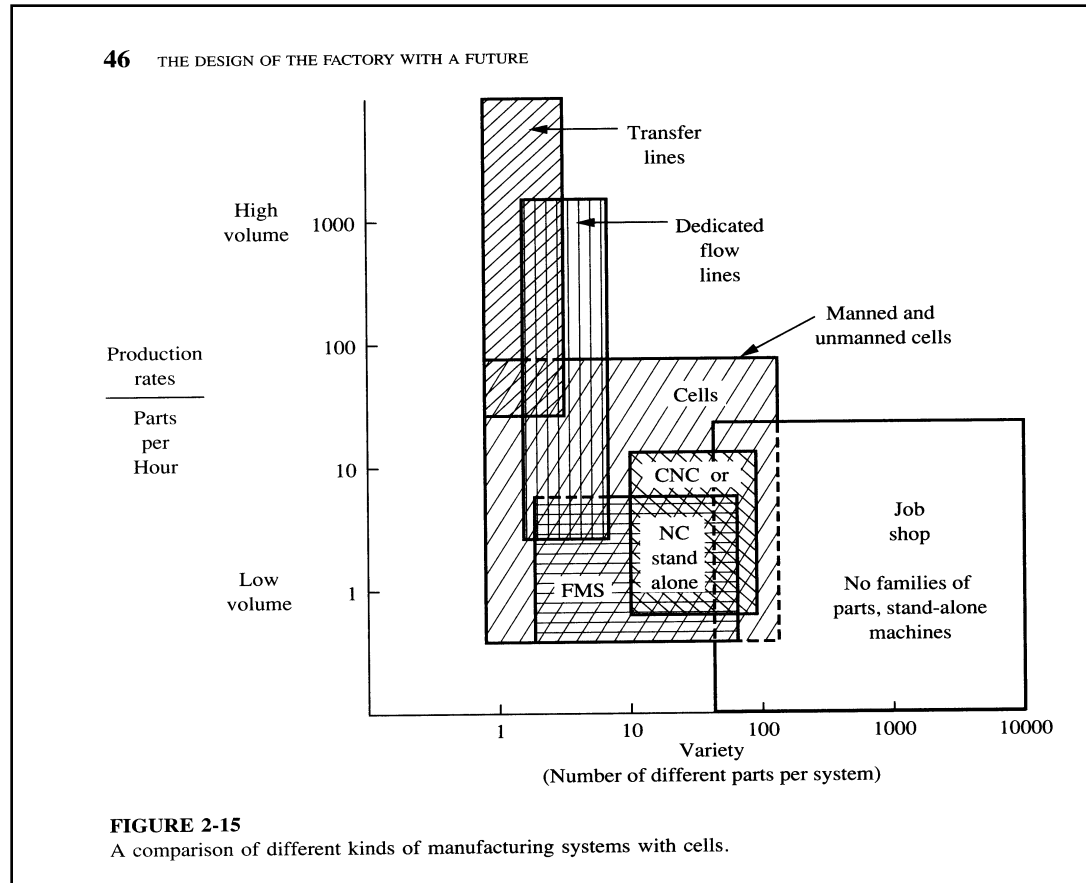
FIGURE 5. Matching Major Stages of Product and Process Life Cycles—The Product-Process Matrix

# System Performance & Product Requirements



Ref J. Miltenburg Manufacturing Strategy

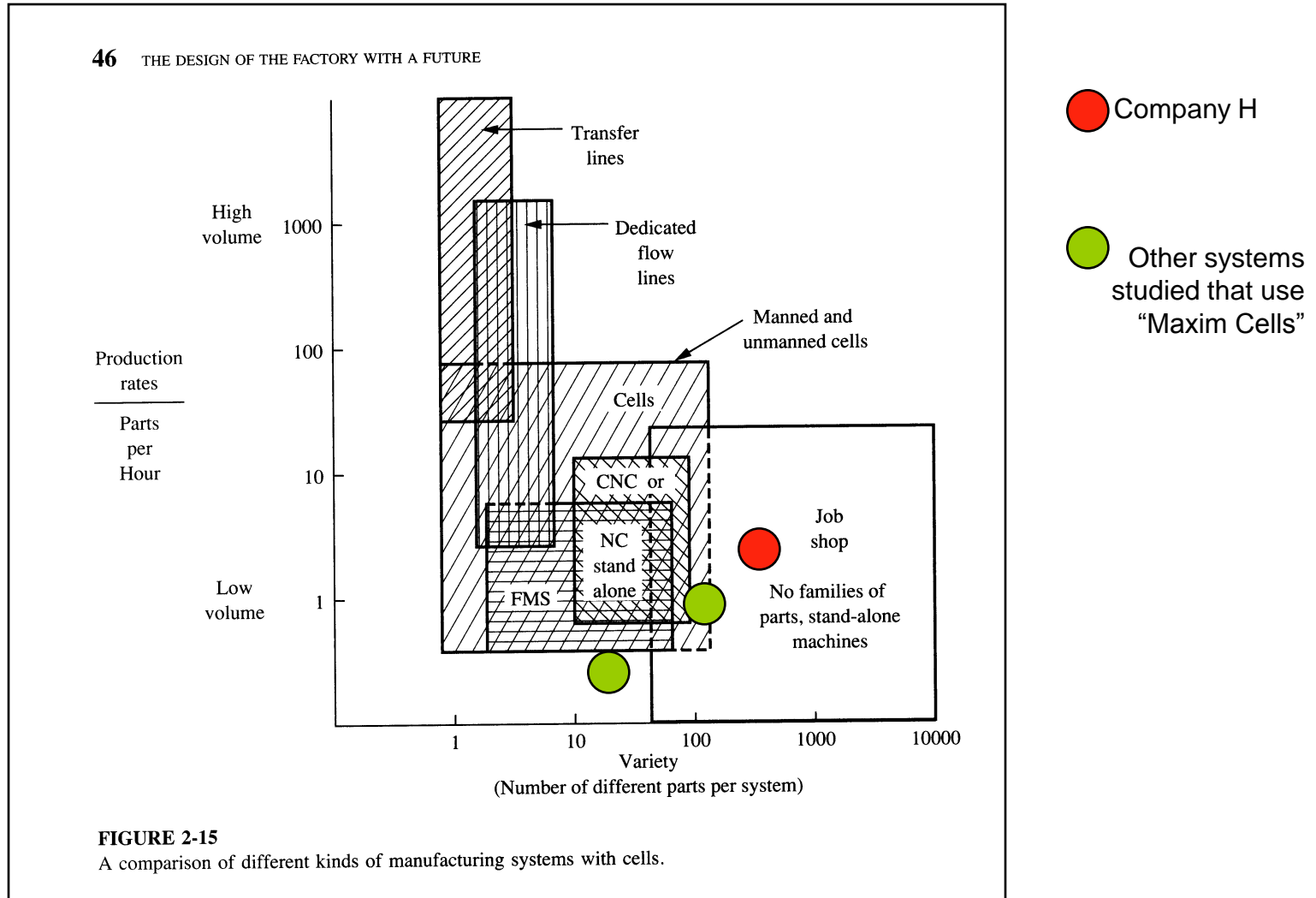
# Machining Systems



Read J T. Black Ch 2 and 4

# Comparison with Other Systems

Ref: J T. Black



# Economic Assessment Chart







## Assembly Systems-Boothroyd/Dewhurst

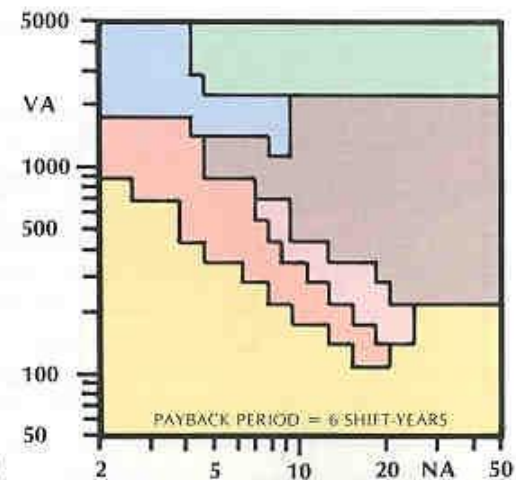
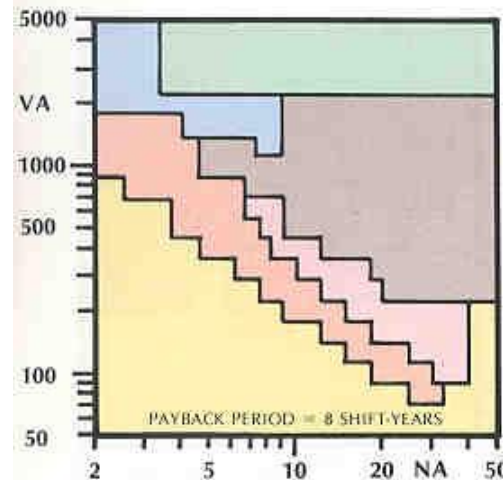
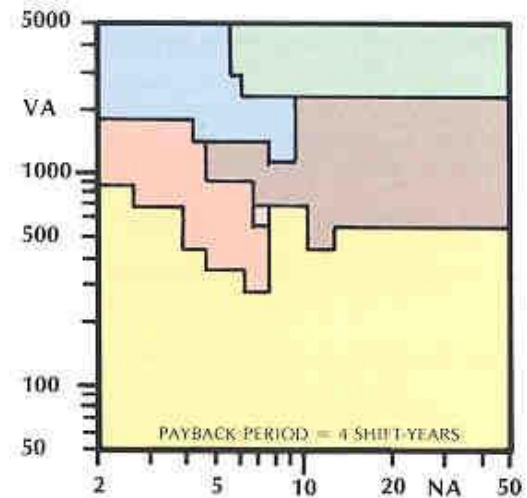
Product with only one style  
(NT/NA = 1)

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.-part. Free-transfer
-  Single-st. one robot arm
-  Single-st. two robot arms
-  Multi-station with robots
-  Manual bench assembly



# Time Estimation for Assembly

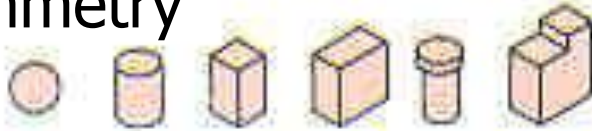
- ◆ Handling
  - ◆ pick up
  - ◆ orient
- ◆ Insertion
  - ◆ location (obstructed view? Self locating?)
  - ◆ hold down and resistance
  - ◆ securing method

DFA

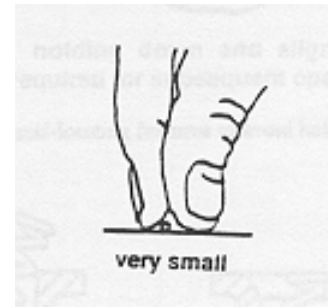


# Handling Issues

## Symmetry



$\alpha$	0	180	180	90	360	360
$\beta$	0	0	90	180	0	360



Size



Fragile/Sharp



will tangle

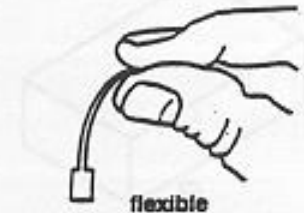


cannot tangle

Nest/Tangle



slippery




flexible

Slippery/Flexible

# B-D Manual handling chart

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key

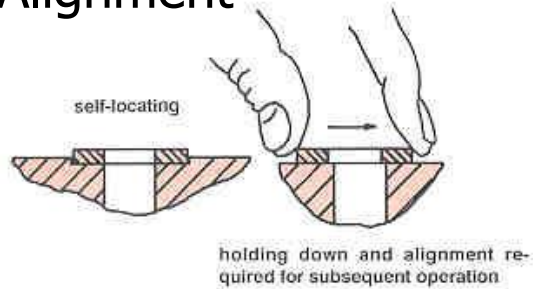
 ONE HAND.

		parts are easy to grasp and manipulate					parts present handling difficulties (1)					
		thickness > 2 mm		thickness ≤ 2 mm			thickness > 2 mm		thickness ≤ 2 mm			
		size > 15 mm	8 mm ≤ size ≤ 15 mm	size ≤ 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	8 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	
		0	1	2	3	4	5	6	7	8	9	
parts can be grasped and manipulated by one hand without the aid of grasping tools	$(\alpha + \beta) < 360^\circ$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	$360^\circ \leq (\alpha + \beta) < 540^\circ$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	$540^\circ \leq (\alpha + \beta) < 720^\circ$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	$(\alpha + \beta) = 720^\circ$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

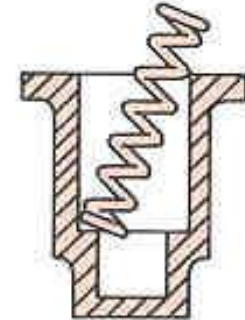
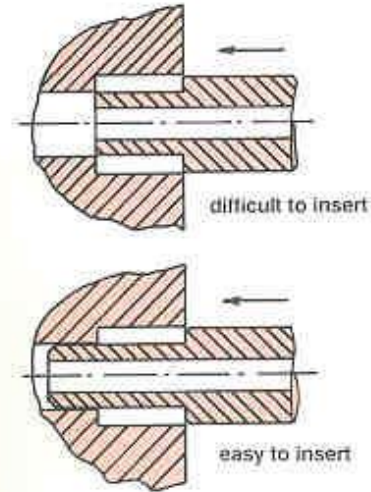
Ref Boothroyd, Dewhurst

