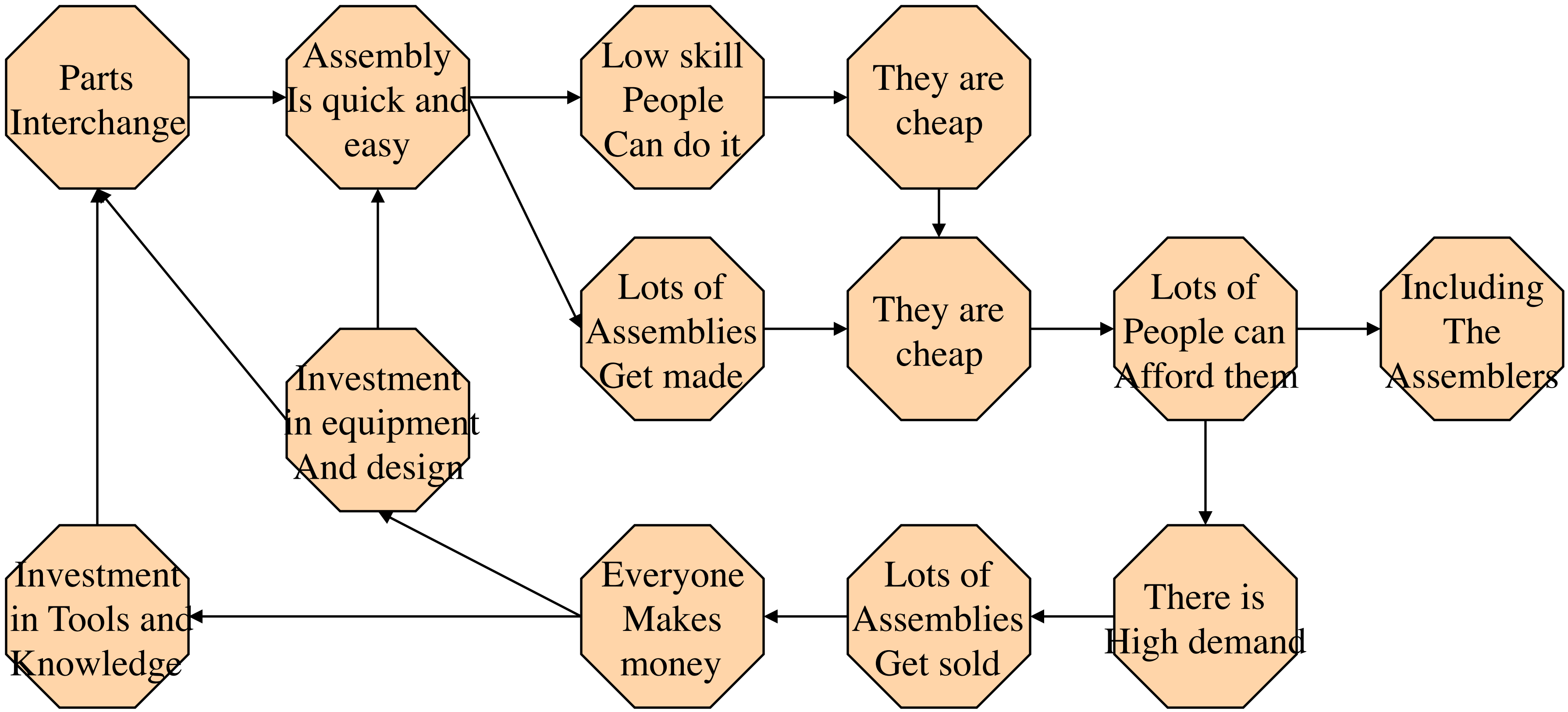
Mechanical Assembly

- Goals of this class:
  - Explain the basics of assembly as a manufacturing process
  - Show some examples
  - Explain Design for Assembly
- Not included:
  - Design processes for creating assemblies
  - Computer representations of assemblies
  - The “reach” of assembly into company operating processes and strategies
  - Relationship to modularity and product architecture

Historical Aspects of Assembly

- All assembly was manual until about 50 years ago
- Little scientific knowledge existed about what happens during assembly operations: people "just do it"
- All fabrication techniques have been mechanized for 100 to 5000 years and a lot is known about them
- Assembly included fitting, adjustment, and selection until the 1830s
- Technology and methods to create interchangeable parts evolved during 1765-1900
- Mass production requires interchangeable parts
- Interchangeable parts enable use of low skill assemblers
- Supply chain implementation of manufacturing requires interchangeable parts and supporting technologies

Interchangeable Parts Enable Mass Consumption

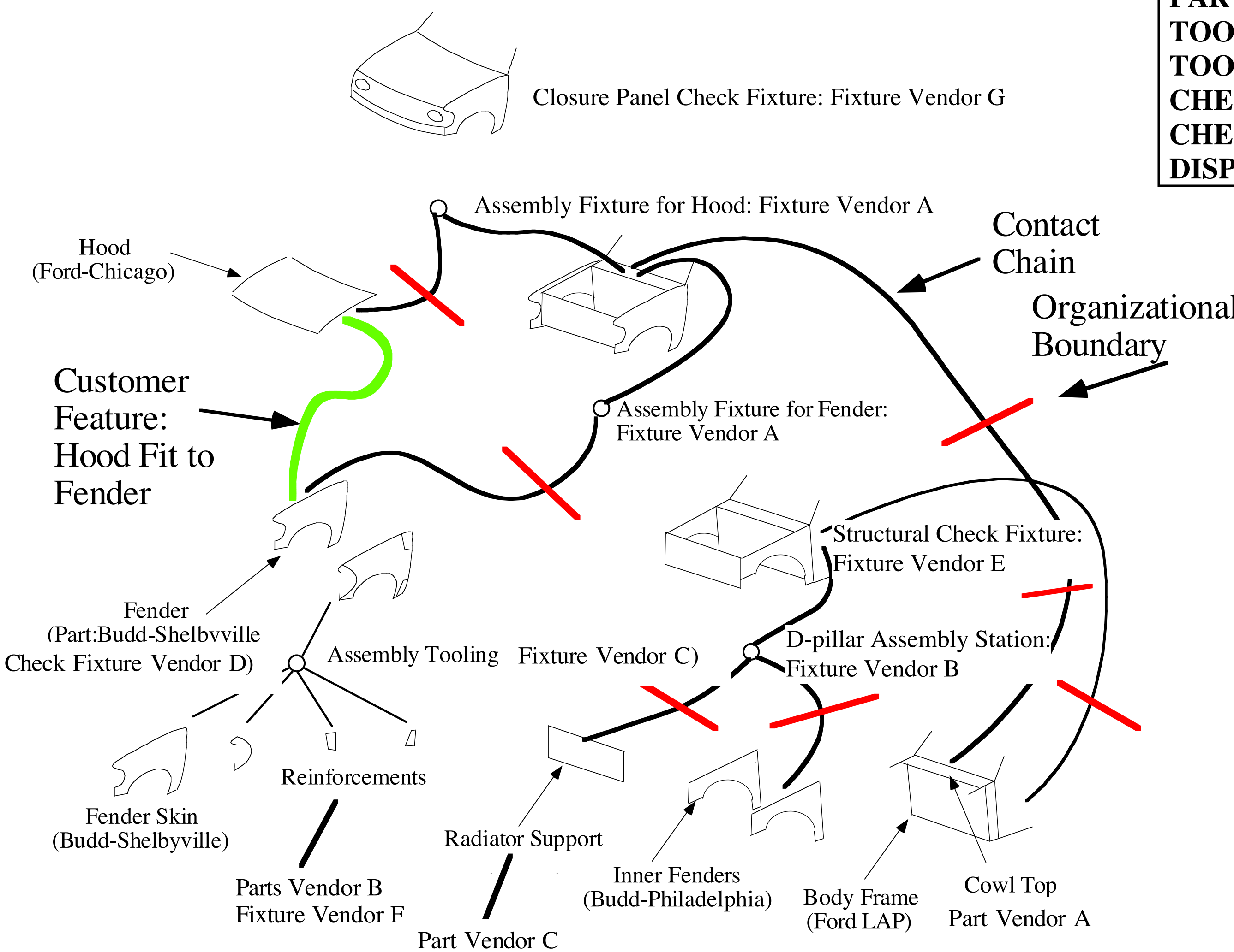


Technical Aspects

- Assembly creates product functions or sub-functions
- Results of assembly can be tested
  - Results of fabrication can be inspected but not tested
- Assembly requires coordination of many parts, tools, fixtures, packages, people, companies
- Assembly step times are short compared to manufacturing process step times
  - Non-assembly actions take proportionately much more time
  - Time is needed to move the assembly from one station to the next or to change tools
  - People and space are needed for incoming parts and outgoing boxes

"Chain of Delivery" of Quality

PART COUNT: 9
PART SOURCES: 7
TOOL COUNT: 5
TOOL SOURCES: 4
CHECK FIXTURE COUNT: 2
CHECK FIXTURE SOURCES: 2
DISPERSAL INDEX: 81%

