

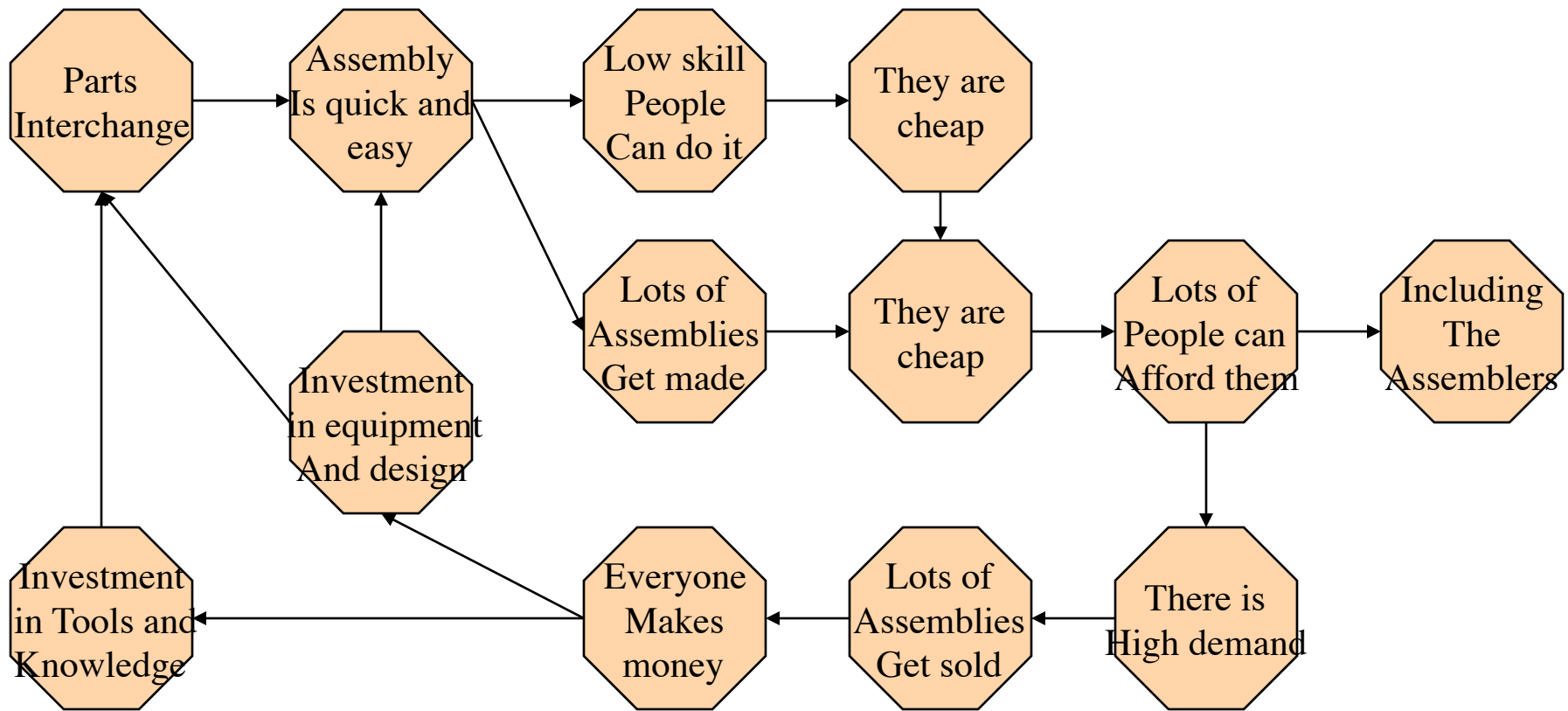
Mechanical Assembly

- Goals of this class:
 - Explain the basics of assembly as a manufacturing process
 - Show some examples
 - Explain Design for Assembly
- Not included: (take 2.875)
 - 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