# Insertion Issues

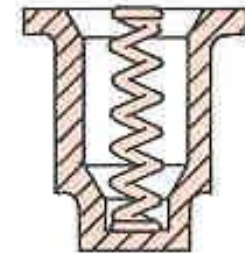
## Alignment



## Insertion Force

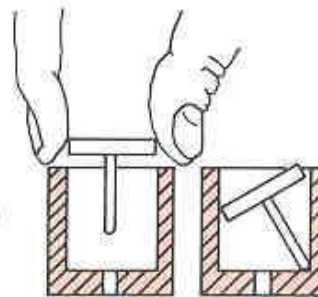
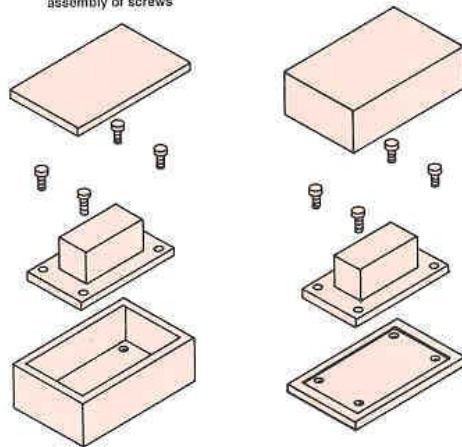


part can hang-up

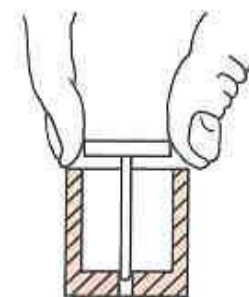


part falls into place

restricted access for assembly of screws



part must be released before it is located



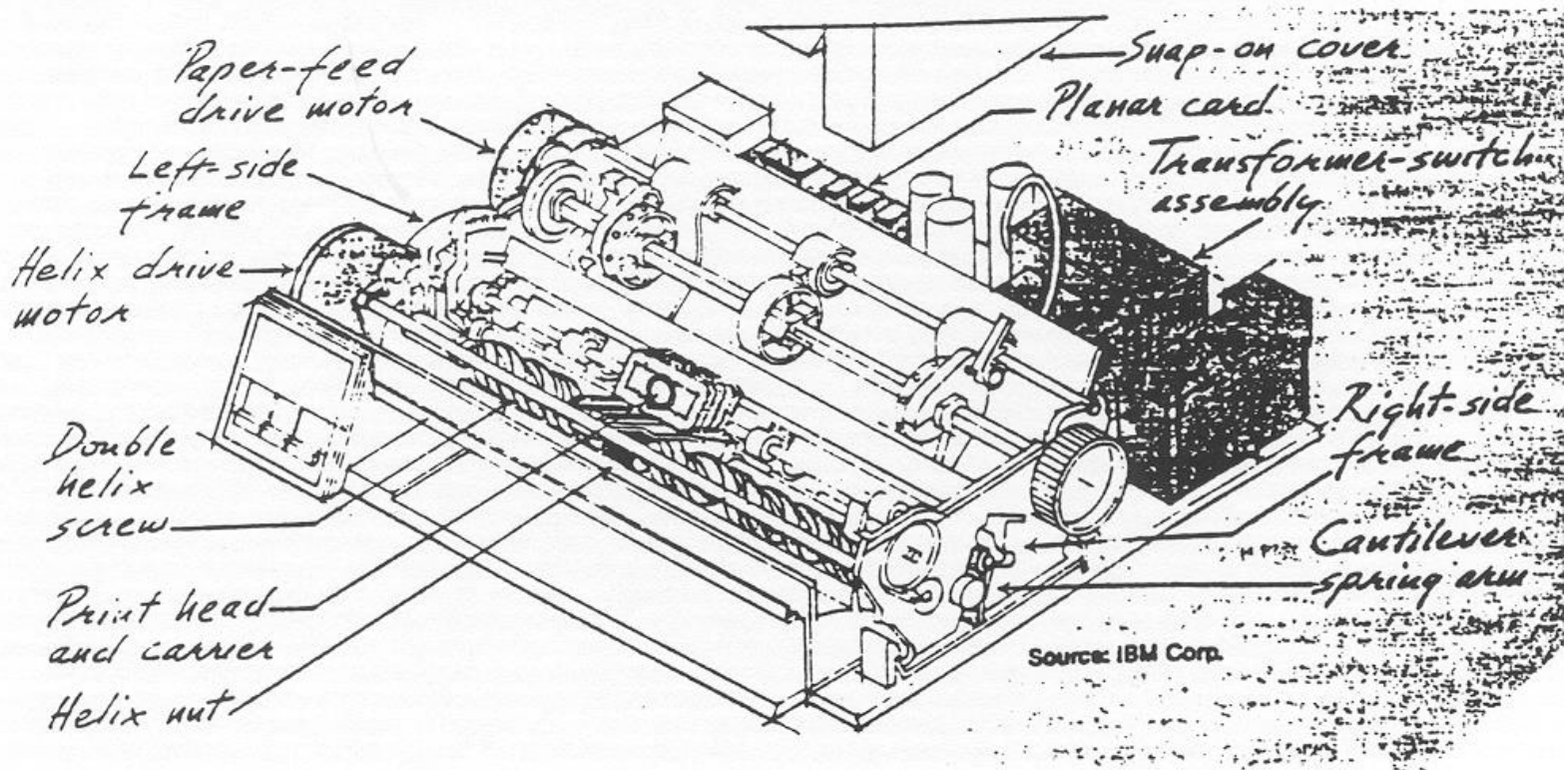
part located before release

## Obstructed Access/View

# Rules to reduce part count

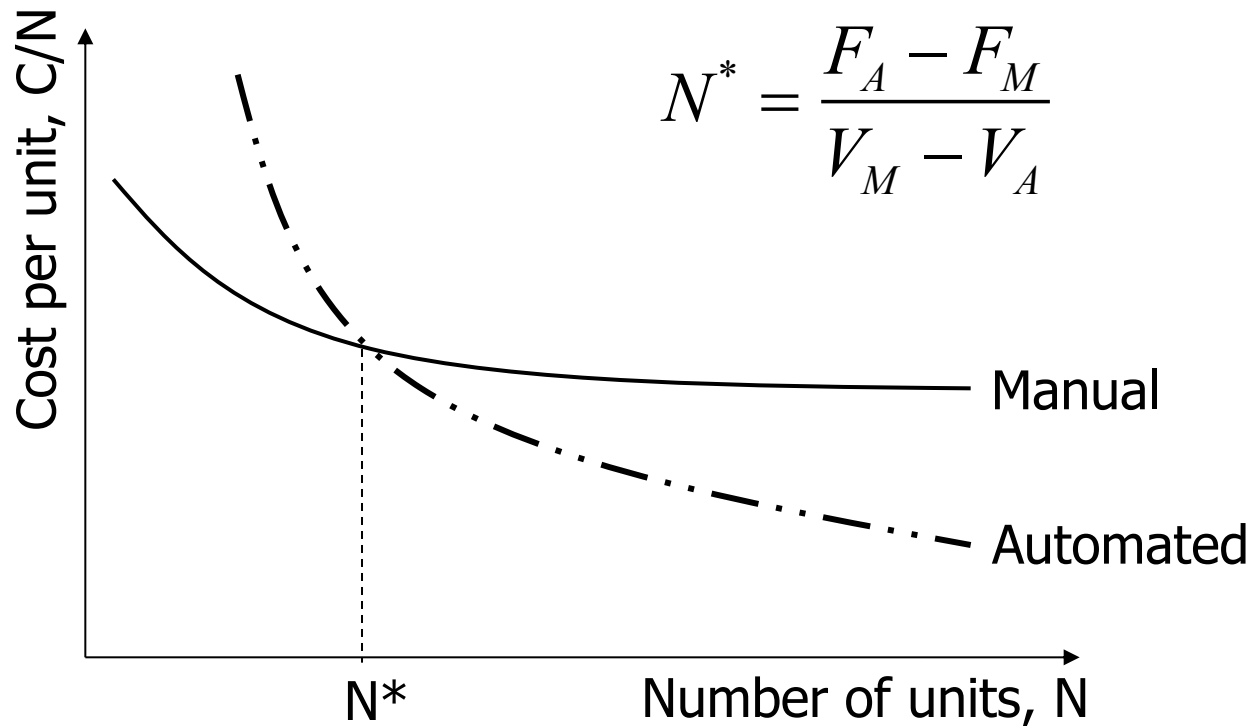
- ◆ During operation of the product, does the part move relative to all other parts already assembled?
  - ☞ Only gross motion should be considered – small motions that can be accommodated by elastic hinges, for example, are not sufficient for a positive answer
- ◆ Must the part be of a different material than or be isolated from all other parts already assembled?
  - ☞ Only fundamental reasons concerned with material properties are acceptable
- ◆ Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

# IBM Proprinter



Competition from Japan - answered with robots and DFA

# *Economic Analysis, $C = F + V \cdot N$*



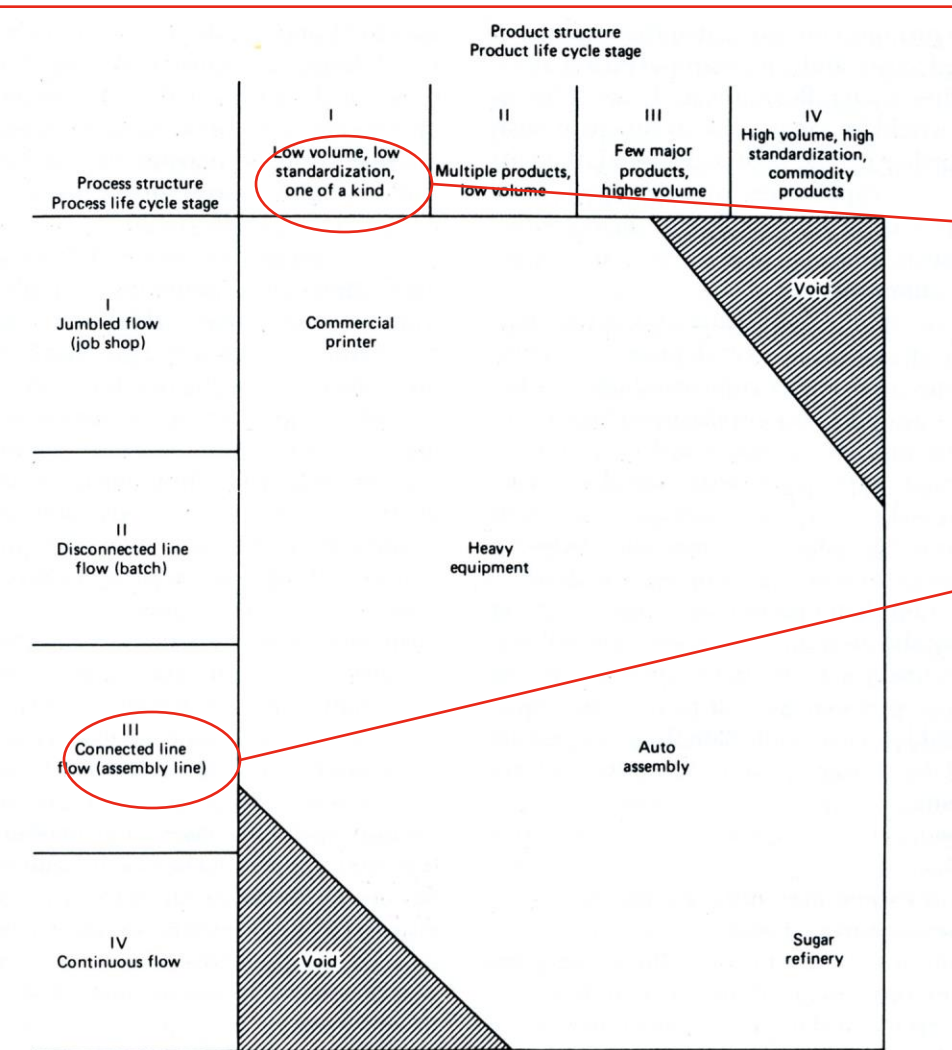
# What conditions lead to a revolutionary new mfg system?

1. A Need
2. Financing
3. Enabling technology

*A Historical Review*



Ford's Moving Assembly Line



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FIGURE 5. Matching Major Stages of Product and Process Life Cycles—The Product-Process Matrix

## Inventing New Mfg Systems:

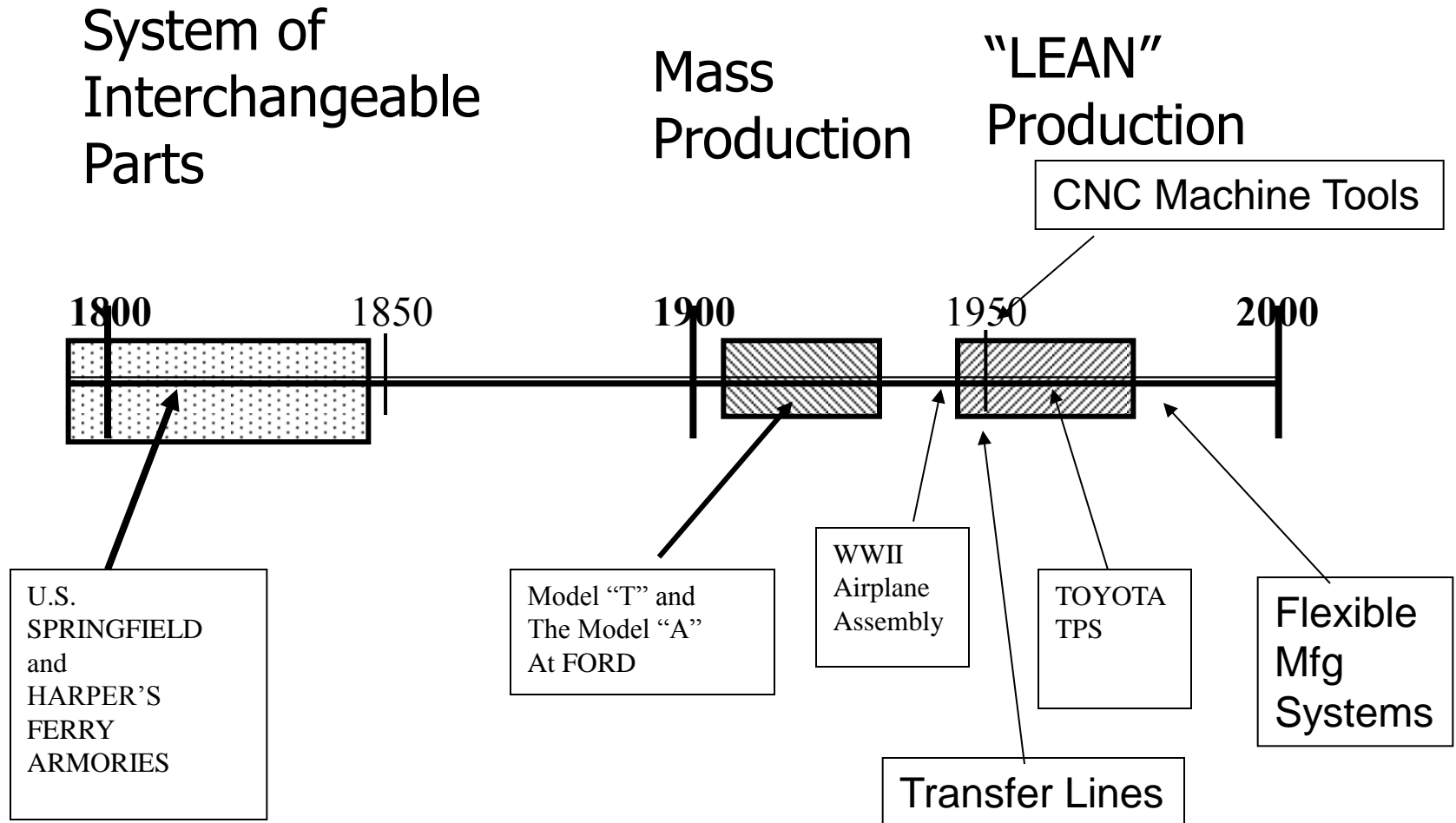
- Interchangeable parts
  - US Armories
- Mechanization of Production
  - Moving Assembly Lines
  - Transfer Machines
- Mechanical to digital control
  - CNC controls
- Production to Demand
  - Toyota Production Sys



# Reoccurring Issues

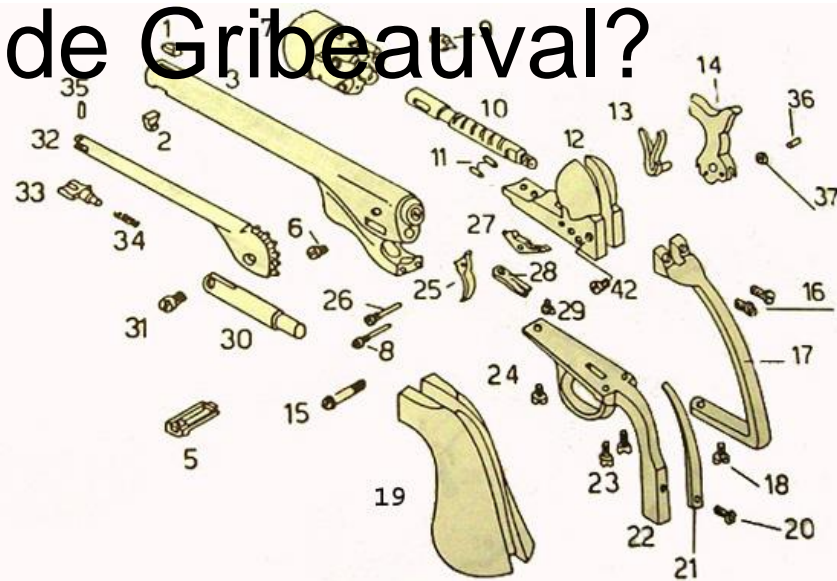
- Cost Effectiveness
- Social disruption
- Standardization Vs Flexibility
- Benefits and Costs of Inventory
- Work Scheduling/Control