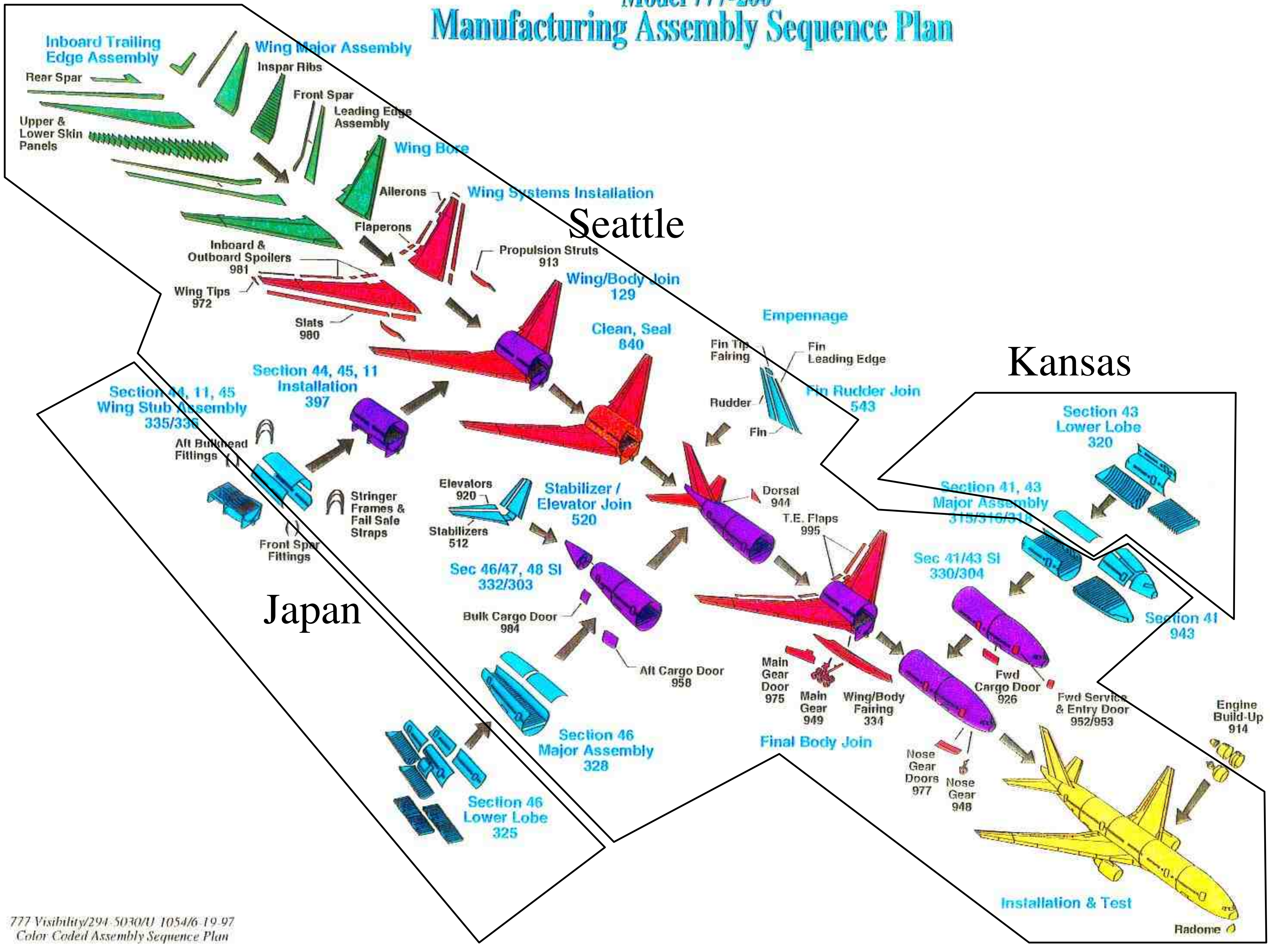


N. Soman, M. Chang

More Technical Aspects of Assembly

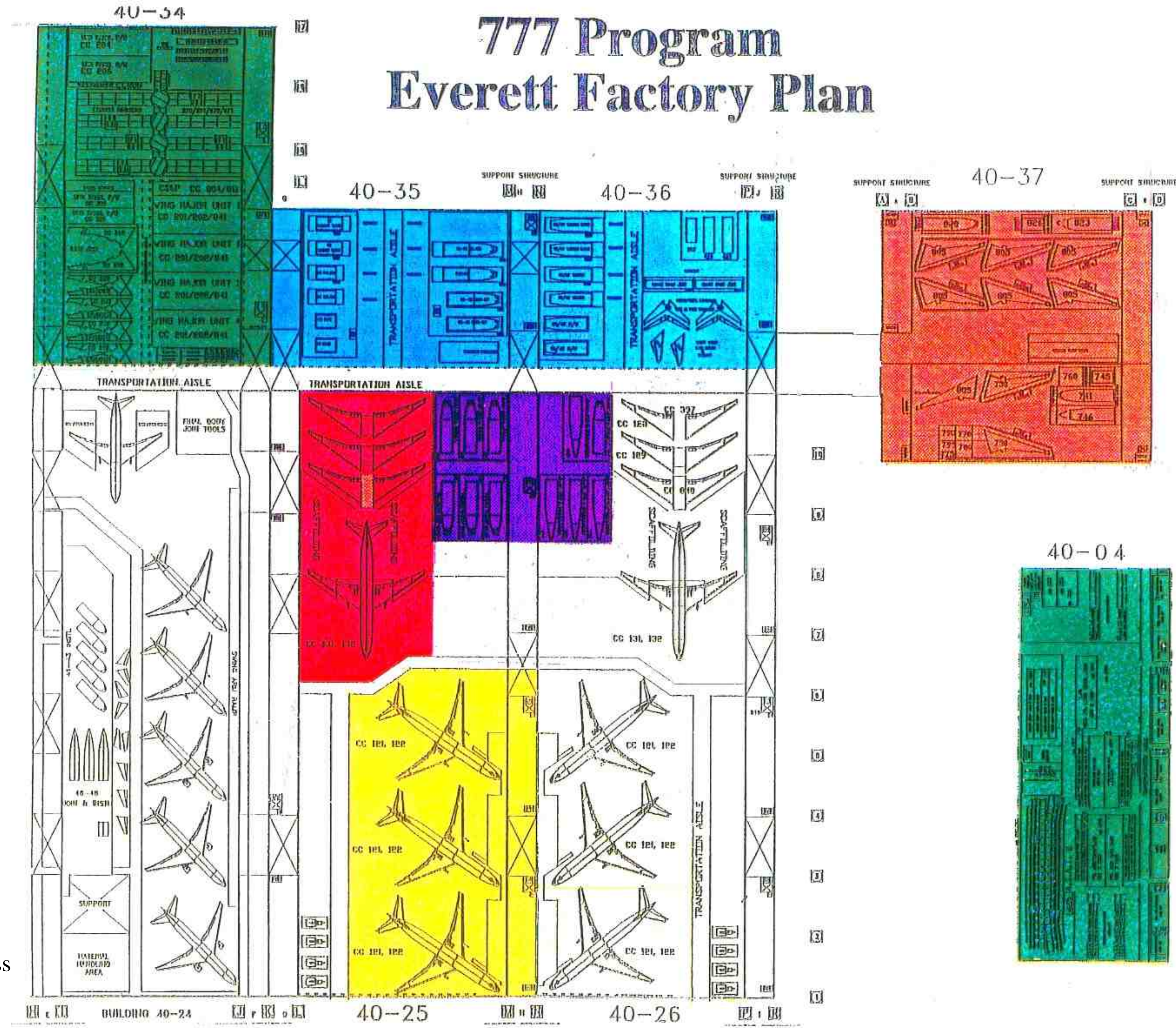
- Three methods are used
  - Manual (always involved for large items; almost always involved for small items)
  - Specialized equipment (used only for small items made in high volumes - units/year in the millions)
  - Robots (used for small and medium sized items)
- Low volume ~ big items: planes, ships
- High volume ~ small items: cigarettes, small toys
- Takt time for 777 airplane: 3 days
- Takt time for Ford or GM car: 59 seconds
- Takt time for a cigarette: 10 ms