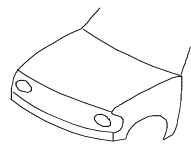


Technical Aspects

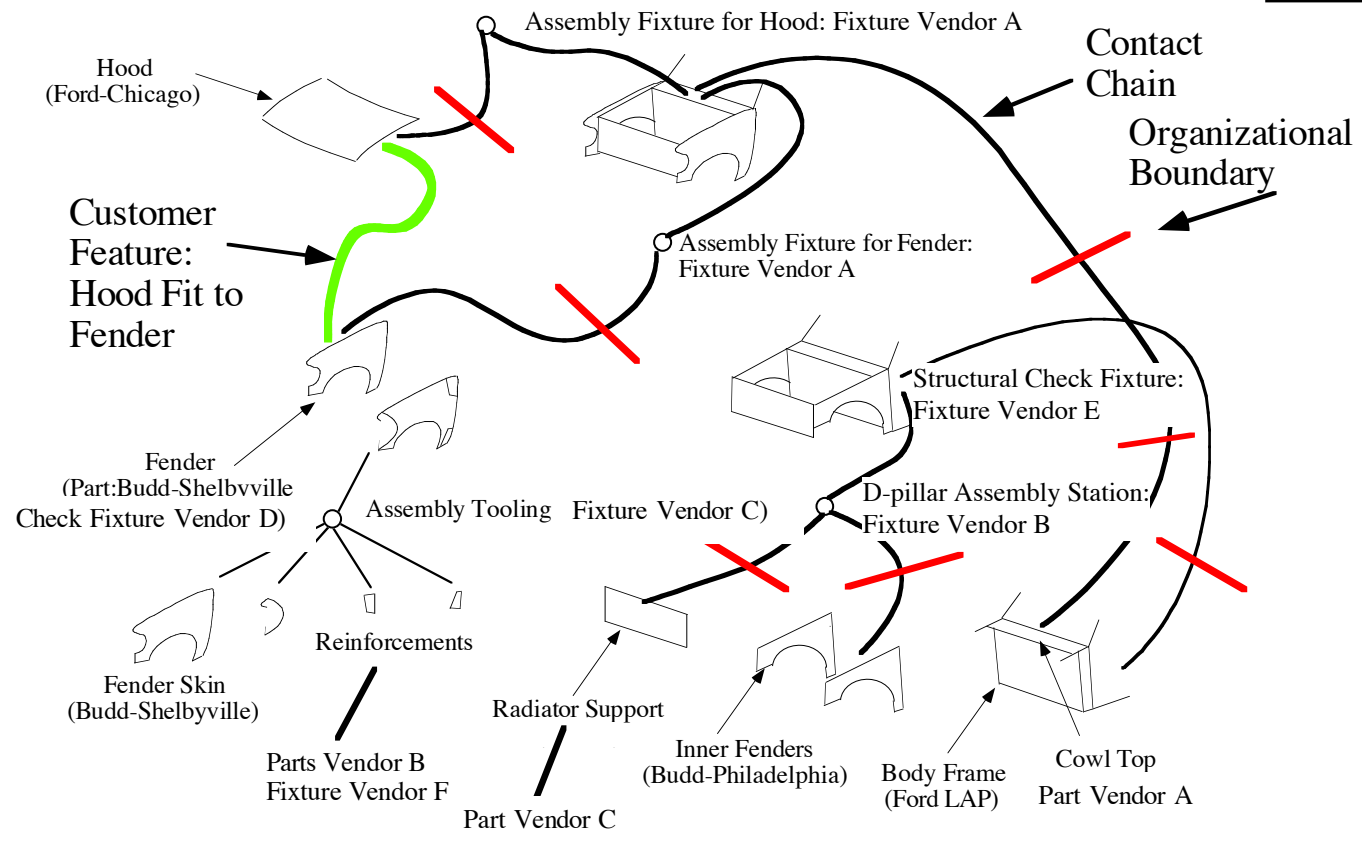
- Assembly creates product functions or sub-functions
- Results of assembly can be tested
 - Results of fabrication can be inspected but not tested
- Assembly requires coordination of many parts, tools, fixtures, packages, people, companies
- Assembly step times are short compared to manufacturing process 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%