# Historical Development of Major Manufacturing Systems from ~1800 to 2000



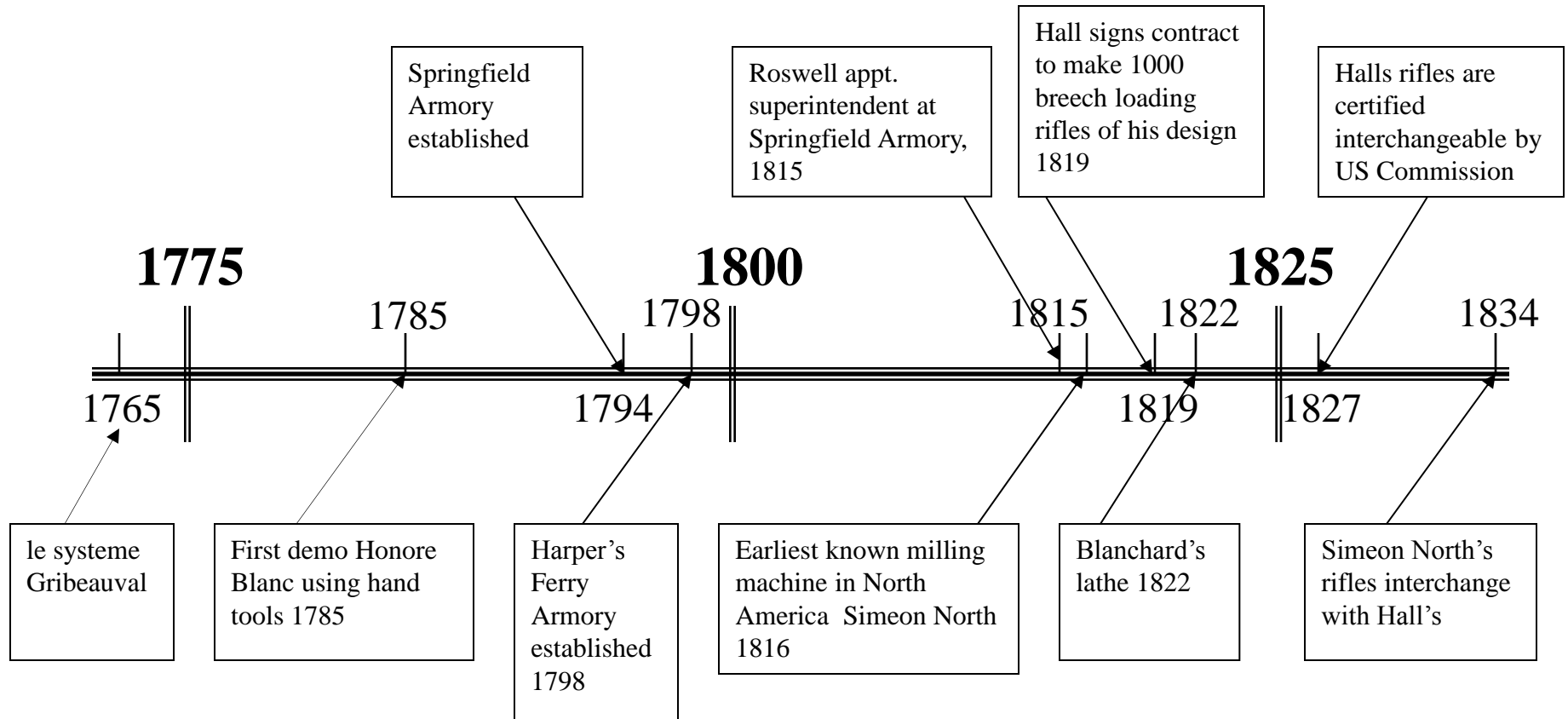
# Who developed interchangeable parts?

1. Eli Whitney?
2. Jean-Baptiste de Gribeauval?
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



# 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.

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



## 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.

# Springfield MA & Harper's Ferry VA US Armories

- Roswell Lee
  - Scarcity of trained gunsmiths
  - Very good transportation
  - Puritan ethics
  - Good schools
  - Rapid adoption of new technology
- James Stubblefield
  - Who's who of gunsmiths
  - Paternalistic society
  - Poor transportation
  - Poor public schools
  - Poor adoption of new technology

Ref Merritt Roe Smith

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

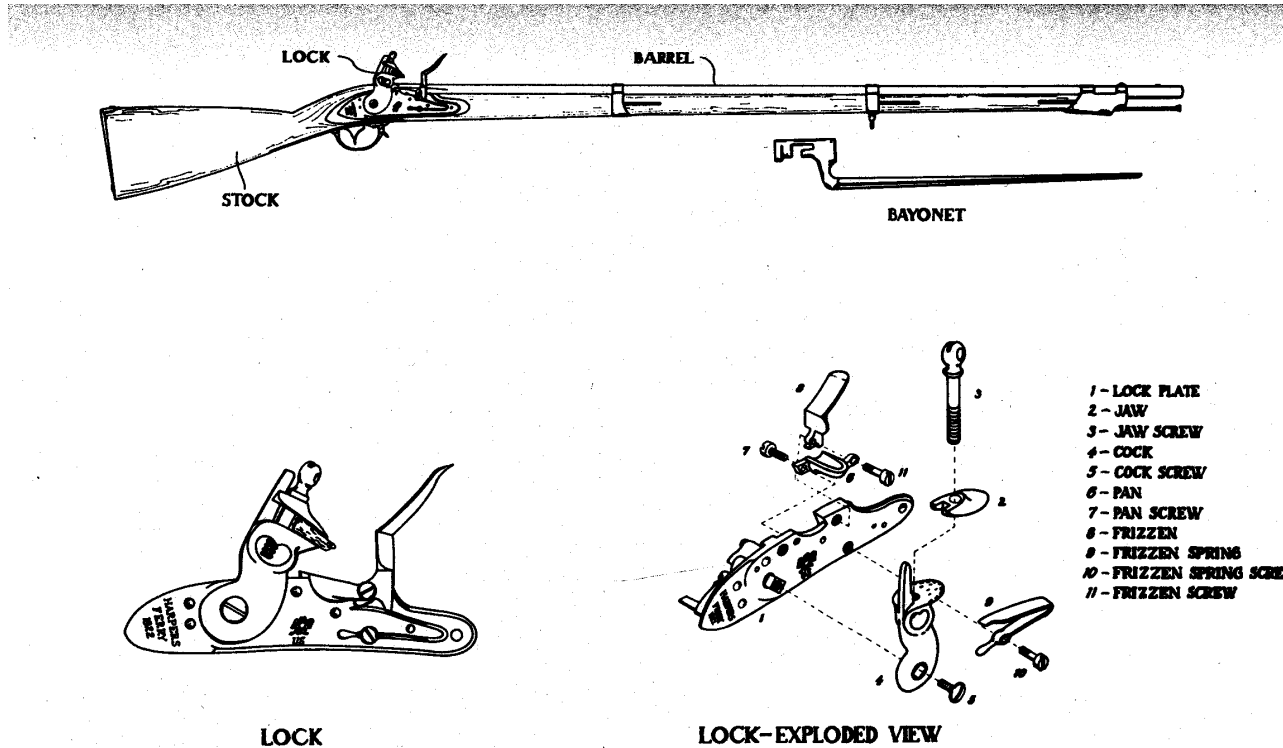
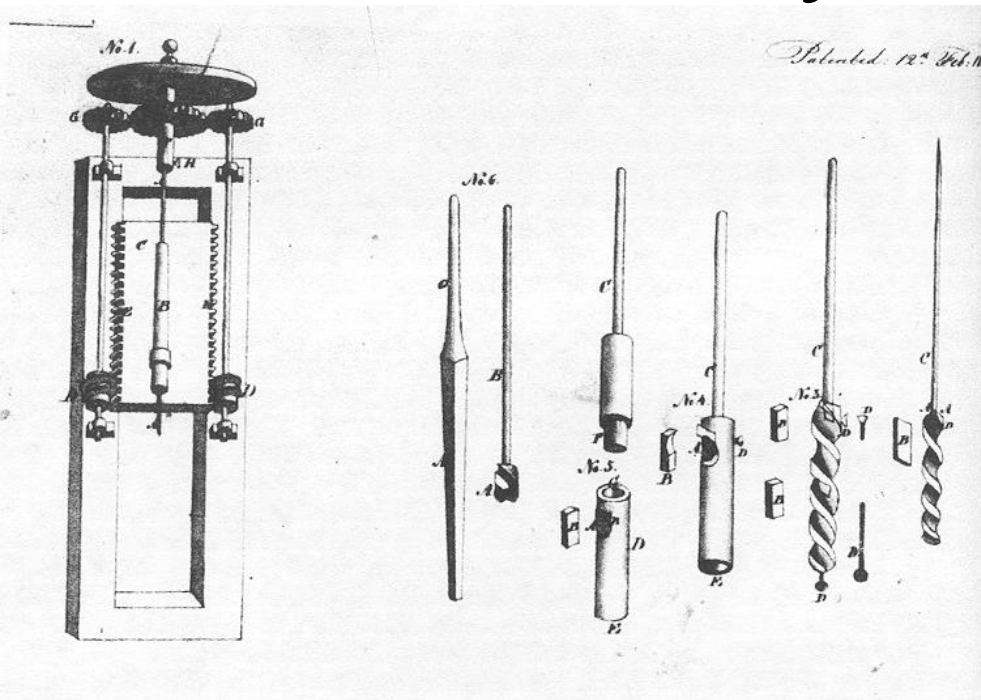


Figure 2. U.S. Model 1816 musket. For views of the tumbler, bridle, sear, and other interior parts of the lock mechanism, see Figure 14  
Drawing by Steve Foutz. Photograph by Christopher Duckworth.

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

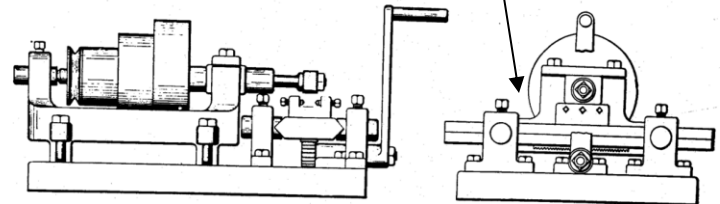


# Technology development in early America



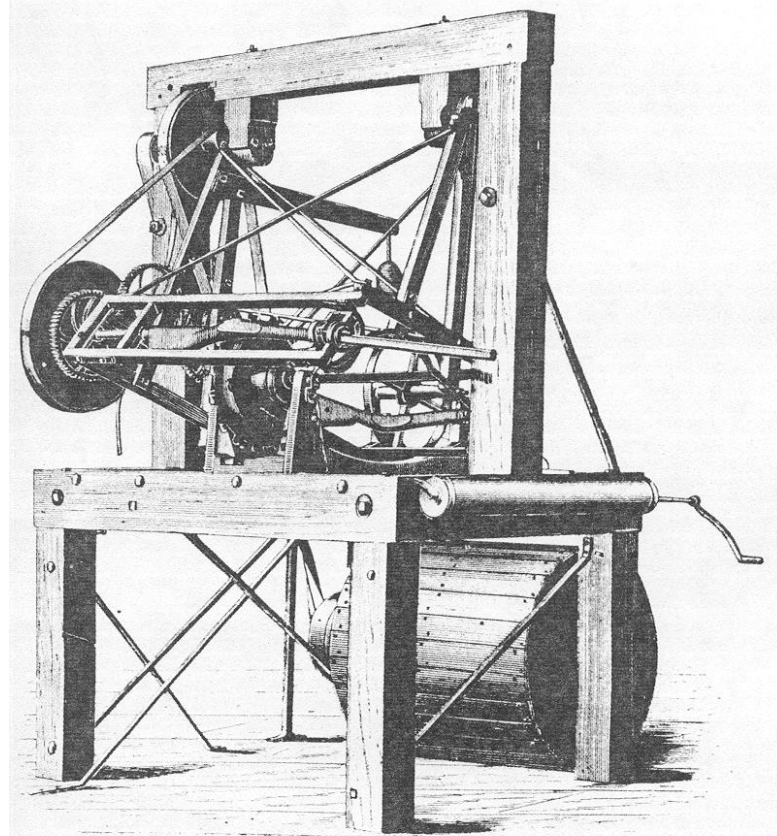
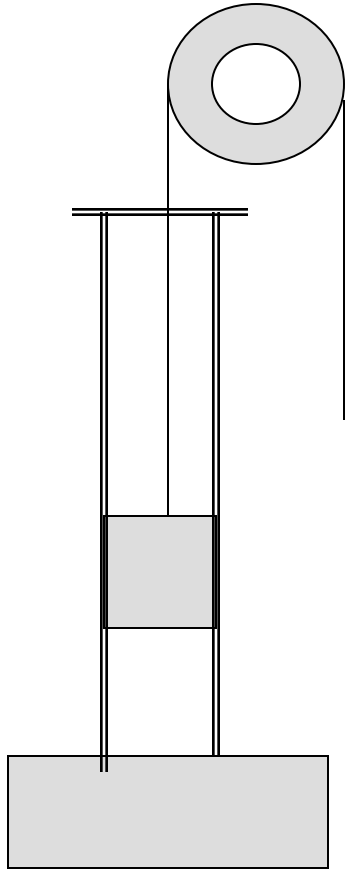
“Earliest known milling Machine in America”  
circa 1816 by Simeon North

Ref Smith



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

Rendering of early drop press used at Philadelphia lamp Factory in 1833 and Thomas Blanchard's eccentric lathe for turning gun stocks circa 1819