Model 777-200
Manufacturing Assembly Sequence Plan



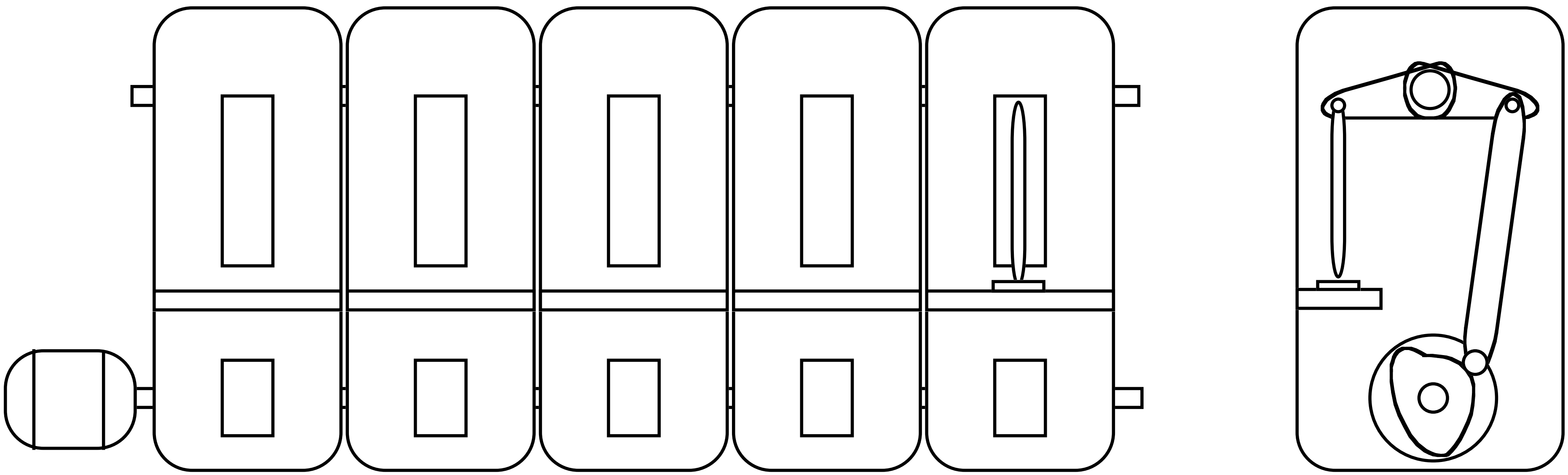
777 Visibility/294-5030/U 1054/6-19-97
Color Coded Assembly Sequence Plan

777 Program
Everett Factory Plan



Ass

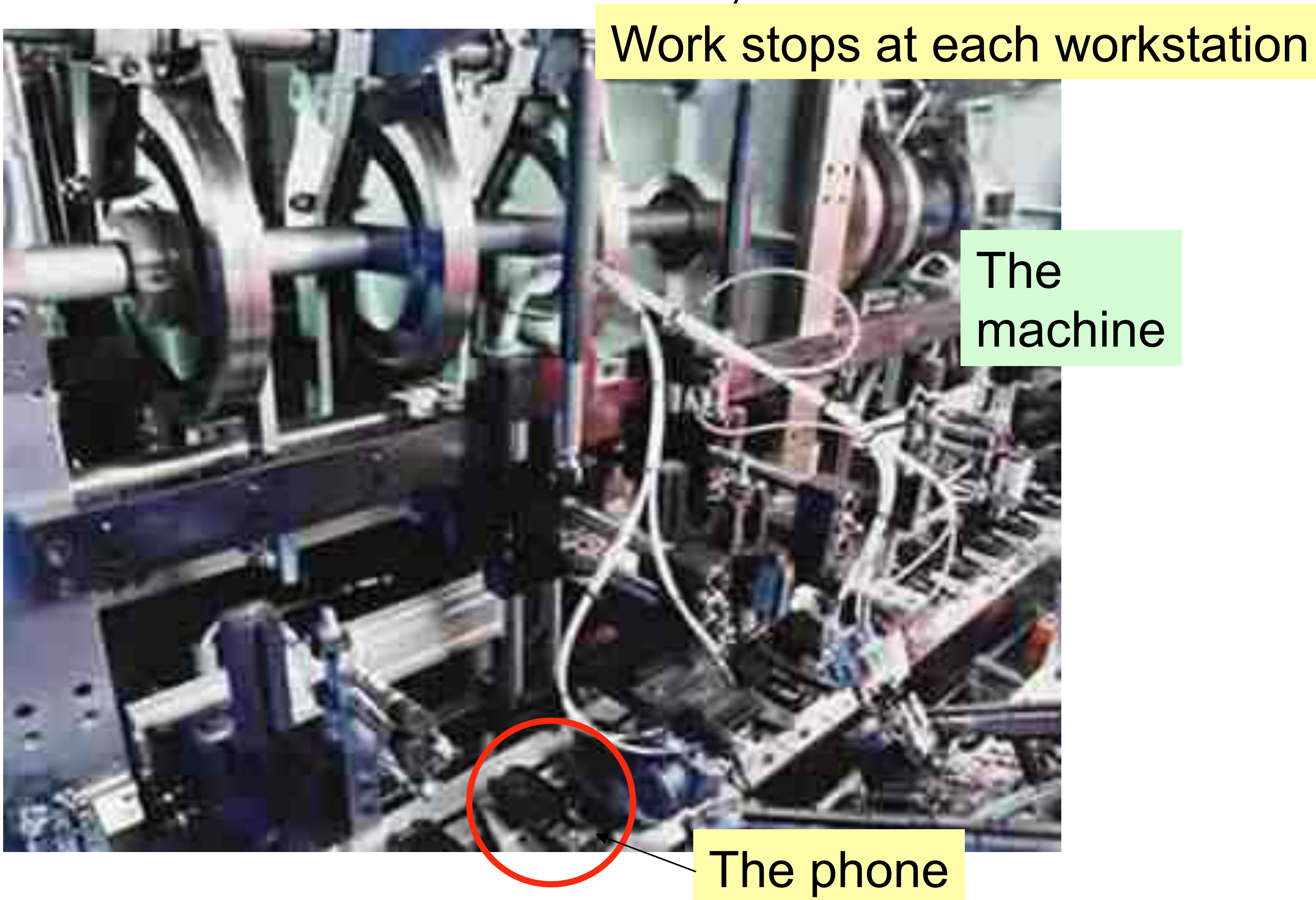
Typical Cam-operated Assembly Machine



Multiple identical base modules bolted together as needed
Cams cut by NC to do the necessary operations