Springfield Armory Video

## 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)

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

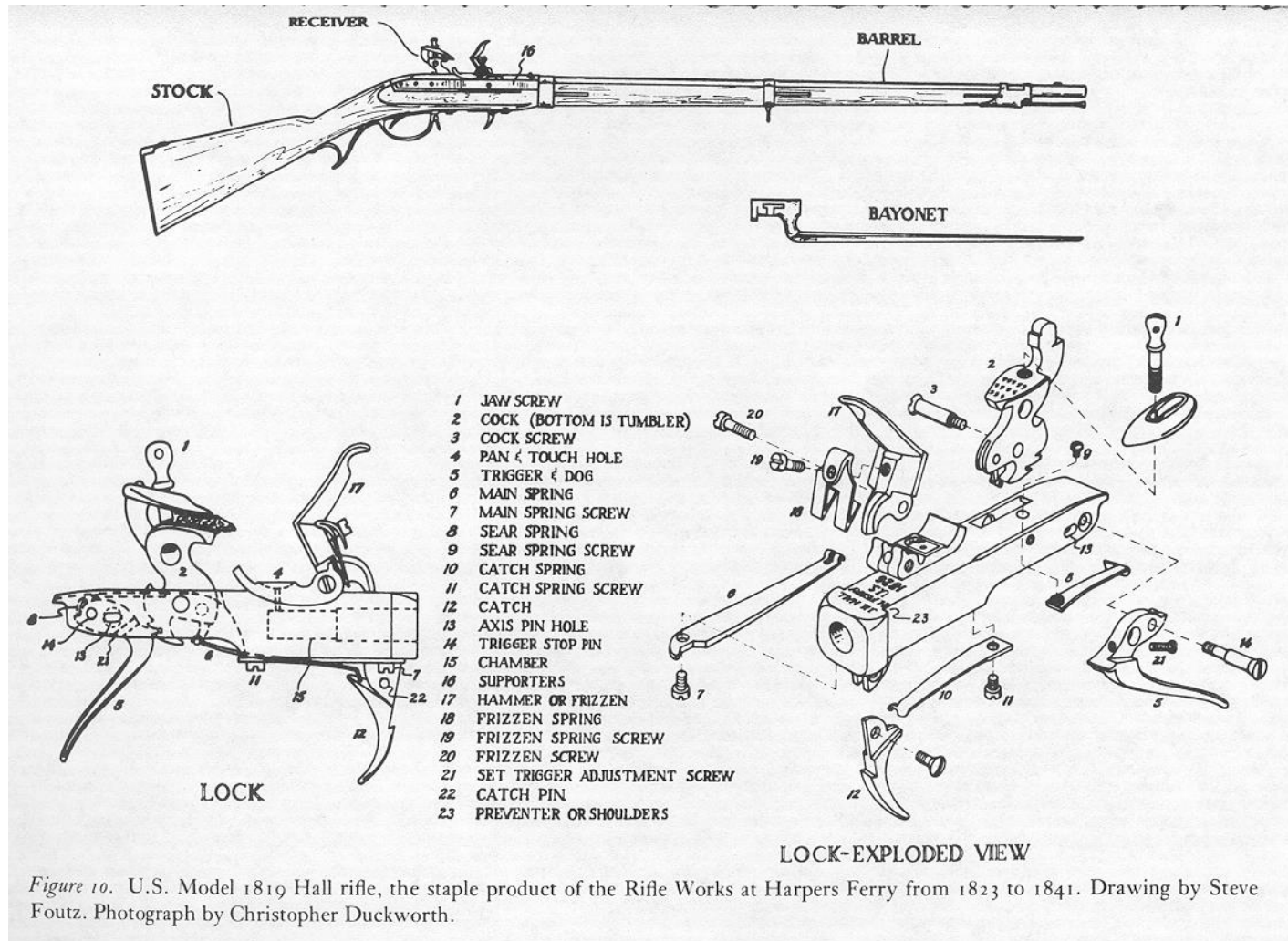


Figure 10. U.S. Model 1819 Hall rifle, the staple product of the Rifle Works at Harpers Ferry from 1823 to 1841. Drawing by Steve Foutz. Photograph by Christopher Duckworth.

Invented in 1811, certified interchangeable in 1827 by military commission

# 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

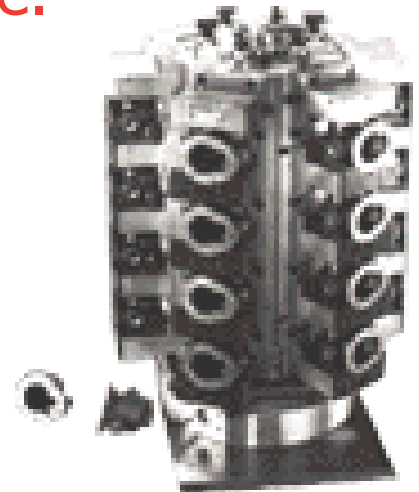
“In making a part of an arm like a prescribed model, the difficulty is exactly the same, as that which occurs in making a piece of Iron exactly square. In such a case, a man would Square the 2d. side by the 1st, the 3d. by the 2d. and the 4th by the 3d., but on comparing the 4th side with the 1st, it 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.

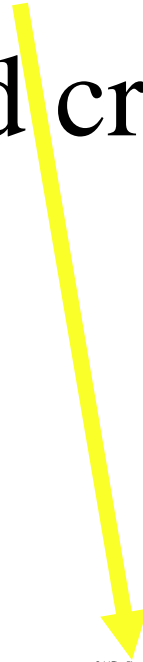
# Fixturing Principles from John Hall;

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

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



# Locating feature for machining of forged crankshaft



QuickTime™ and a  
PowerPC™ are needed to see this picture.

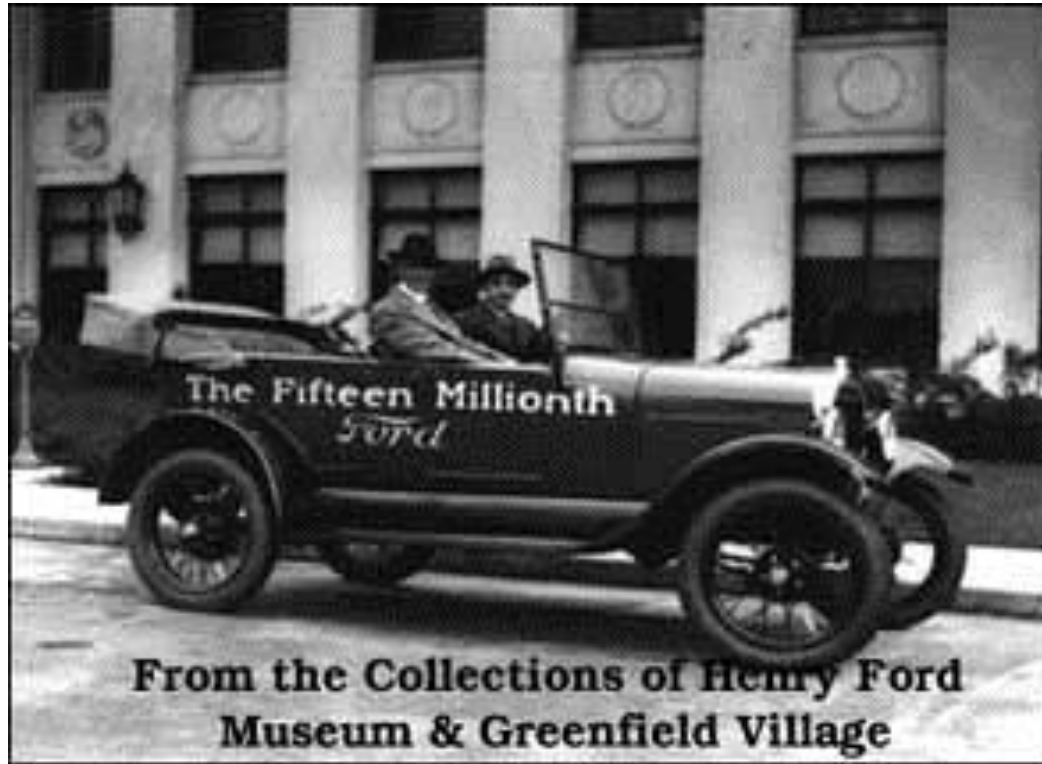


# Interchangeable Parts at U.S. Armories circa 1800-1860

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



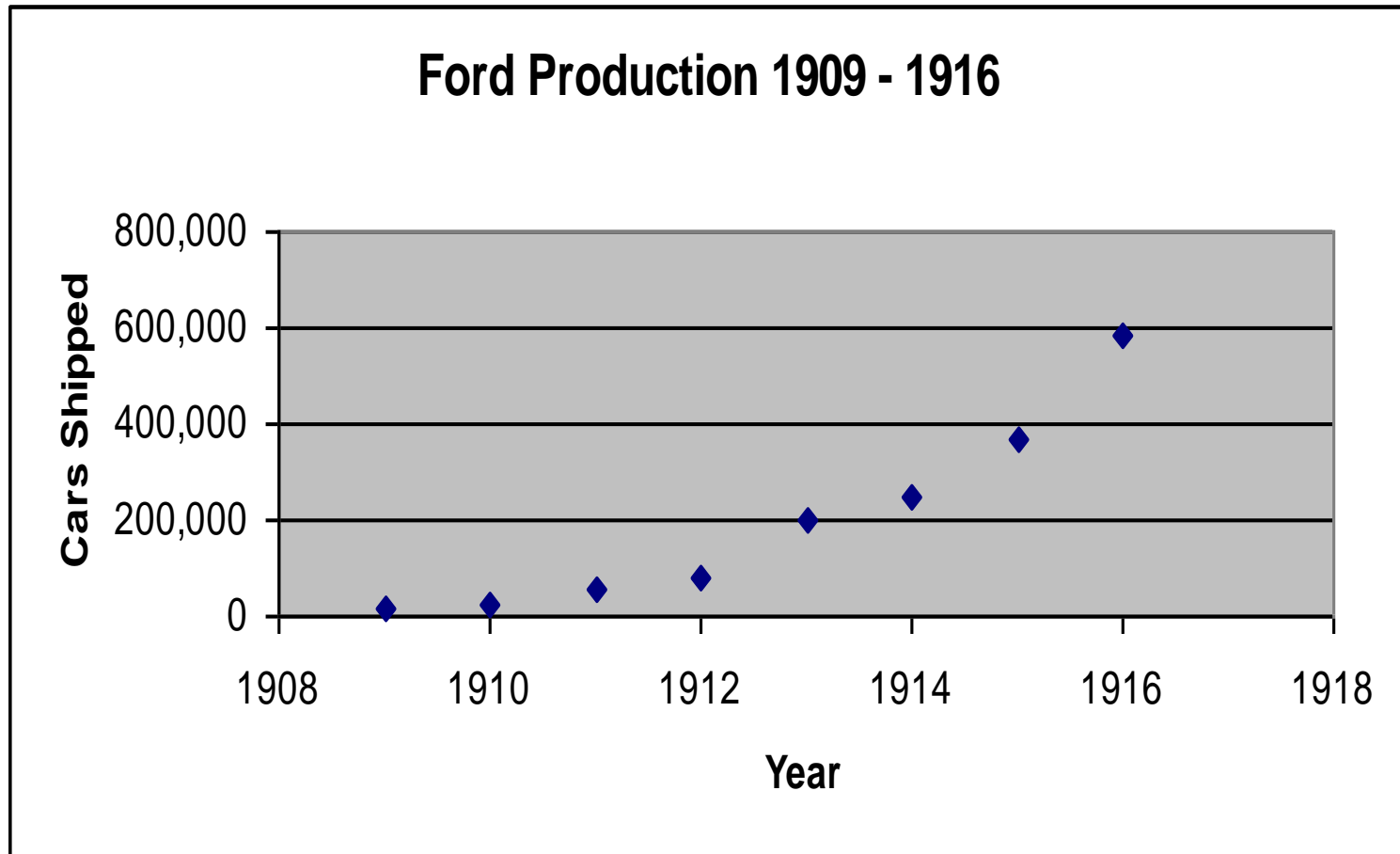
Finally after the Models A, B, C, F, K, N, R, and S came the Model “T” in 1908. Here are Henry and Edsel Ford in the last Model T produced in 1927.

Refs:

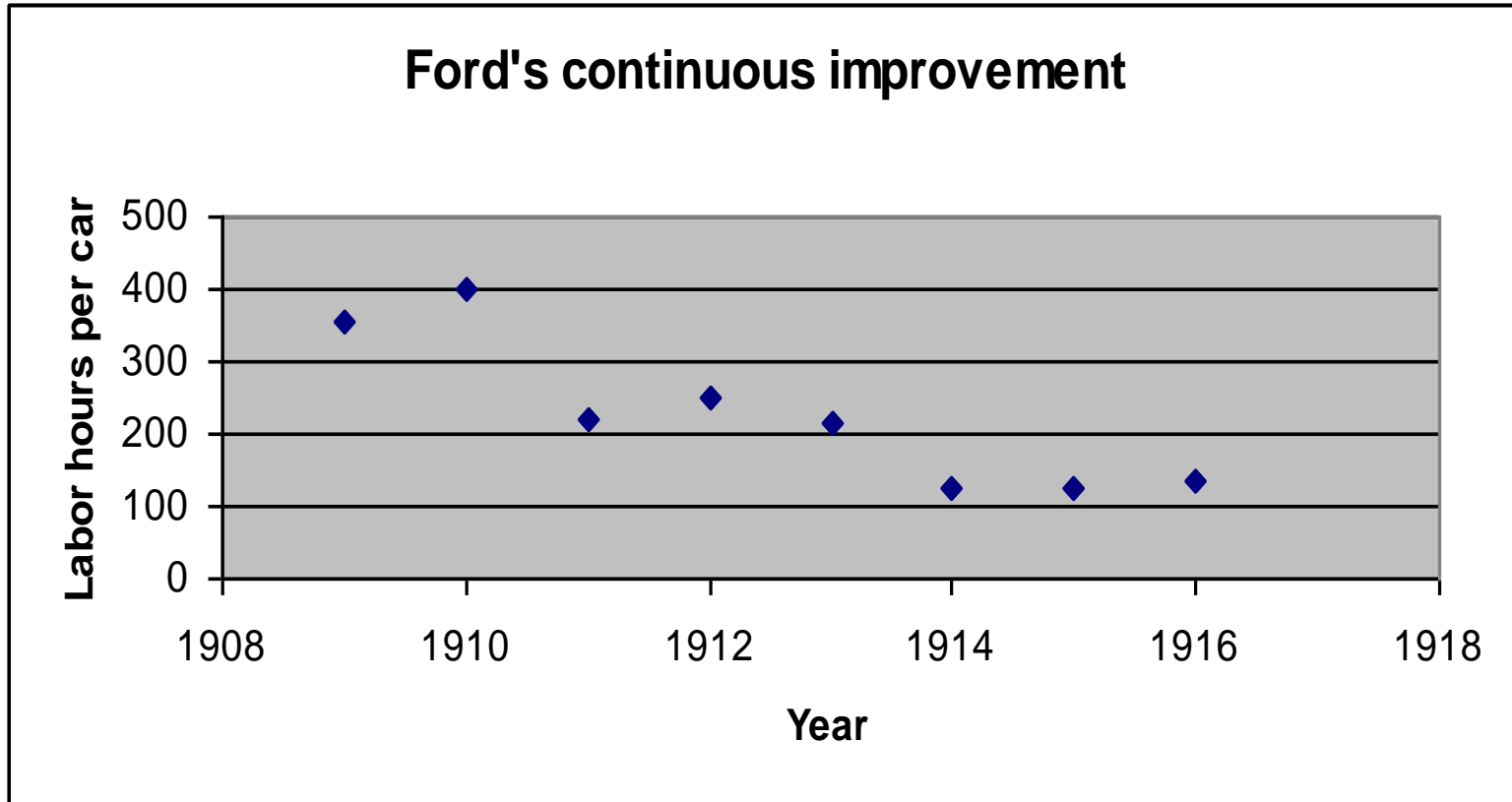
David A. Hounshell, *From the American System to Mass Production, 1800-1932*,  
The John Hopkin’s University, Press, 1984.

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

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



# Ford's response.....

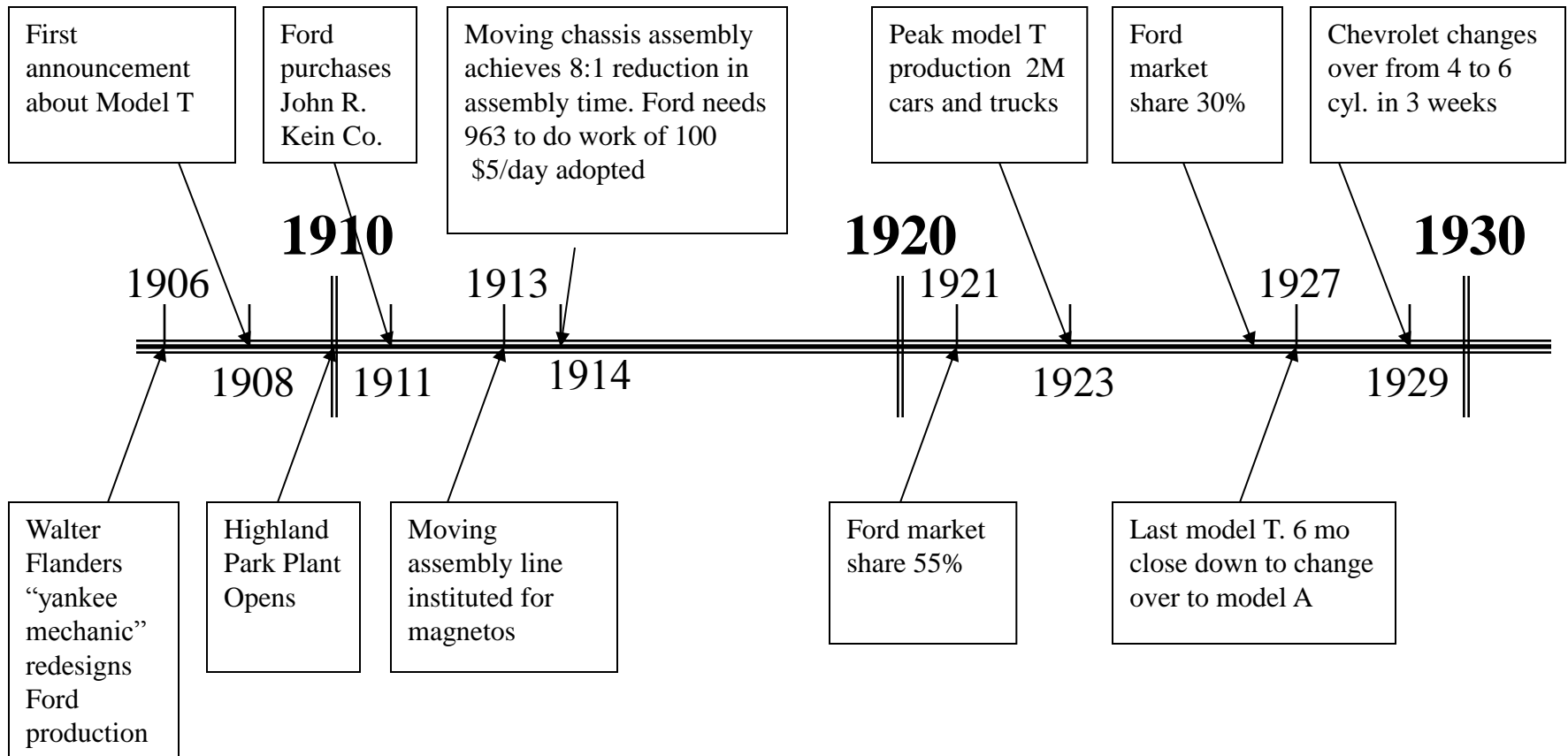


# Ford's continuous improvement 1909-1916

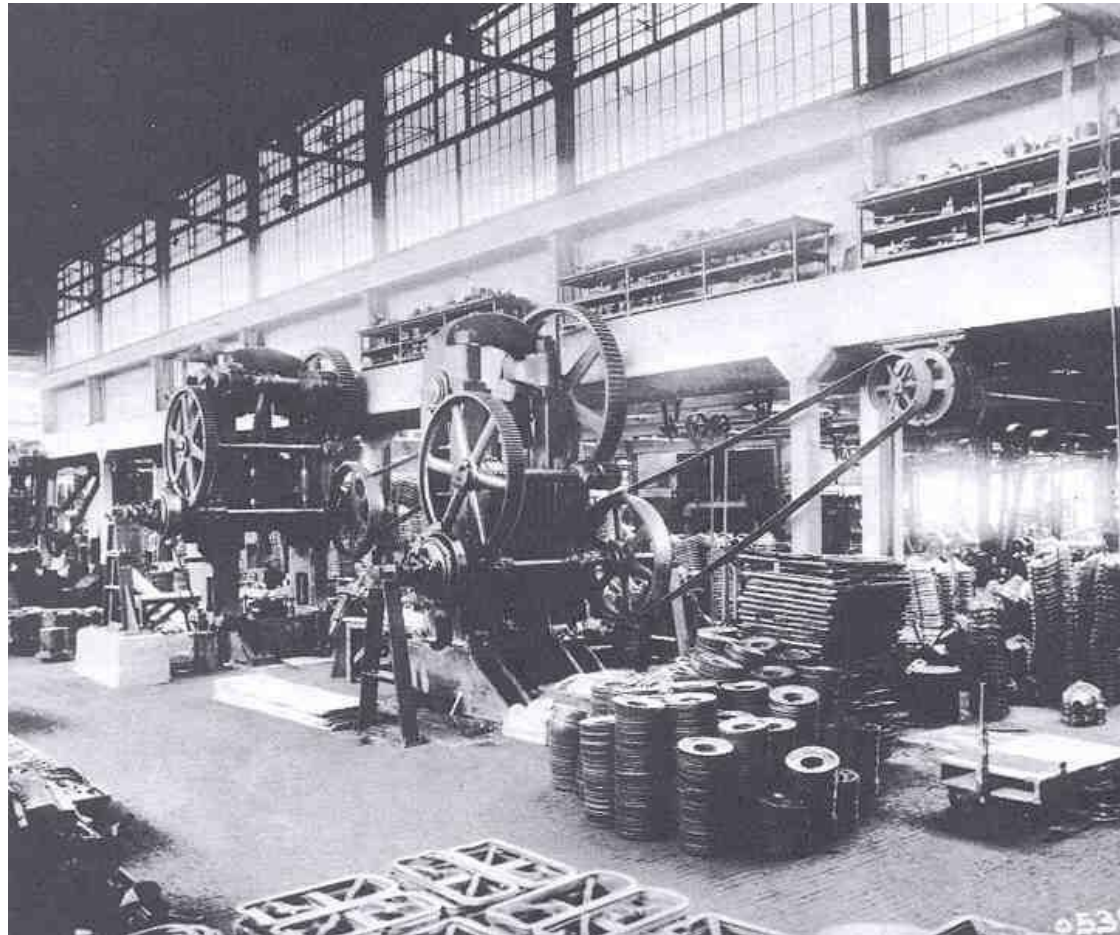
	<b>Cars Shipped</b> <b>(i)</b>	<b>Number of employees</b> <b>(ii)</b>	<b>Cars per man year</b> <b>(iii)</b>	<b>Labor hours per car</b> <b>(iv)</b>
<b>1909</b>	13,941	1,655	8.4	357
<b>1910</b>	20,738	2,773	7.5	400
<b>1911</b>	53,800	3,976	13.5	222
<b>1912</b>	82,500	6,867	12.0	250
<b>1913</b>	199,100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

70%  
reduction

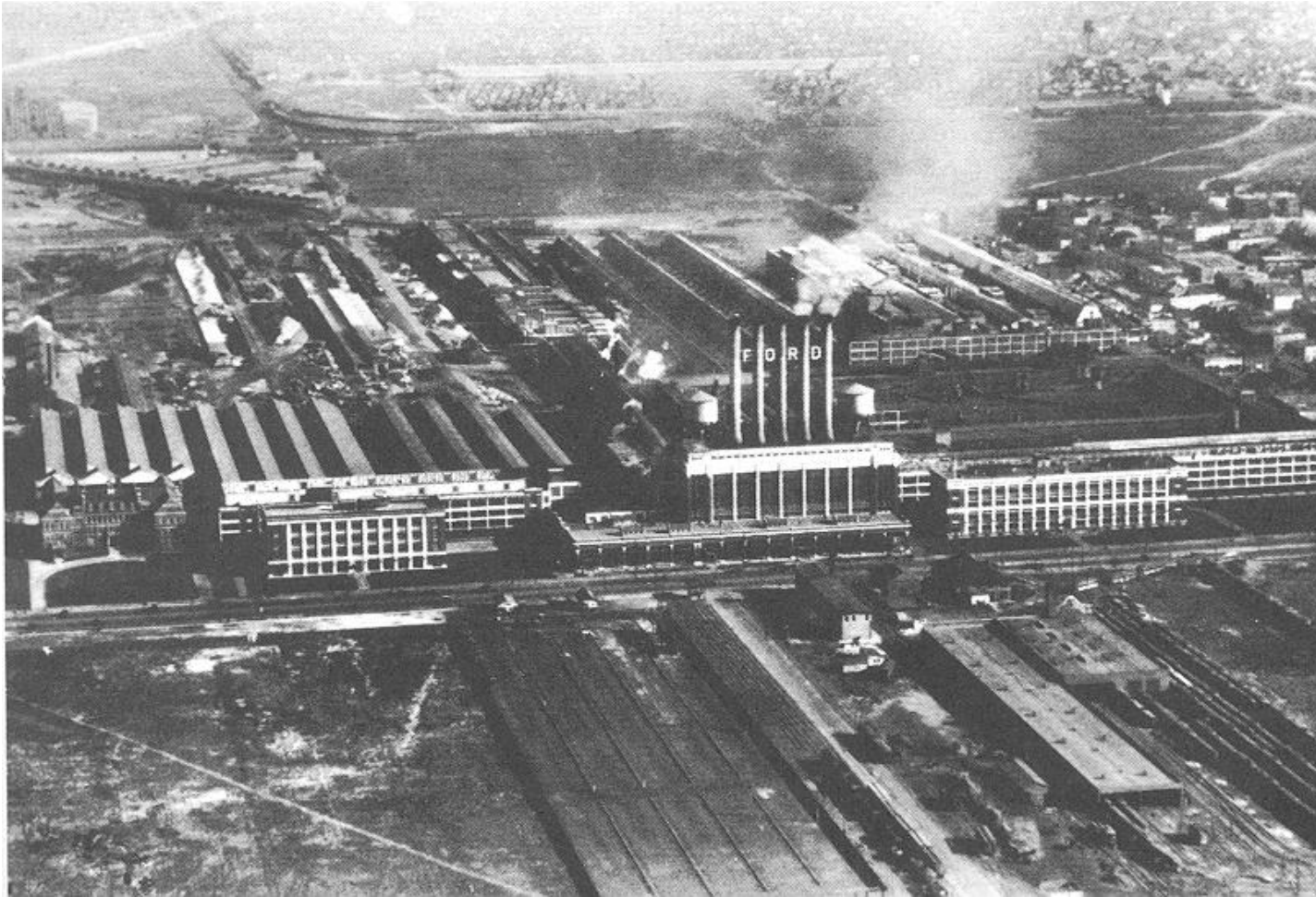
# Historical Development of Mass Production at Ford.



“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

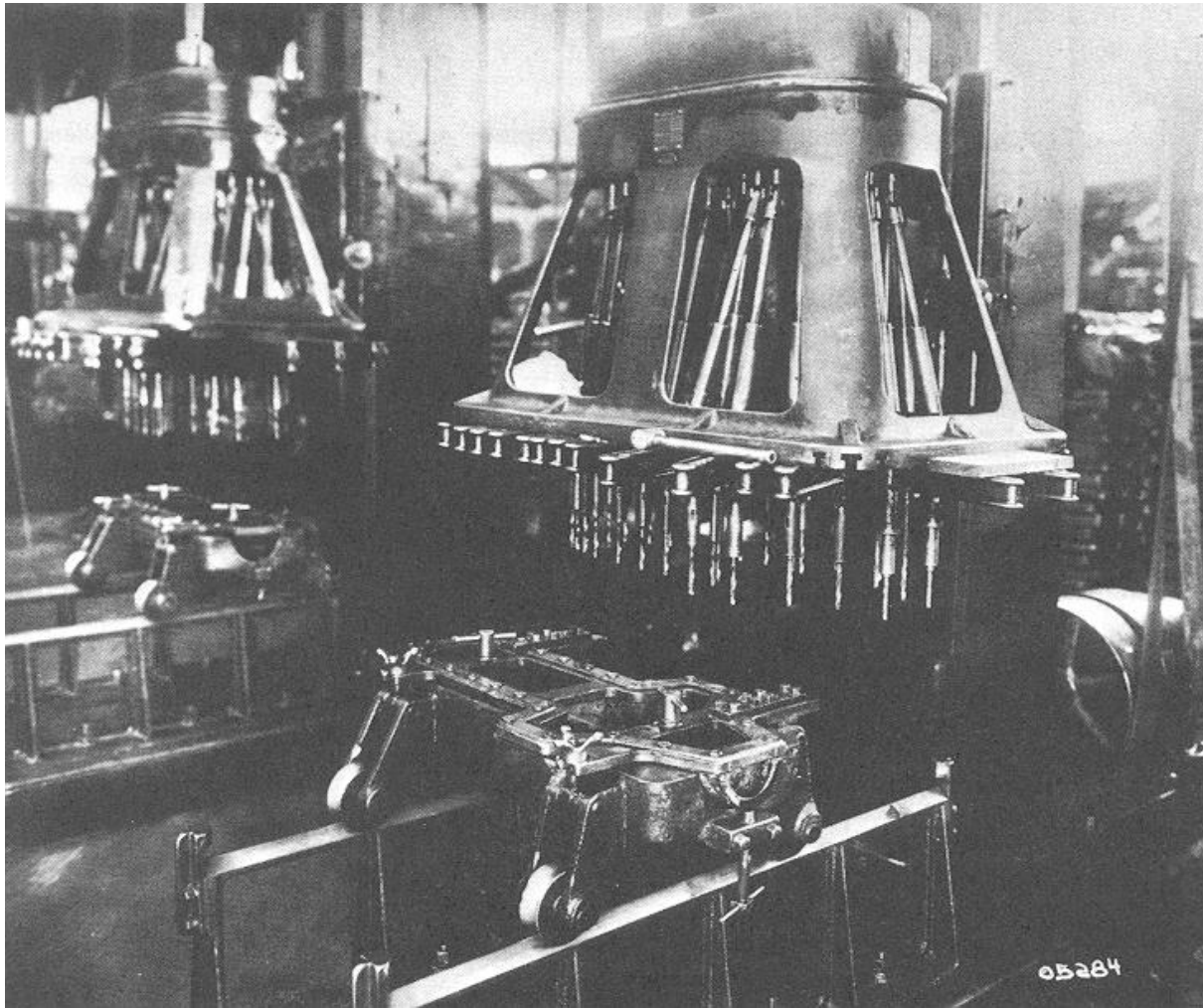


Ford's Highland Park Plant where the moving assembly line was first developed for automobiles in 1913