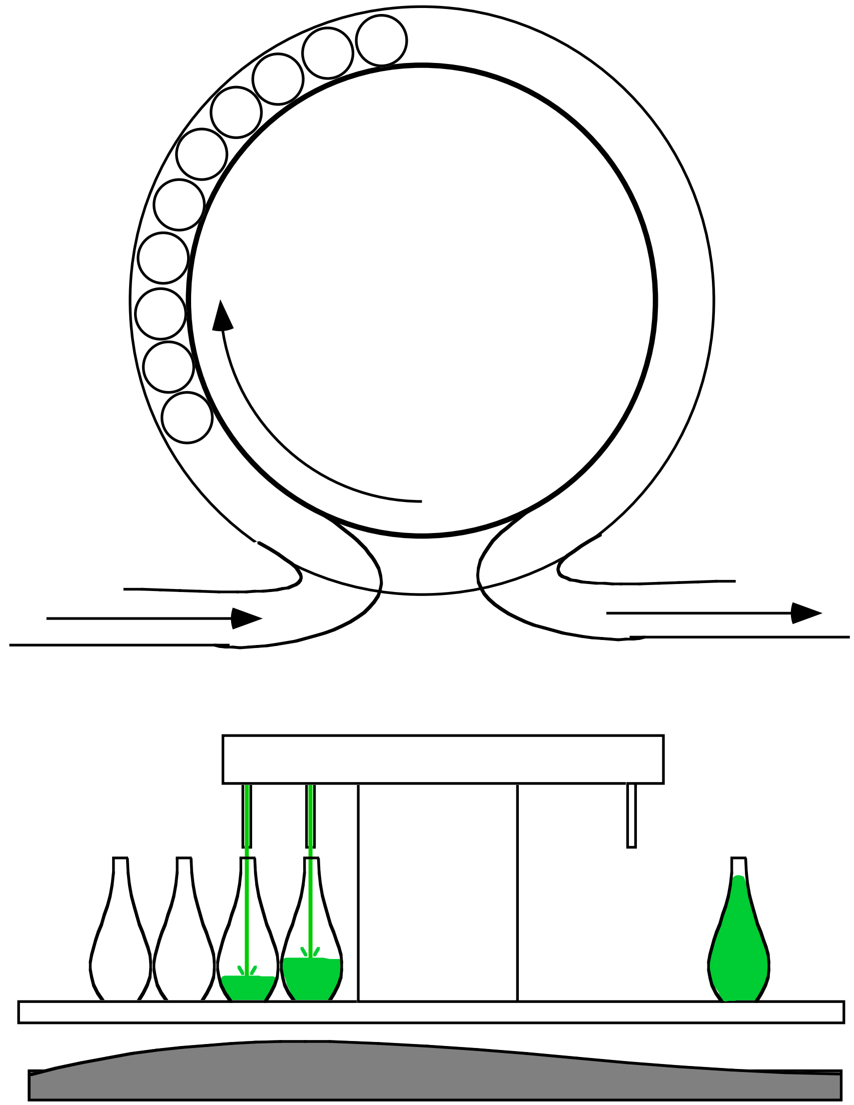
Synchronous parts transport

Cell Phone Assembly Machine

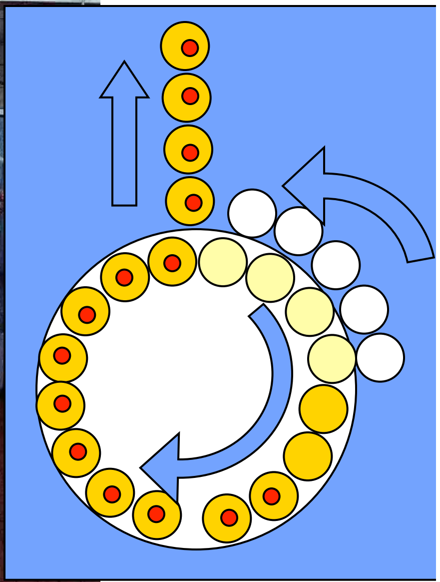


http://www.modular.co.uk/pages/solutions.htm

Typical Dial Machine

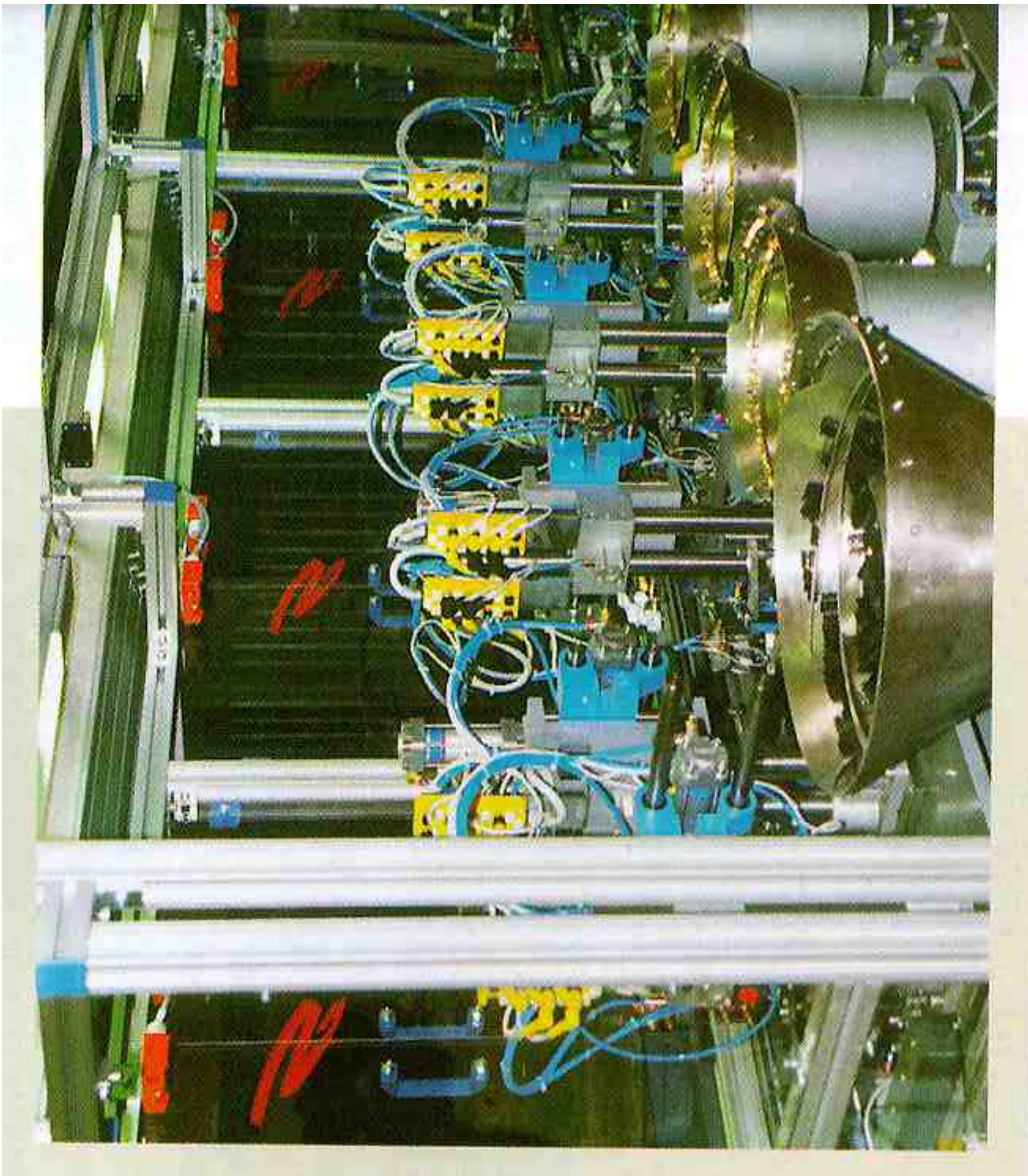


Bottle Filling Machine



Machine Makes Washer Tubs

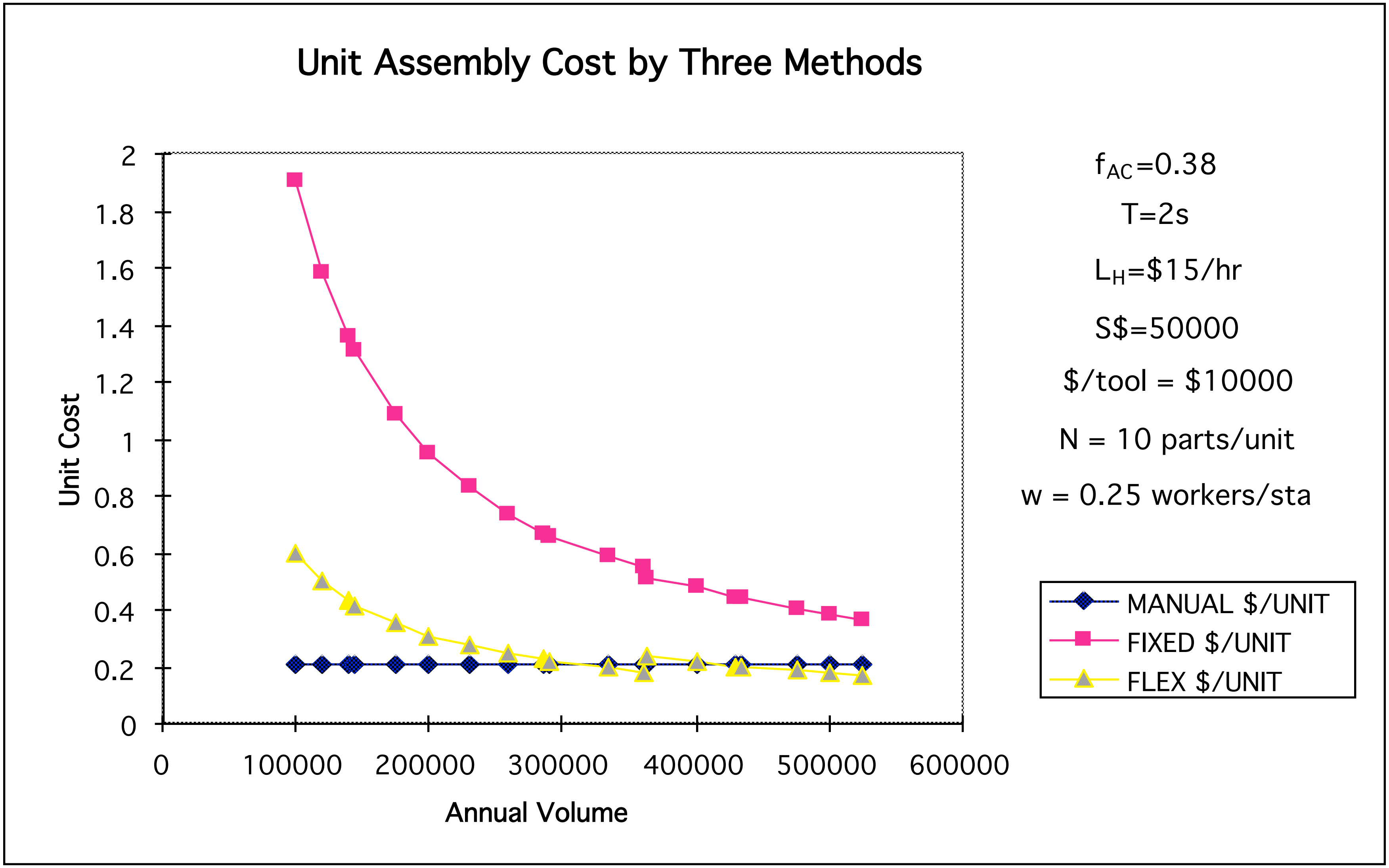
Typical Small Parts Assembly Machine



Economic Aspects

- Assembly employs more people than any other phase of manufacturing
- Short assembly takt times mean that cost of assembly is a small fraction of manufacturing cost
- Each technical kind of assembly has its own economic features