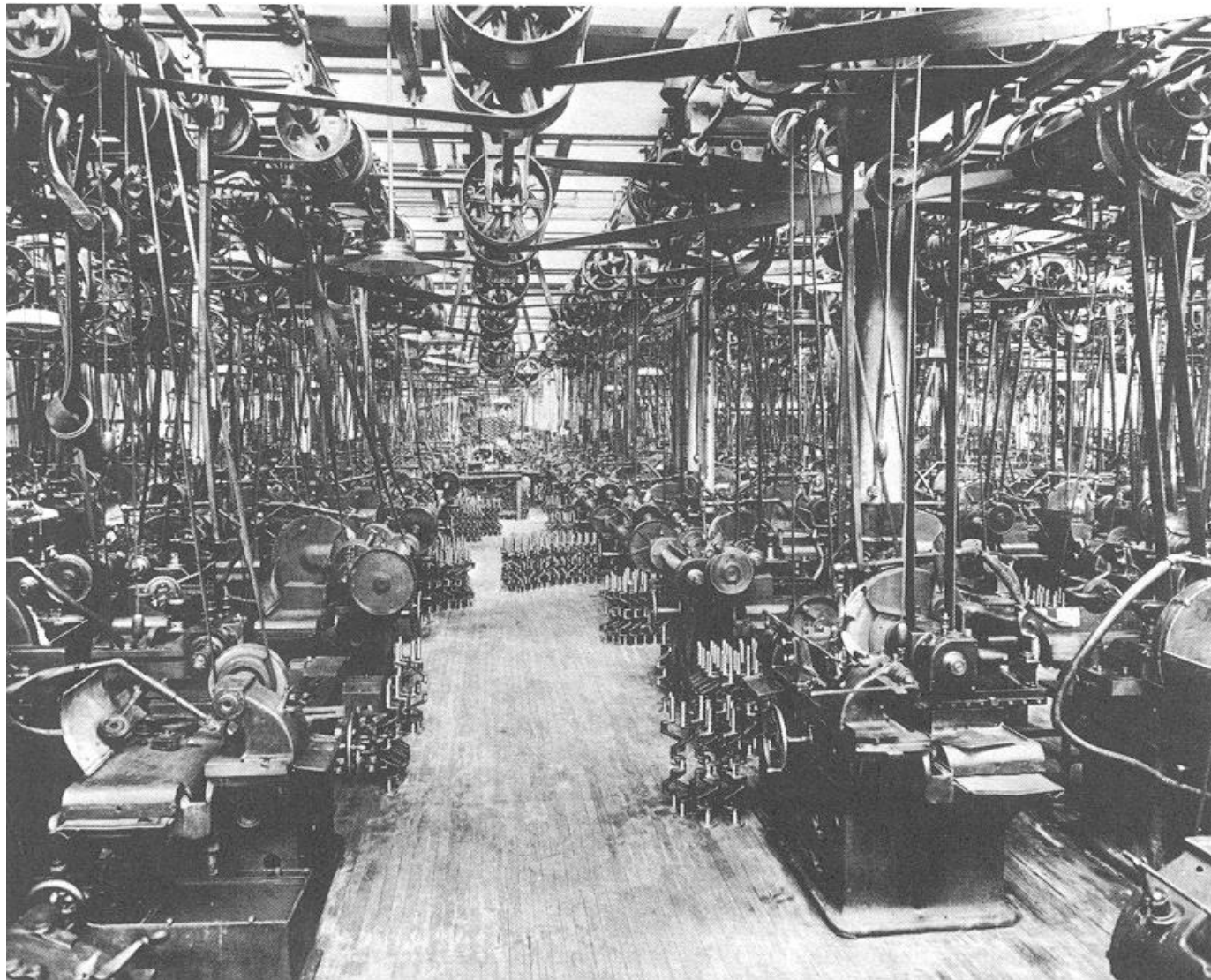




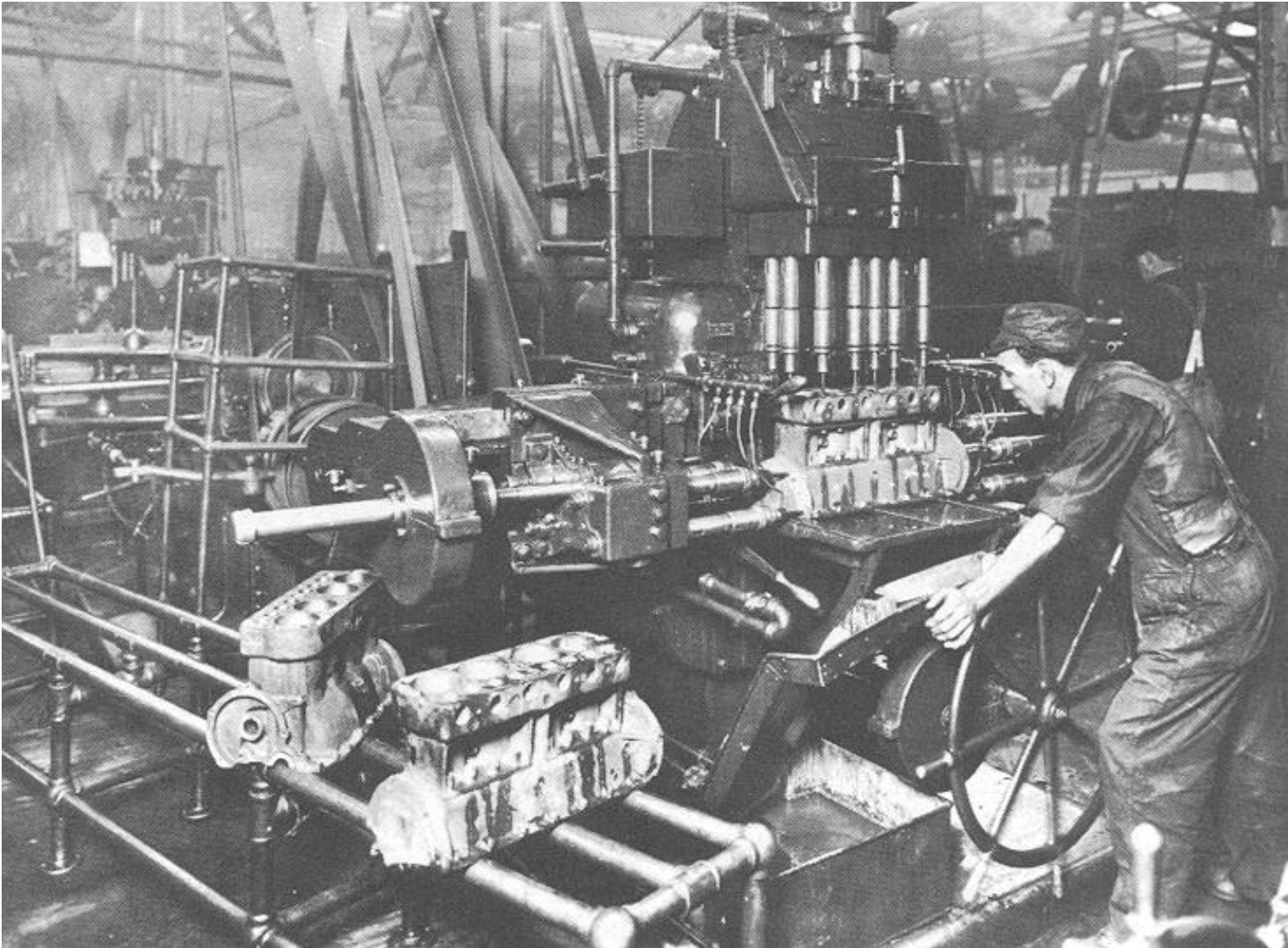
Multiple spindle drilling of the crankcase, notice the quick-change fixturing.



# Ford Crankshaft Grinding Machines 1915

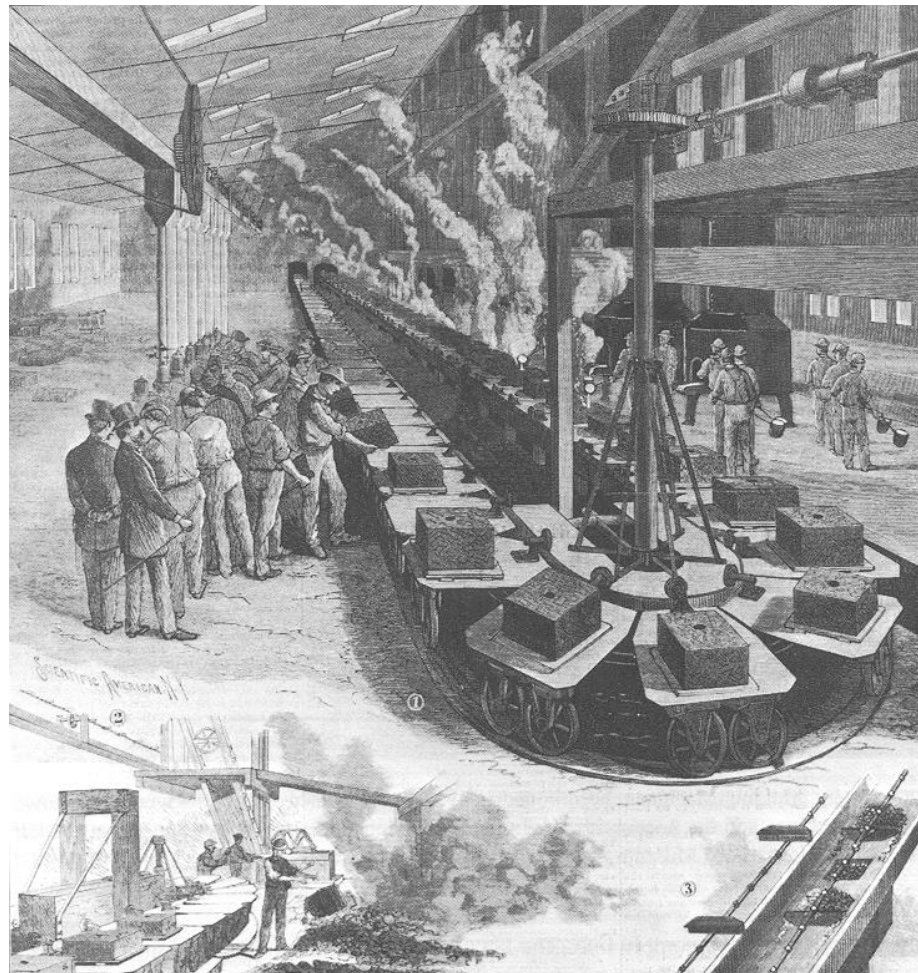


# Multi-spindle drilling and reaming of engine blocks



# Westinghouse Foundry in 1890

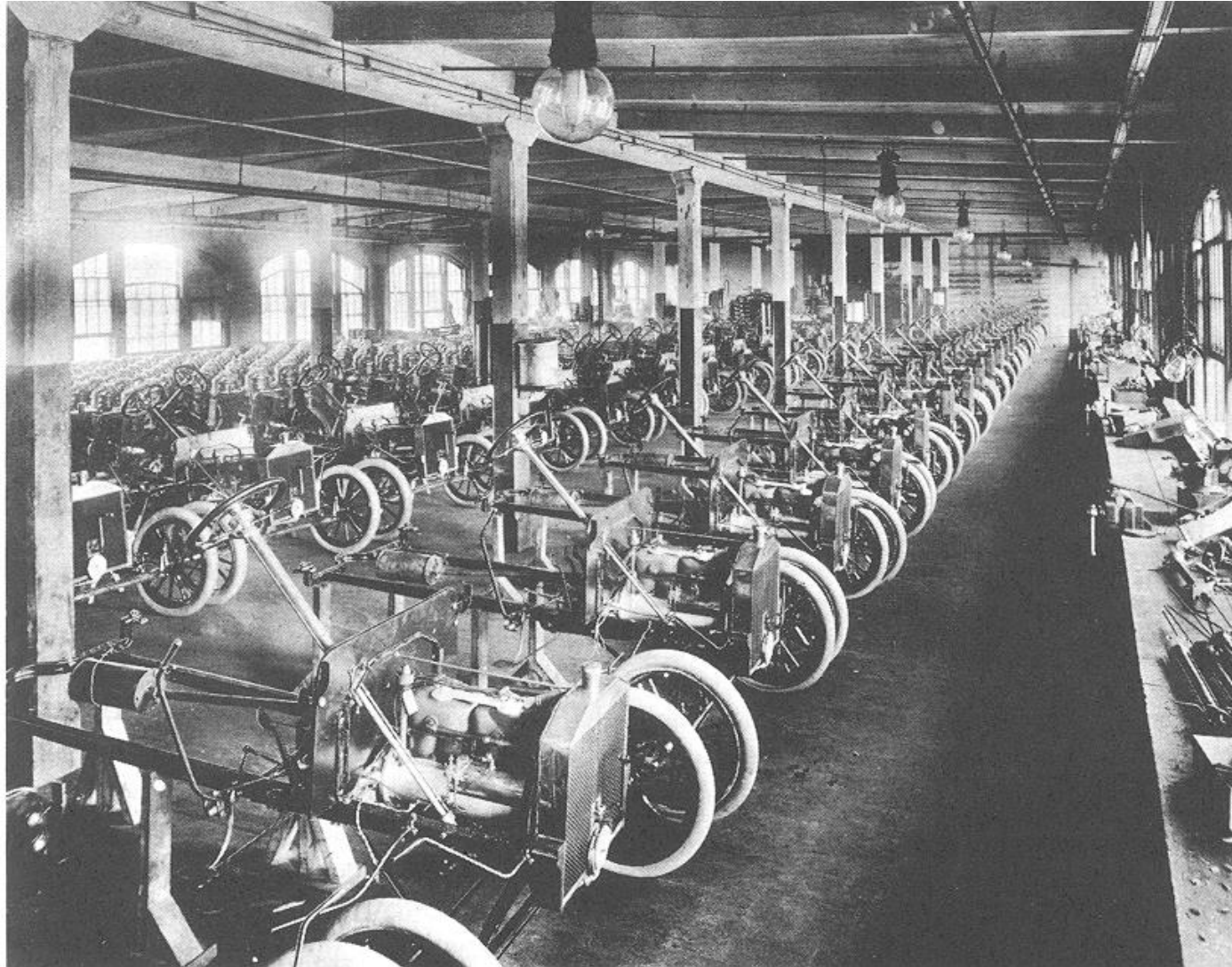
Machine made molds are moved past pourer on conveyor system. A similar system was used at Ford