Unit Cost Example - 2



Operational Organization of Assembly

- One person or station does all assembly operations
- Subassemblies are made and flow into a final assembly process
- Assembly is done in a small area by a team where each member does many operations
- Assembly is done on a long line where each person does a small amount
- As production rates and volumes rise, the line becomes the only efficient way

Operational Aspects - Line Balancing

- Different operations take different lengths of time
- When only one or a few ops are done at each station, large differences in station time can result
- Slow stations make fast stations wait
- Sometimes a different sequence will have better balance
- Sometimes, extra stations in parallel are provided
- Queues can build up behind slow stations
- Fast stations can become starved
- "A cycle lost on the bottleneck station is a cycle lost forever"

Architecture Aspects

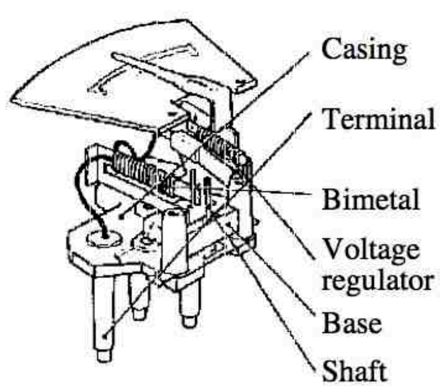
- Architecture is the definition and arrangement of the parts with respect to the product's functions
- Architecture affects
  - Definition of subassemblies
  - Assembly sequence options
  - Testing options
  - Customization and just-in-time operations
  - Design for assembly

Model Mix, Customization, and Changeover Happen During Assembly

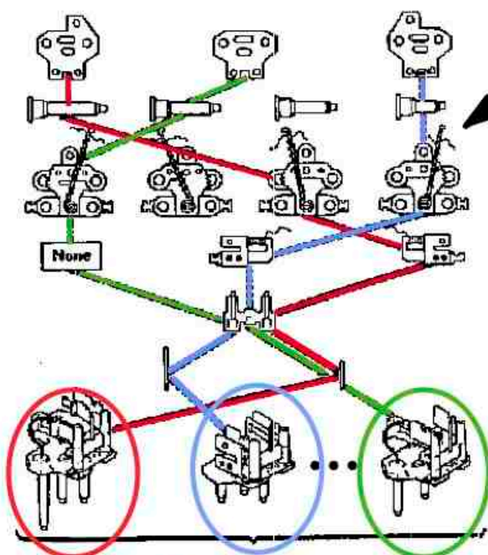
- Marketing wants them in 30 colors while manufacturing wants them all to be white
- "Decoupling point" is the last point where the product is the same for everyone
  - Can be at the beginning of assembly
  - Can be during assembly
  - Can be at a distribution point or with the user
- How much variety to offer?
- How to design the product and the production system?
- How to manage it, deliver quickly, avoid being caught with items no one wants, or not having what is wanted?

Product Design for Model Mix

Nippondenso makes many kinds of panel meters for Toyota. Toyota orders different ones in different amounts every day. ND designed an “assembly family” of meters and can make any quantity of any kind at any time by selecting the right parts. Assembly interfaces were standardized for all parts. The result is ‘assembly-driven manufacturing.”



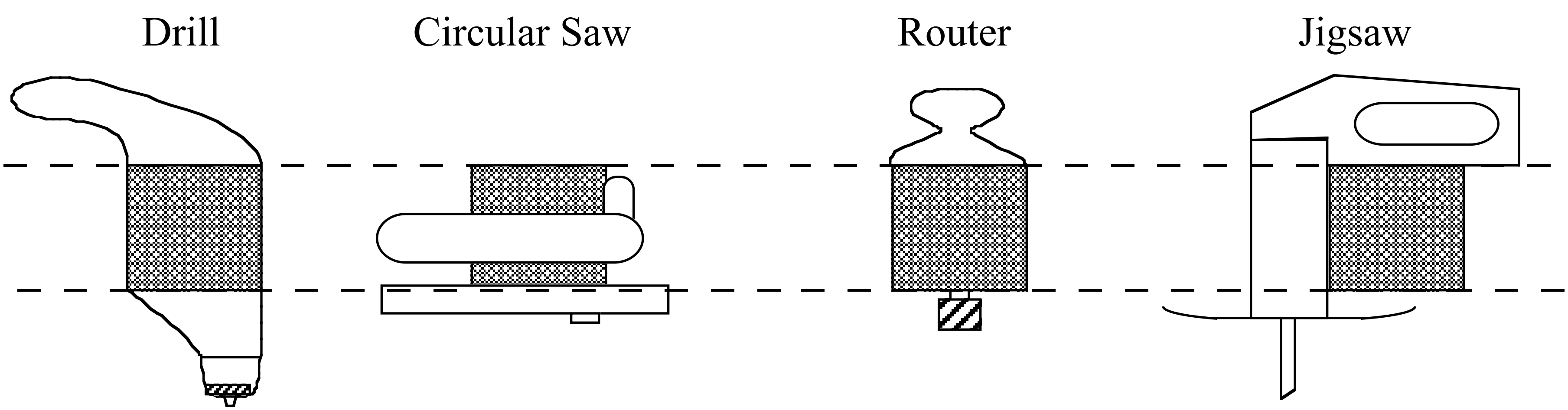
Inventory of only 16 part types



Each path yields a different kind of meter.

288 different kinds of meters can be made with no additional cost or delay, and almost no changeover time.

Stack Architecture for Power Tools



AXIAL/STACK ARCHITECTURE WITH COMMON MOTOR MODULE

Black & Decker ~ 1981
(still used)

See Lehnerd, Alvin P, "Revitalizing the Manufacture and Design of Mature Global Products" In Bruce Guile and Harvey Brooks, eds, Technology ad Global Industries, Washington, National Acaedmy Press, 1987.

Scroller Saw Family

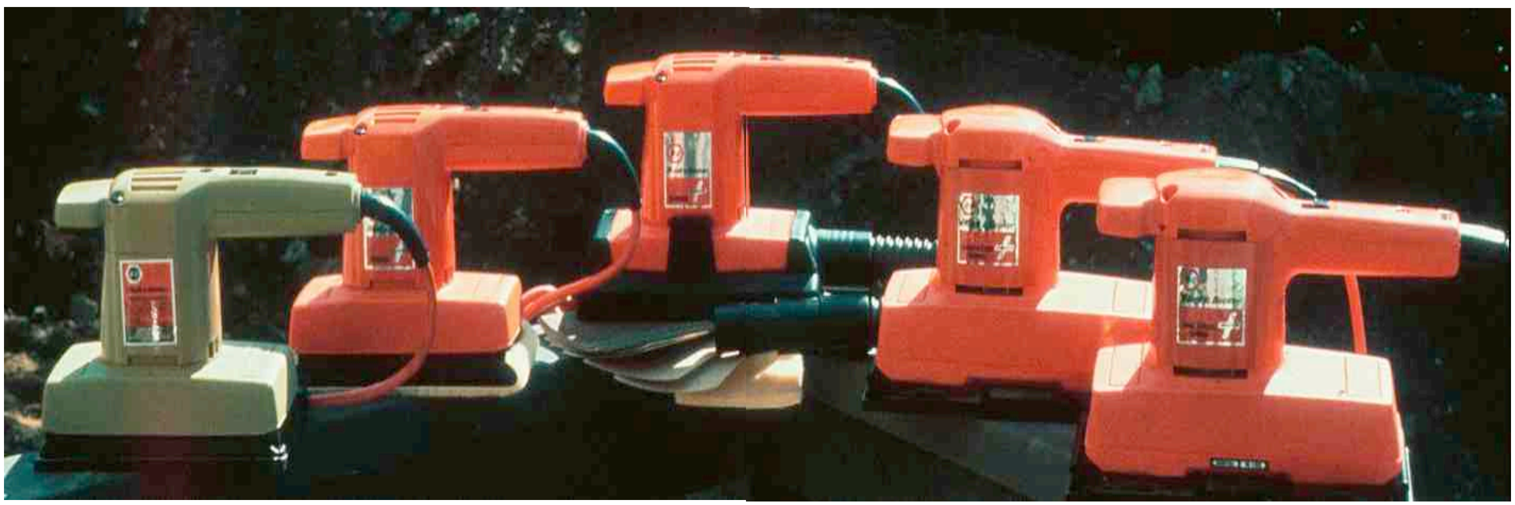


Photo courtesy of Albert Lenherd and James Utterback

Operational Problems

- When a station fails, work stops
- Many cycles are lost
- Deliberate queues (work in process inventory) are used to "protect" against these losses
- Queues then create different problems
  - WIP = money
  - Defects can hide in queues and a whole batch can be spoiled before the defect is detected
  - Changeover to a different model is difficult because the queues have to be cleansed of the old items before the new ones can be launched
  - Queue mentality breeds complacency

Ergonomics and Job Design

- Manual assembly work is boring due to short takt time
  - "I' m retiring tomorrow after 30 years. I' m going to the end of the line to see what we make here."
- Repetitive strain injuries are possible
- Mistakes are more likely than injuries
  - Wrong part (when there is model mix)
  - Part installed incorrectly, or damaging another part
  - Bad part used instead of being discarded
- Authoritarian management methods are often employed to combat these problems but they do not work

“The Multiplier” According to Ford and GM or: Why Is DFM/DFA Important?

- For every product part, there are about 1000 manufacturing equipment parts*
- Or, for every toleranced dimension or feature on a product part, there are about 1000 toleranced dimensions or features on manufacturing equipment
- Such “equipment” includes fixtures, transporters, dies, clamps, robots, machine tool elements, etc

*Note: Ford’s estimate is 1000, GM’s is 1800. Both are informal estimates.

Robot Car Welding Lines

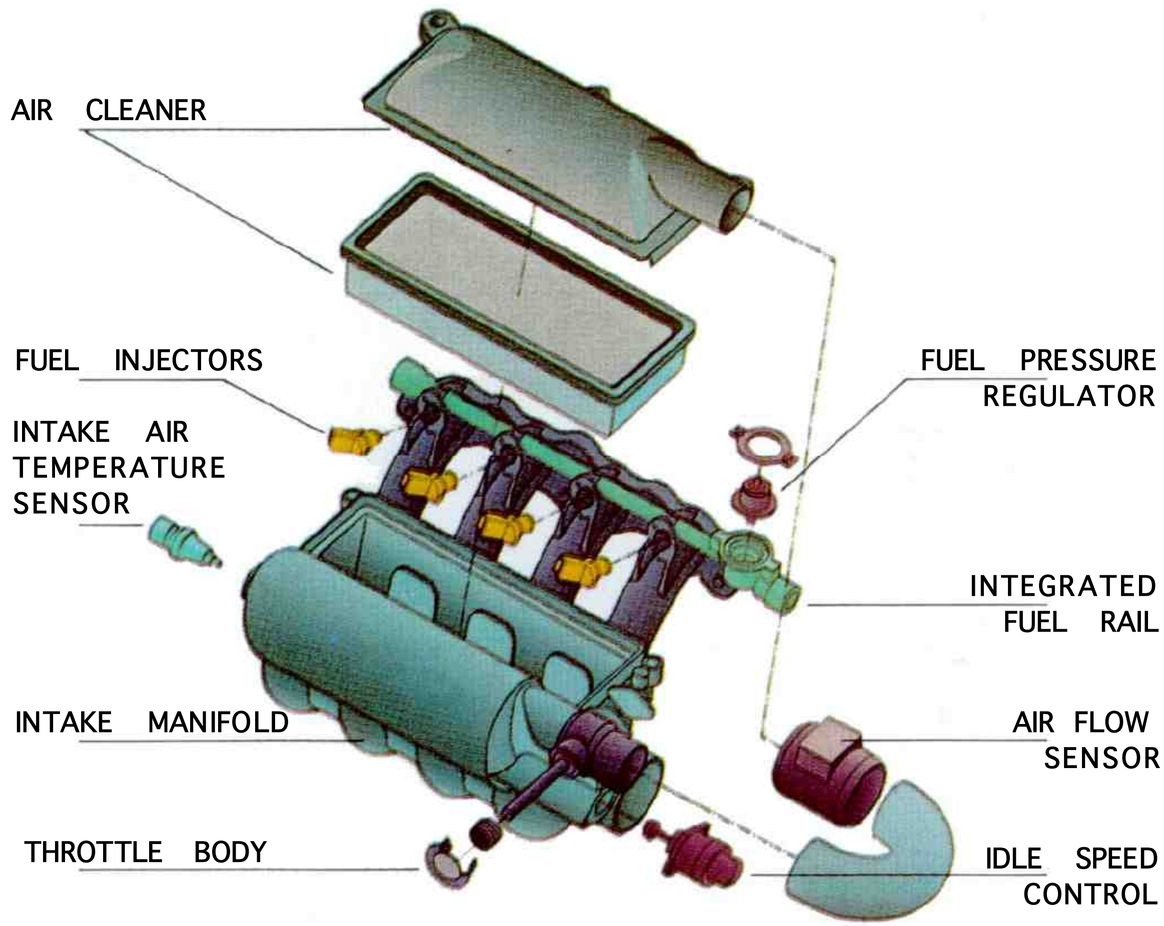
www.aska.co.jp/fasystem/ image/faweld.jpg

www.abb.com/.../ aut+spot+welding+line+150px.jpg

Goals of DFM/DFA

- Historically, conventionally
  - reduce costs, simplify processes
  - improve awareness of manufacturing issues during design
- More broadly
  - align fabrication and assembly methods to larger goals
  - ability to automate, systematize, raise quality, be flexible
  - access to assembly-driven business methods like delayed commitment
  - innovative designs, outsourcing (Siemens intake manifold)
- Inevitably pushes DFM/DFA earlier into the product development process where it blends with architecture

Complete Outsourced Subassembly



Courtesy Siemens VDO

History of DFA

- Deep background in Group Technology
  - classification schemes
- European design tradition
- Value Engineering
  - each part must be justified
- Boothroyd - educated in the UK
  - part feeding physics - 1960s
  - part handling and insertion experiments- 1970's
  - DFA methodology and software - 1970's-80's
- Today, DFA is part of basic product design, materials choice, and communication between engineering and manufacturing

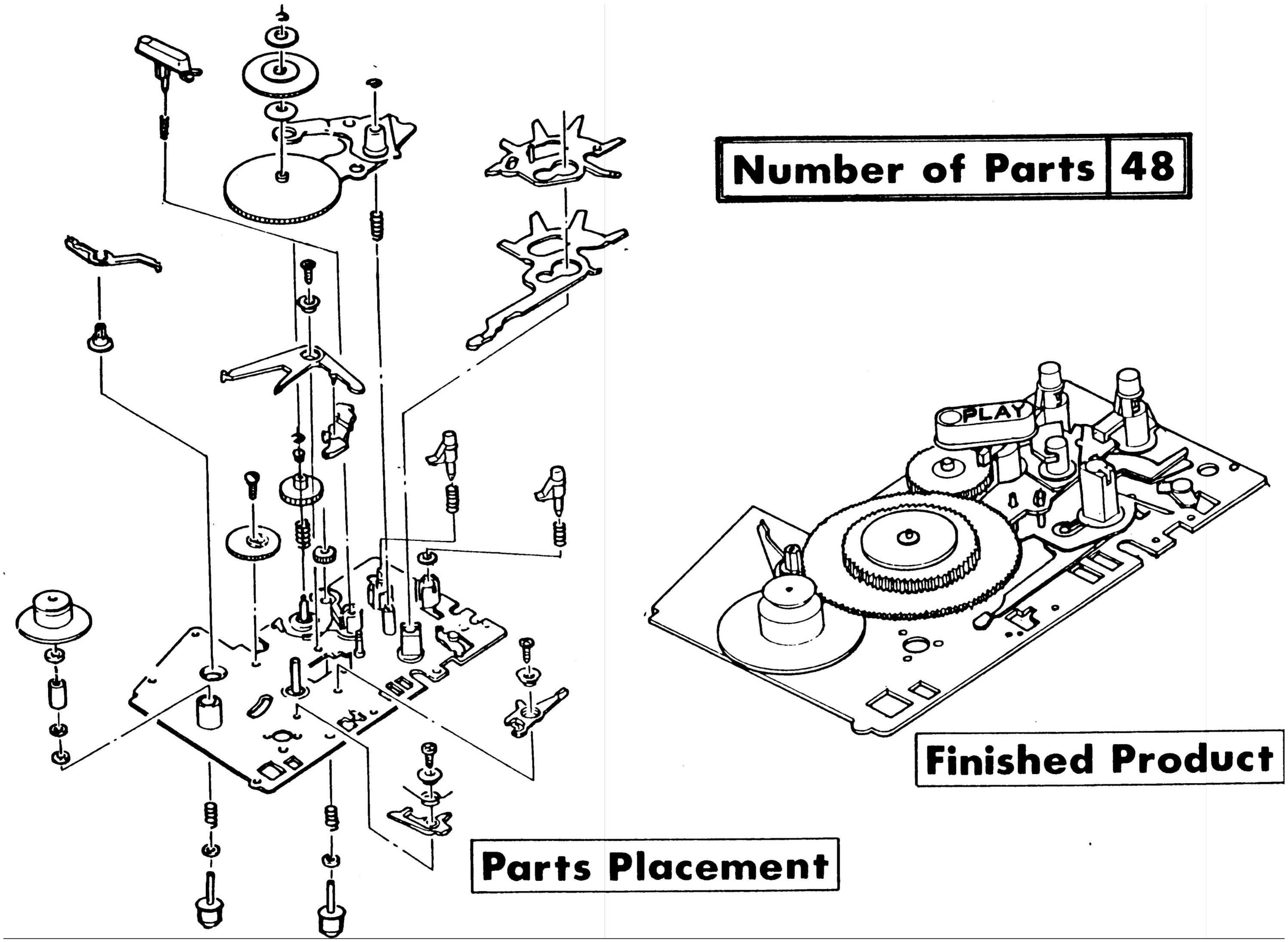
Characteristics of Traditional DFA

- Uses an easy to understand metrics-driven approach
- Uses a *relative* cost and time metric
- Emphasizes part count reduction
- Tends to focus on
  - single parts
  - manual assembly
  - small parts
- Uses many context-free metrics to assess difficulty levels of feeding and handling