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

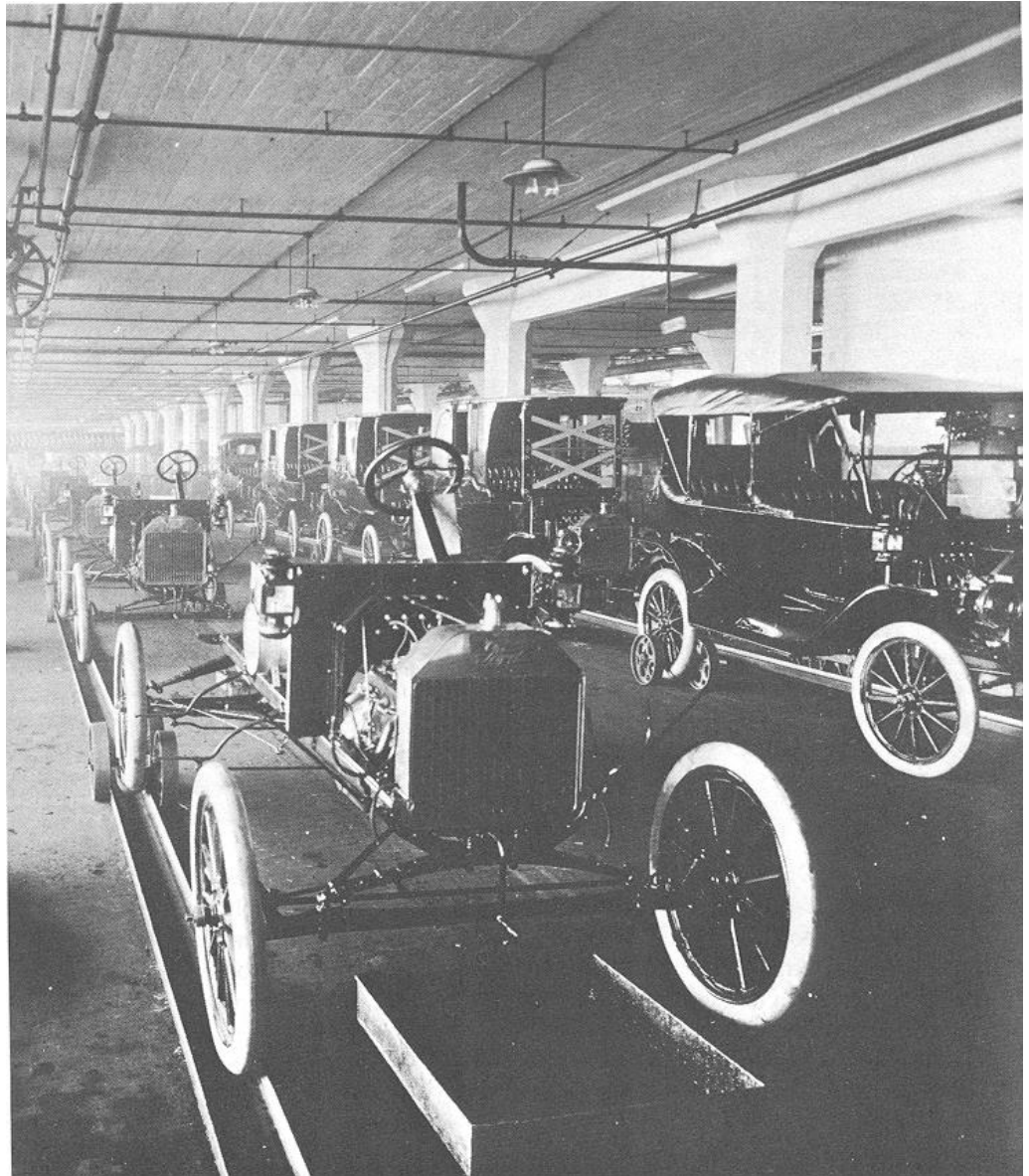


# Static Assembly of the Model "N" At the Piquette Avenue Factory 1906



# 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 CONVERED TO  
**MOVING ASSEMBLY.**





<http://silodrome.com/ford-model-t-assembly-line/>



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

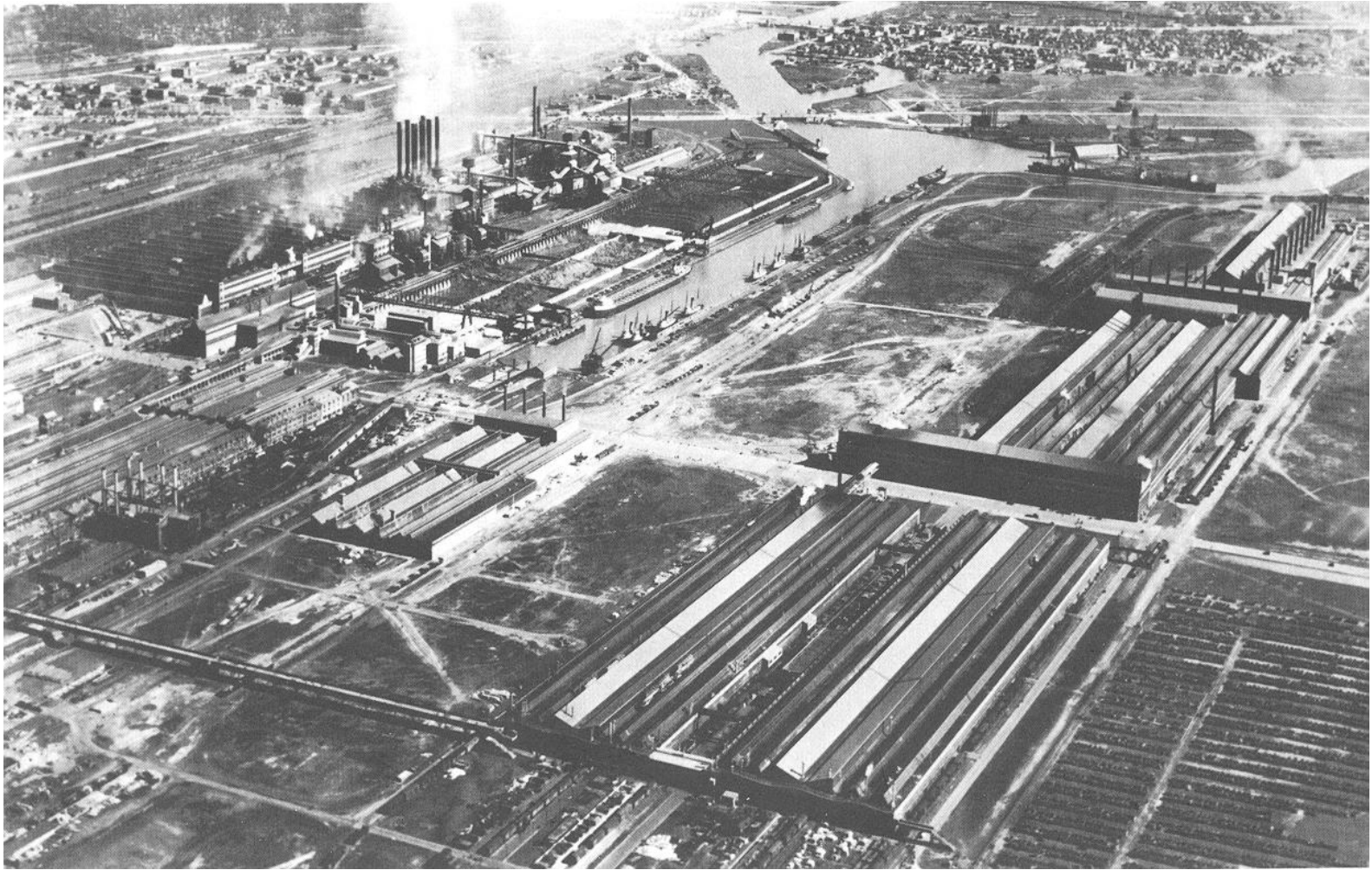
**FORD MODEL T VIDEO**

<http://www.youtube.com/watch?v=S4KrIMZpwCY>

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

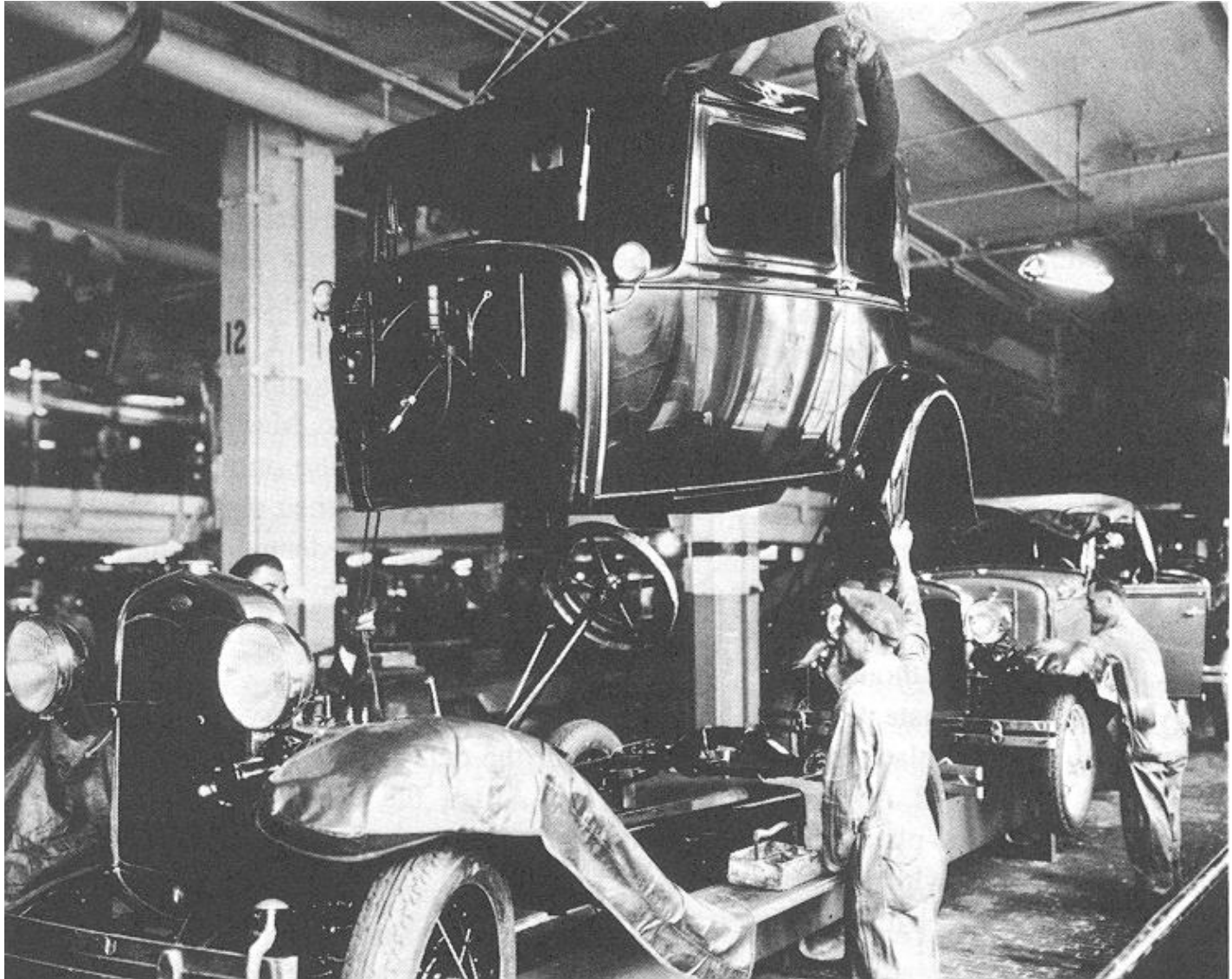


# Ford's River Rouge Plant; 27 miles of conveyor, the epitome of vertical integration.



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



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

# 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.



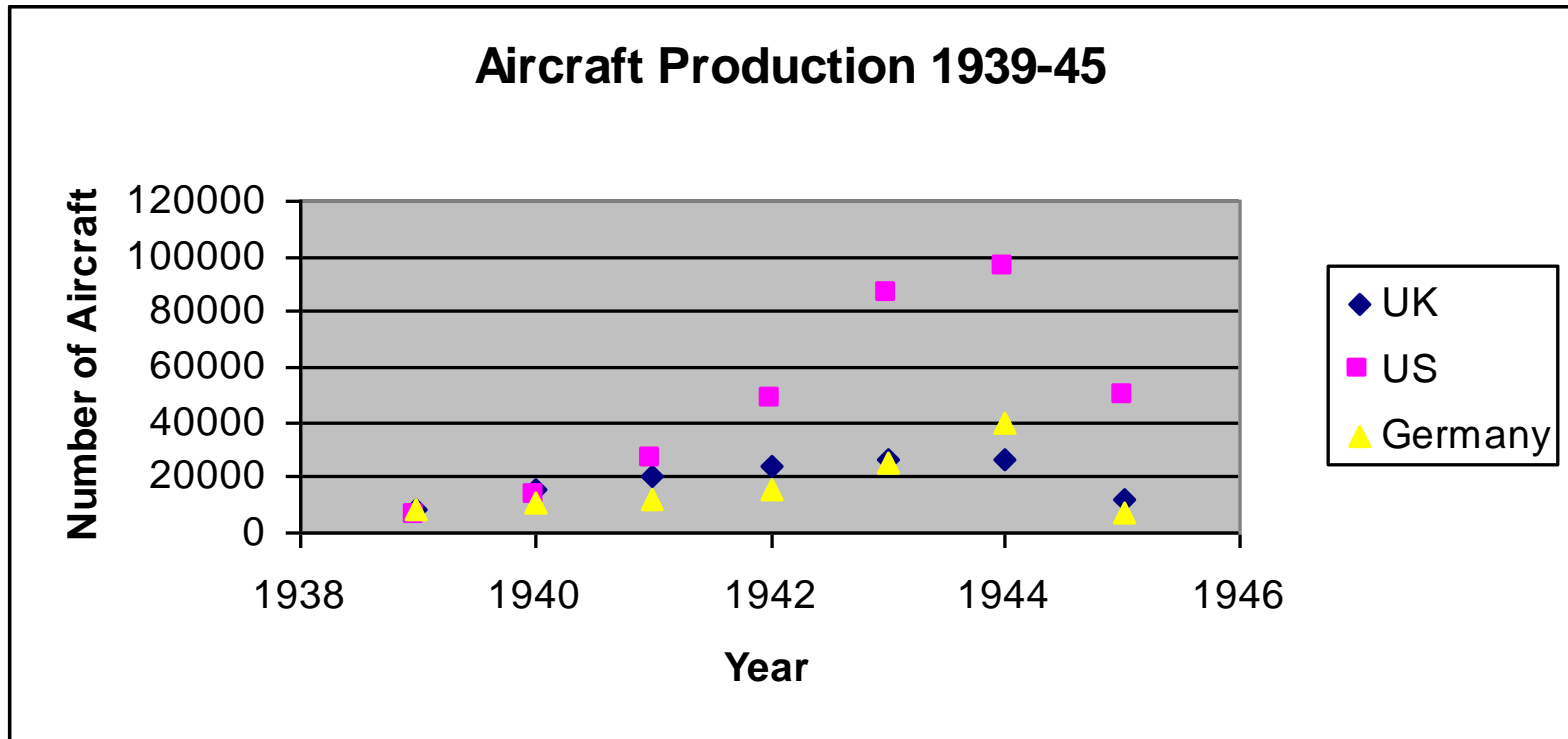
# Common elements between Ford and “lean”

- 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
- Redesign for mfg
- Interchangeable parts
- Pre-fabrication strategy
- Moving assembly line