Conventional DFA

- The issues are: (Boothroyd except where noted)
  - assembling each part -
    - feeding/presenting
    - handling/carrying/getting into position (Sony exploded views)
    - inserting without damage, collisions, fumbling
  - reducing part count (driven by local economic analysis)
    - two adjacent parts of same material?
    - do they move wrt each other after assembly
    - is disassembly needed later (use, repair, inspection, upgrade...)
    - is the part a main function carrier? (Fujitsu, Lucas, (Pahl & Beitz))
    - if not, consider combining them (but this affects architecture)
    - are there too many fasteners?
  - identifying cost drivers (Denso)

Sony Exploded View



How to Do DFA

- Make a structured bill of materials
- Identify every part mate and understand it
- Choose a reasonable assembly sequence
- Use the tables to estimate handling and mating times
- Label theoretically necessary parts, *excluding* all fasteners
- Calculate

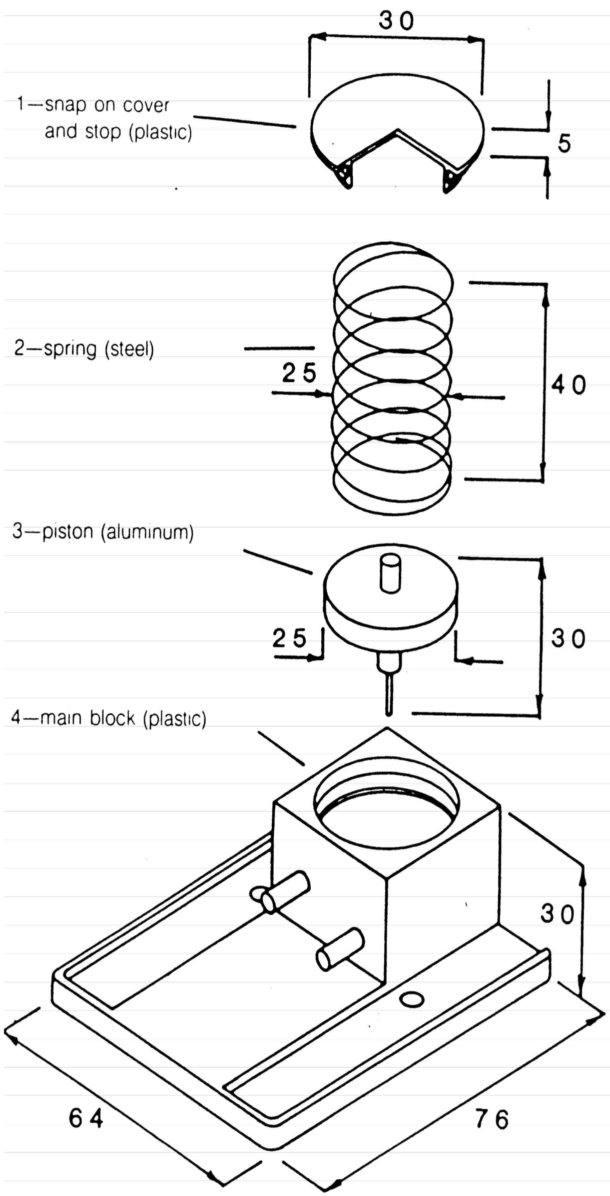
$$assembly\ \ efficiency = \frac{3*\ \#\ \ of\ \ theoretically\ \ needed\ \ parts}{total\ \ predicted\ \ assemby\ \ time}$$

- This ranges from 5% for kludges to 30% for good designs

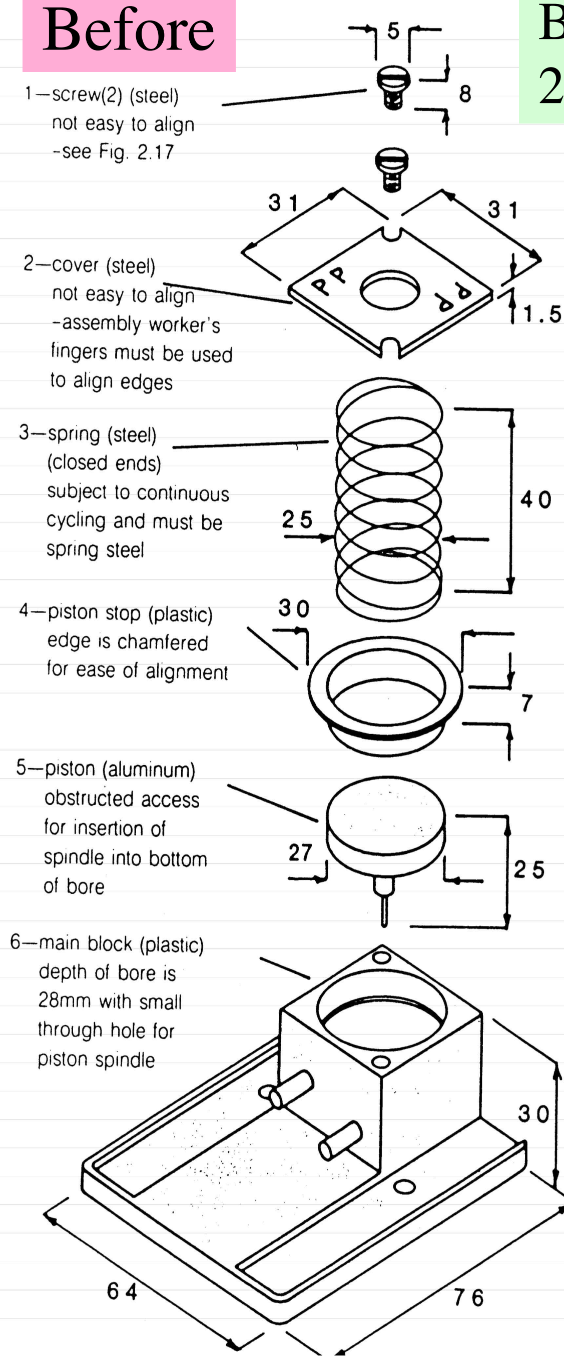
B&D Pump Redesign

Bore * stroke = 25*17

After



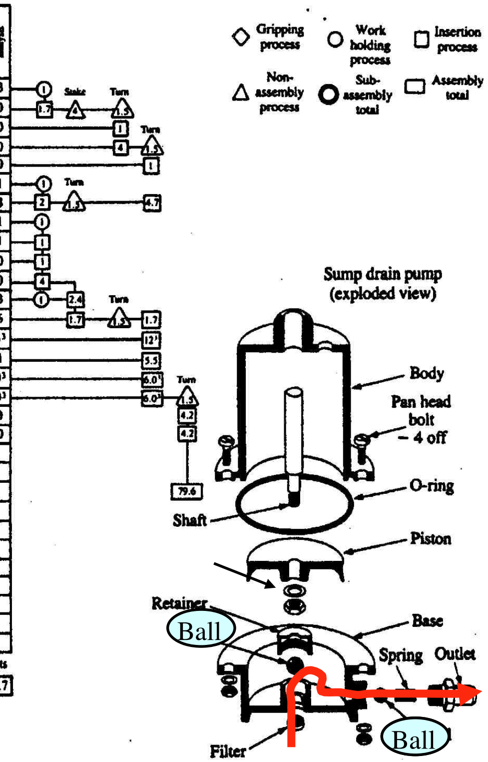
Before

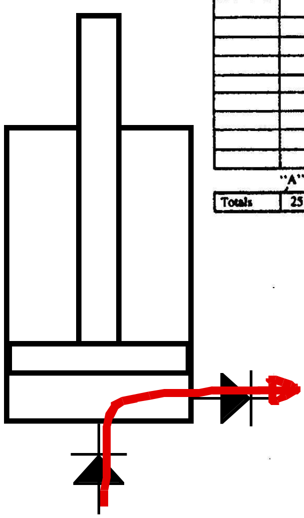


Bore * stroke = 27*20

Redford-Chal Pump Redesign

Component description	Component number	Functional analysis	Feeding analysis
Base	1	A	1.3
Filter	2	B	1.0
Ball	3	A	1.0
Retainer	4	B	1.0
Ball	5	A	1.0
Outlet	6	B	1.1
Spring	7	B	1.8
Shaft	8	B	1.1
Piston	9	A	1.1
Washer	10	B	1.0
Nut	11	B	1.0
Body	12	B	1.3
O-ring	13	B	1.6
Bolt	14 abc	B^3	3.3^3
Bolt	14d	B	1.1
Washer	15 abc	B^3	3.0^3
Nut	16 abc	B^3	3.0^3
Washer	15d	B	1.0
Nut	16d	B	1.0
Totals	25	4 ("A" components)	27.7





Design efficiency = $\frac{\text{"A" components } 4}{\text{total components } 25}$ × 100 per cent = 16 per cent

Feeding/handling ratio = $\frac{\text{Index total } 27.7}{\text{"A" components } 4}$ = 6.9

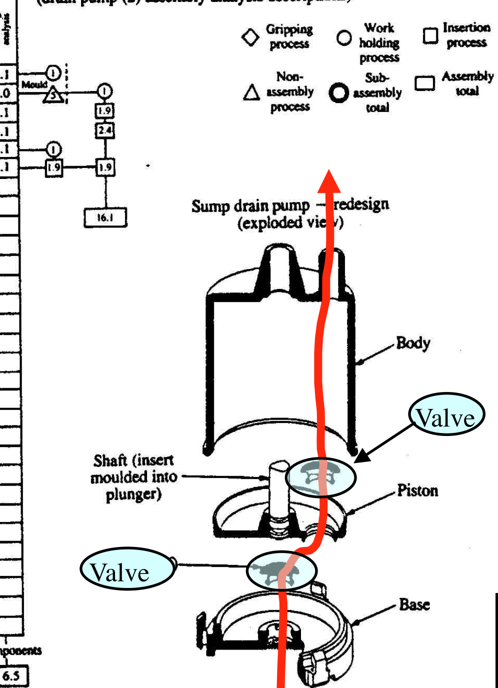
Fitting ratio = $\frac{\text{Grip + fit + fix } 79.6}{\text{"A" components } 4}$ = 19.9

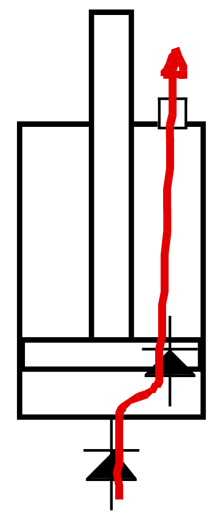
	Drain pump assembly analysis	Drawing no.

Figure 8.5 Lucas method—assembly sequence flow-chart example

Design for assembly analysis chart (drain pump (2) assembly analysis descriptions)

Component description	Component number	Functional analysis	Feeding analysis
Shaft	1	B	1.1
Piston	2	A	1.0
Valve	3a	A	1.1
Body	4	A	1.1
Base	5	B	1.1
Valve	3b	A	1.1
Totals	6	4 ("A" components)	6.5





Design efficiency = $\frac{\text{"A" components } 4}{\text{total components } 6}$ × 100 per cent = 66.7 per cent

Feeding/handling ratio = $\frac{\text{Index total } 6.5}{\text{"A" components } 4}$ = 1.63

Fitting ratio = $\frac{\text{Grip + fit + fix } 16.1}{\text{"A" components } 4}$ = 4.0

Drawn:	Drain pump (2) assembly analysis	Drawing no.
Date:		

Figure 8.6 Lucas method—redesigned example

Boothroyd-Dewhurst Handling Times

Cover piston spring

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key: ONE HAND

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

ONE HAND with GRASPING AIDS

parts can be grasped and manipulated by one hand but only with the use of grasping tools		parts need tweezers for grasping and manipulation; parts can be manipulated without optical magnification; parts are easy to grasp and manipulate: thickness >0.25 mm	thickness ≤0.25 mm	parts present handling difficulties (1): thickness >0.25 mm	thickness ≤0.25 mm	parts require optical magnification for manipulation; parts are easy to grasp and manipulate: thickness >0.25 mm	thickness ≤0.25 mm	parts present handling difficulties (1): thickness >0.25 mm	thickness ≤0.25 mm	parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		0	1	2	3	4	5	6	7	8	9
α ≤ 180°, 0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°, β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°, 0 ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°, β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties: α ≤ 180°, size > 15 mm	α ≤ 180°, 6 mm ≤ size ≤ 15 mm	α ≤ 180°, size < 6 mm	α = 360°, size > 6 mm	α = 360°, size ≤ 6 mm	parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1): α ≤ 180°, size > 15 mm	α ≤ 180°, 6 mm ≤ size ≤ 15 mm	α ≤ 180°, size < 6 mm	α = 360°, size > 6 mm	α = 360°, size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance; parts do not severely nest or tangle and are not flexible; part weight < 10 lb; parts are easy to grasp and manipulate: α≤180°	α=360°	parts present other handling difficulties (1): α≤180°	α=360°	parts are heavy (> 10 lb); parts are easy to grasp and manipulate: α≤180°	α=360°	parts present other handling difficulties (1): α≤180°	α=360°	parts severely nest or tangle or are flexible (2)	parts need special tools for grasping and manipulation
		0	1	2	3	4	5	6	7	8	9
two hands required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

CHART 2-1

Boothroyd-Dewhurst Insertion Times

MANUAL INSERTION—ESTIMATED TIMES (seconds)

piston

spring

Key:

PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

CHART 2-2

2-27

DFA Spreadsheet

- On class website there is a folder called DFA Software
- In it is DFA05.xls with the handling and insertion data from the previous two slides
- Enter your code numbers and labor rate ($/sec) and the sheet will calculate times and costs

DFA Spreadsheet

DFA05.xls DFA05.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Cost/hour	Cost per sec		Type cost per hour in cell A2														
2	$10.00	$0.00278			Type handling codes in column E						Type insertion codes in column K							
3	Boothroyd-Dewhurst Data ©				If you type a nonexistent code, the value will be #N/A													
4	Used in book by permission				Don't change values in yellow cells											Repeated this		
5	Handling	Code	Time, sec		Part handling codes		Part handling times			Handling Cost	Part Insertion codes		Part insertion times		Insertion Cost	many times	Total time	Total cost
6		-1	0		0		1.13			$0.0031	1		3		$0.0083	2	8.26	$0.0229
7		0	1.13		71		#N/A			#N/A	11		5.2		$0.0144	1	#N/A	#N/A
8		1	1.43		11		1.8			$0.0050	10		3.7		$0.0103	1	5.5	$0.0153
9		2	1.69		15		3			$0.0083	11		5.2		$0.0144	1	8.2	$0.0228
10		3	1.84		11		1.8			$0.0050	11		5.2		$0.0144	1	7	$0.0194
11		4	2.17		0		1.13			$0.0031	33		#N/A		#N/A	1	#N/A	#N/A
12		5	2.45		-1		0				-1		0			1	0	$0.0000
13		10	1.5		-1		0				60		5.2			1	5.2	$0.0144
14		11	1.8		-1		0				-1		0			1	0	$0.0000
15		12	2.06		-1		0				-1		0			1	0	$0.0000
16		13	2.25		-1		0				-1		0			1	0	$0.0000
17		14	2.57		-1		0				-1		0			1	0	$0.0000
18		15	3		-1		0				-1		0			1	0	$0.0000
19		20	1.8		-1		0				-1		0			1	0	$0.0000
20		21	2.1		-1		0				-1		0			1	0	$0.0000
21		22	2.36		-1		0				-1		0			1	0	$0.0000
22		23	2.57		-1		0				-1		0			1	0	$0.0000
23		24	2.9		-1		0				-1		0			1	0	$0.0000
24		25	3.18		-1		0				-1		0			1	0	$0.0000
25		30	1.95		-1		0				-1		0			1	0	$0.0000
26		31	2.25		-1		0				-1		0			1	0	$0.0000
27		32	2.51		-1		0				-1		0			1	0	$0.0000
28		33	2.73		-1		0				-1		0			1	0	$0.0000
29		34	3.06		-1		0				-1		0			1	0	$0.0000
30		35	3.34		-1		0				-1		0			1	0	$0.0000
31		40	4.1		-1		0				-1		0			1	0	$0.0000
32		41	4.5		-1		0				-1		0			1	0	$0.0000
33		42	5.6														Total time	Total cost
34							#N/A			#N/A			#N/A		#N/A	28	#N/A	#N/A
35																		
36	Insertion	Code	Time, sec															
37		-1	0															
38		0	1.5															
39		1	3															
40		2	2.6															
41		3	5.2															
42		4	1.8															
43		5	3.3															

Takeaways

- Assembly is the place where the product comes to life
- Assembly reaches from the factory floor to the executive suite
- Assembly reaches from the bottom to the top of the supply chain and beyond to the distribution chain