# B-24 Assembly line in Ft. Worth



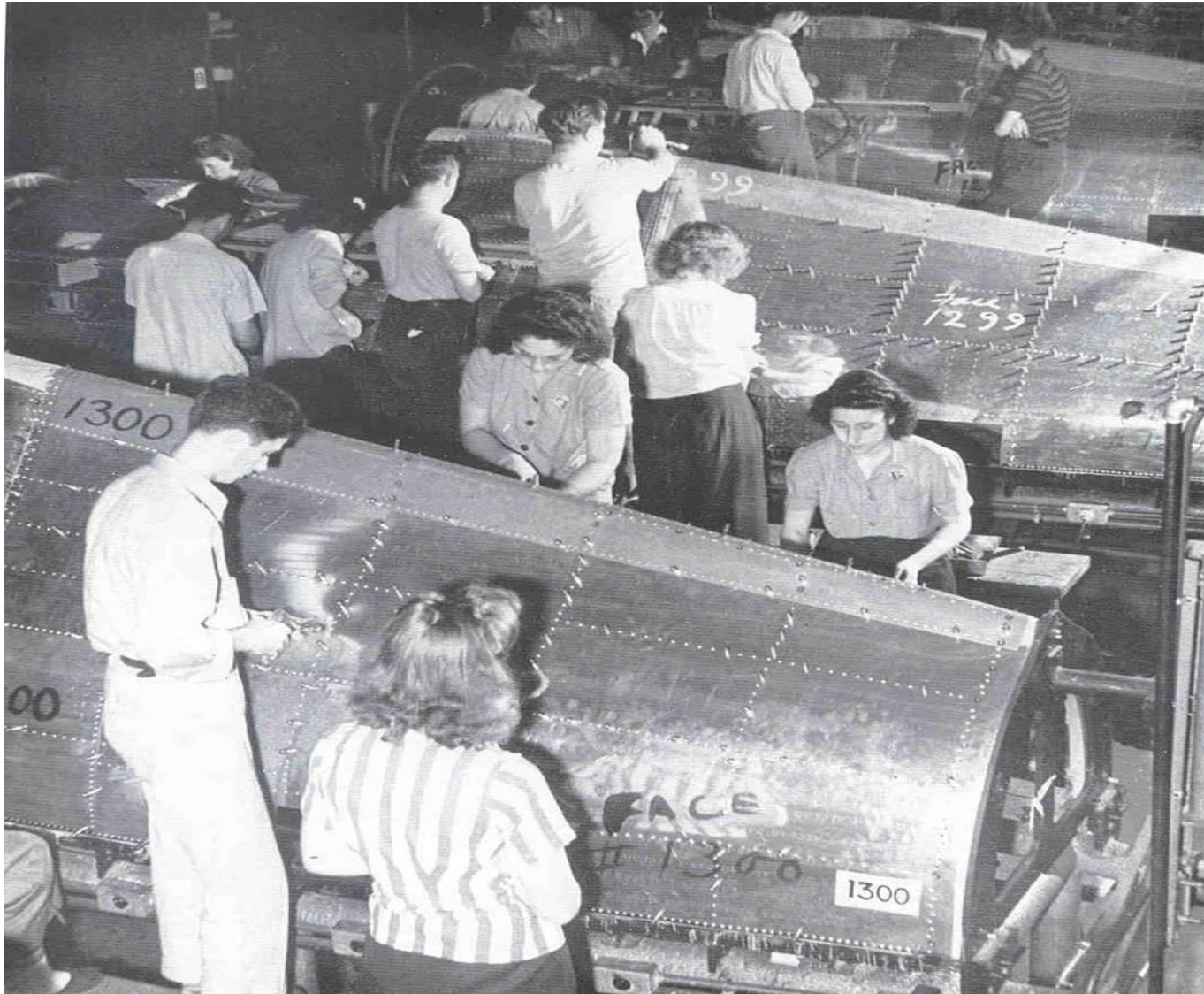
Consolidated, later General Dynamics, 4000 ft long

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



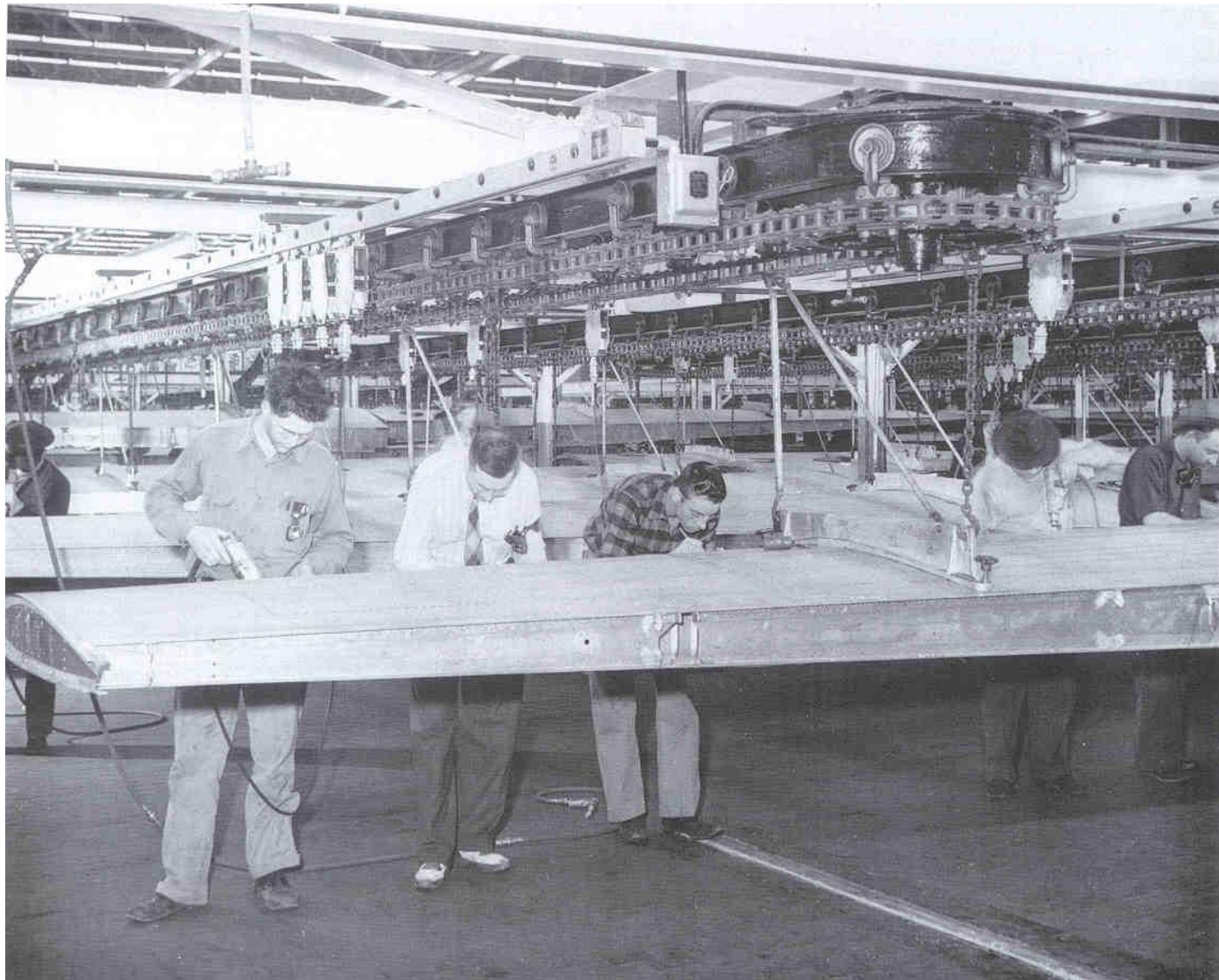
Moved every 5 minutes

# P-47 fuselage riveting



Division of Labor

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



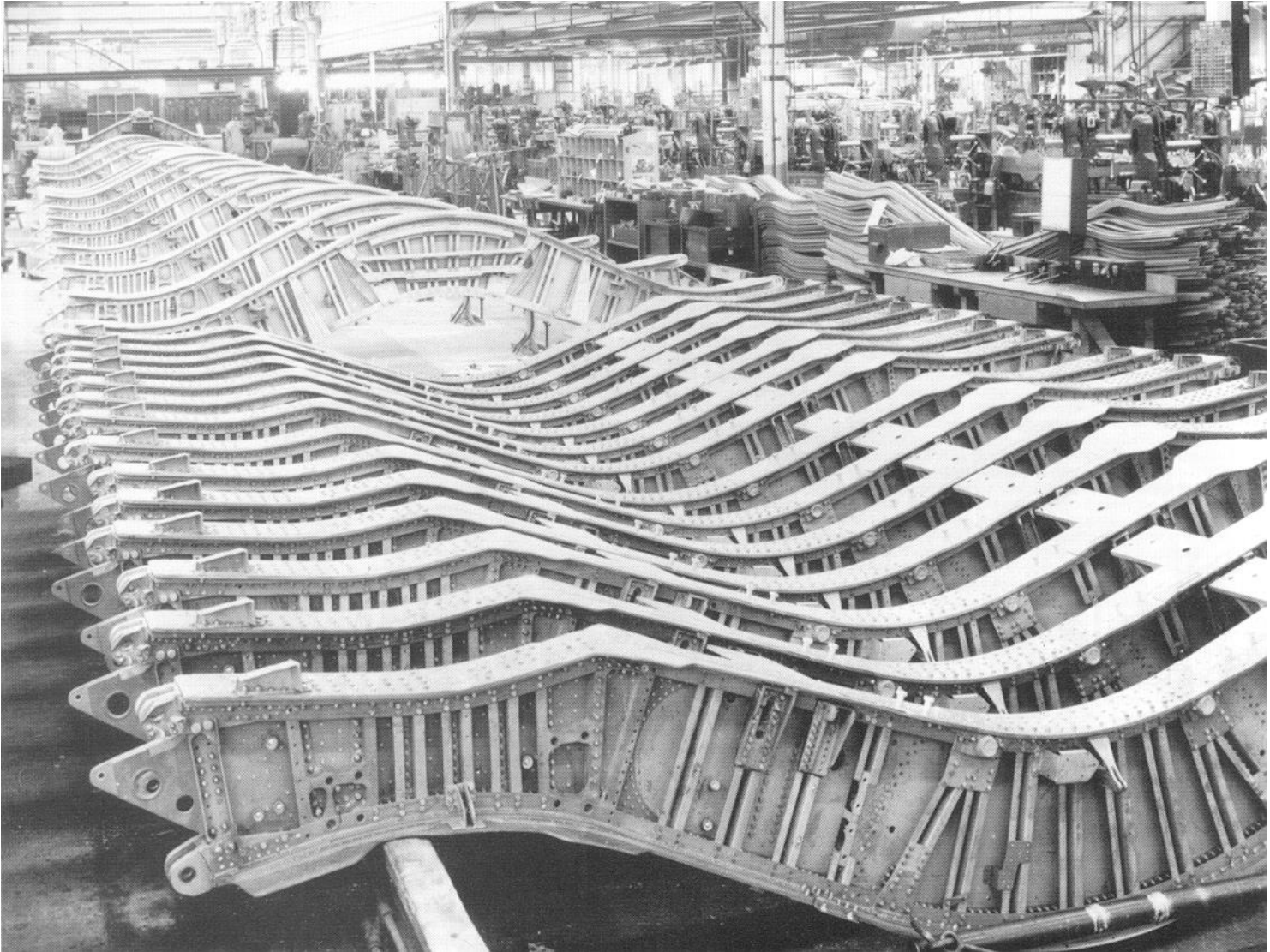


# B-17 "precompletes" for Boeing's "multiline" production



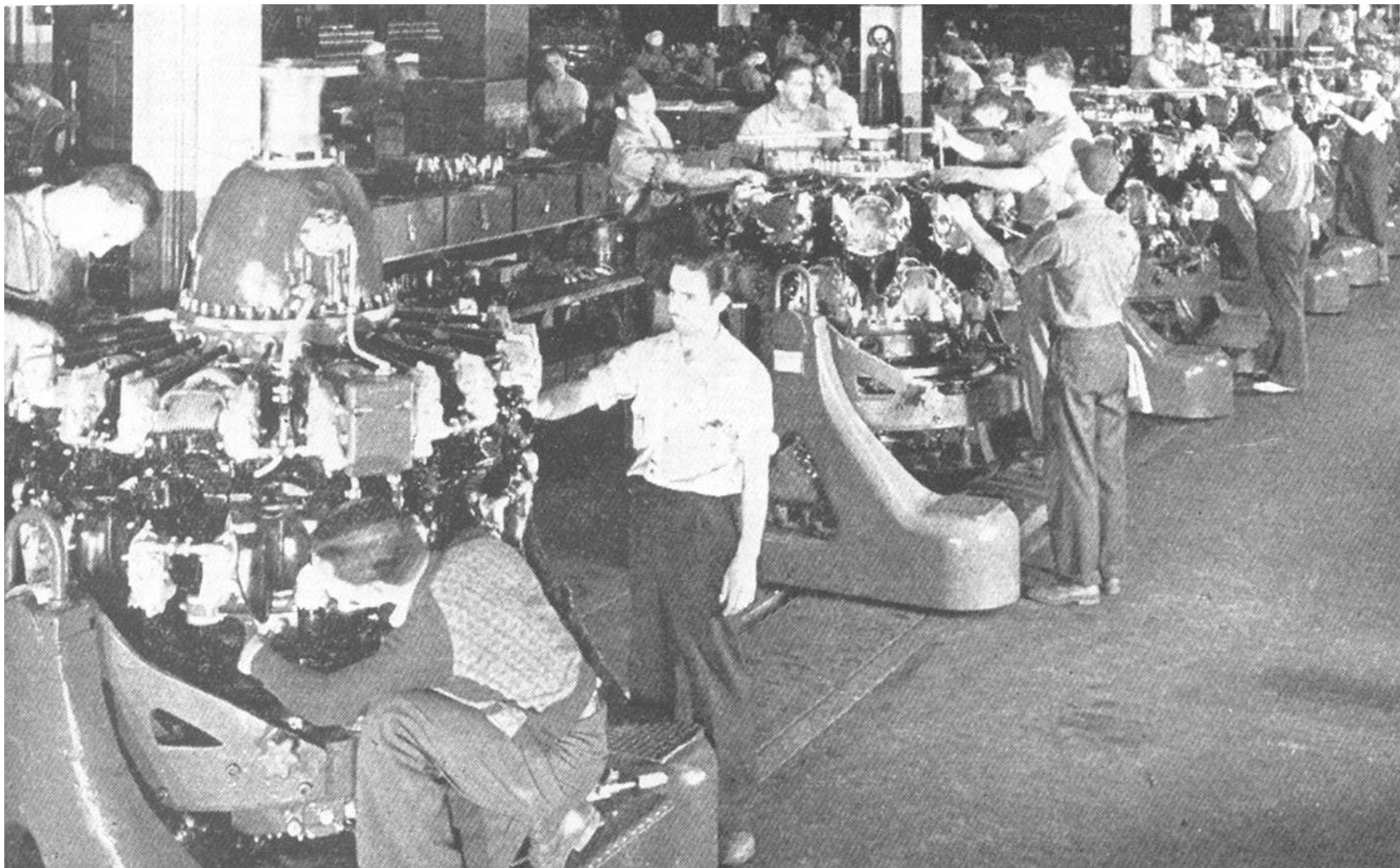
Saves room, improves access to interior

# Vought F4U "Corsair" main spars for wing center sections



13 ft propeller, 200 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 change into the line; U.S. & U.K.

# What conditions lead to a revolutionary new mfg system?

	Interchangeable parts	Moving Assembly	TPS
Need	field repairs, Higher volume	Transportation	Re-build after WWII
Financing	U.S. Gov'n	Self	Japanese Banks
Enabling Technology	Mechanization of machining	Interchangeable parts & Mechanization Stamping	Many

# Reoccurring Issues-Summary

Issue	US Armories	Ford	Toyota
Cost Effectiveness	Doubtful for long time	immediately	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 & prod to demand	JIT, low inventories...
Work Scheduling/ control	Master Vs Gauge Blocks	MODERN TIMES MOVIE	Push Vs pull