Closure Panel Check Fixture: Fixture Vendor G



N. Soman, M. Chang

More Technical Aspects of Assembly

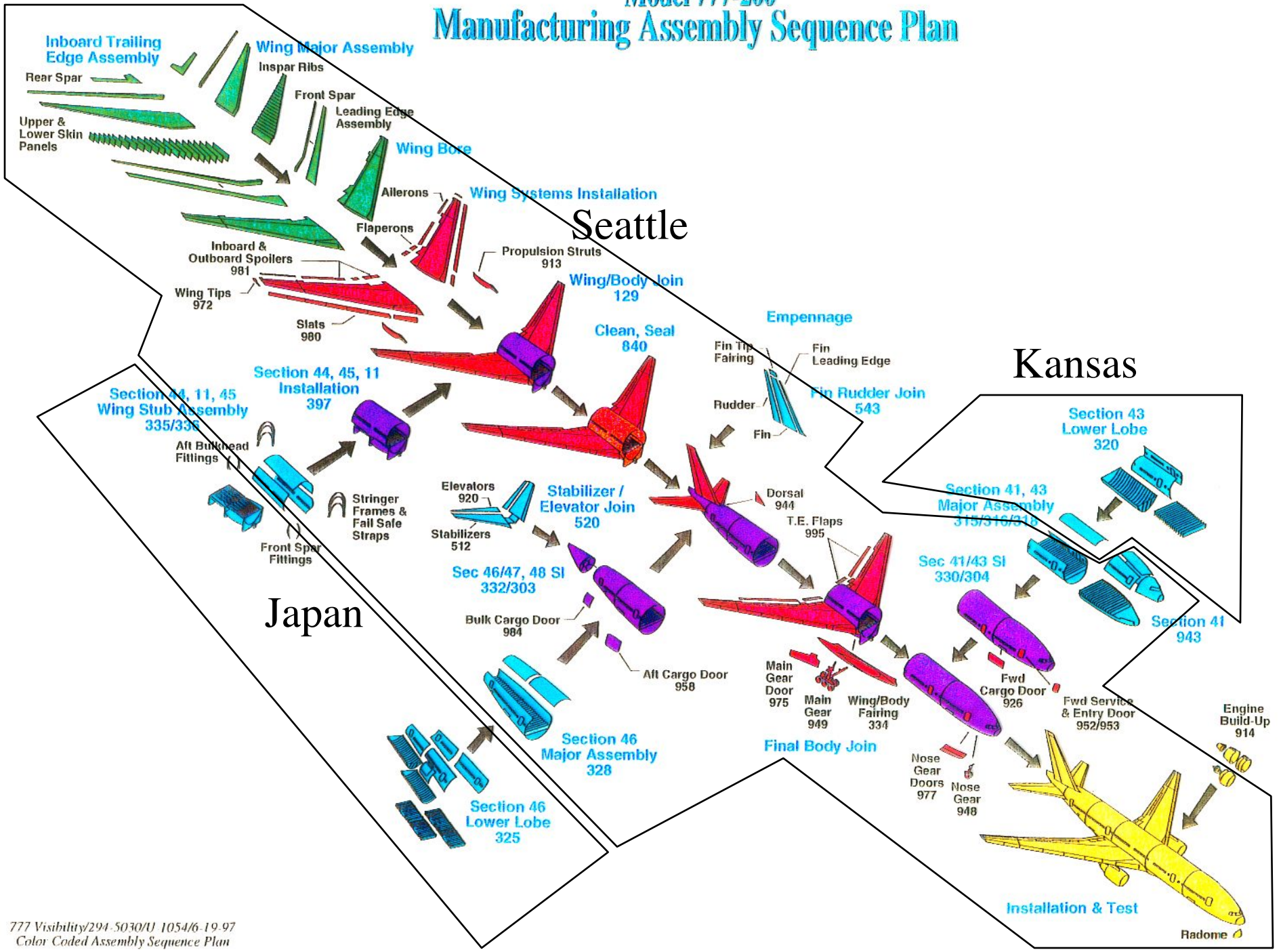
- Three methods are used
 - Manual (always involved for large items; almost always involved for small items)
 - Specialized equipment (used only for small items made in high volumes - units/year in the millions)
 - Robots (used for small and medium sized items)
- Low volume ~ big items: planes, ships
- 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

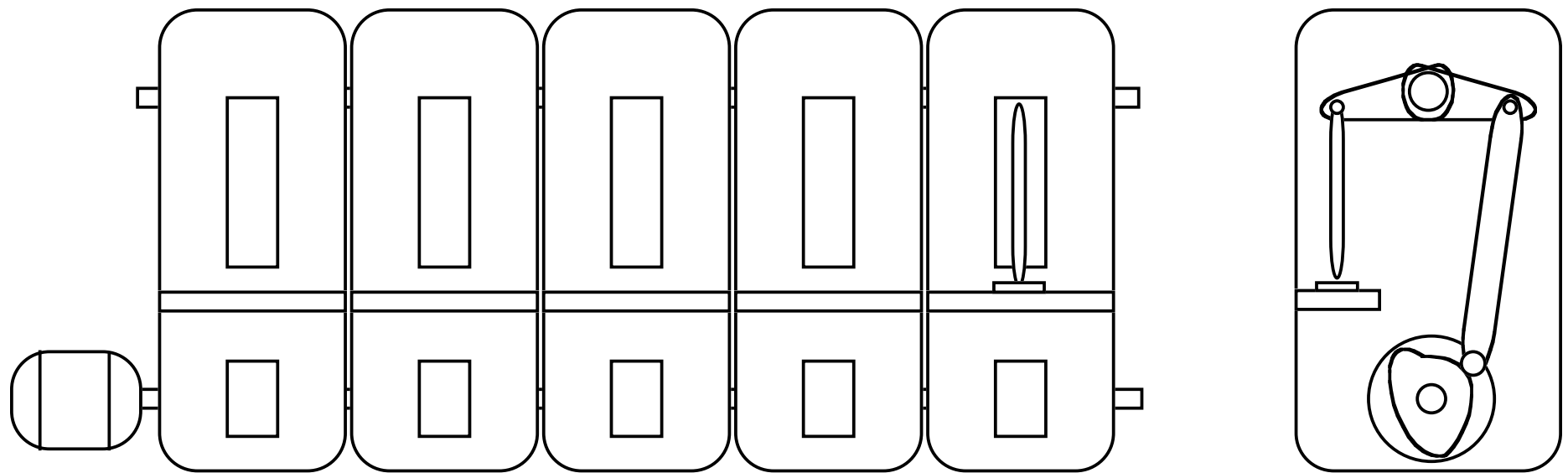
Seattle

Kansas

Japan



Typical Cam-operated Assembly Machine

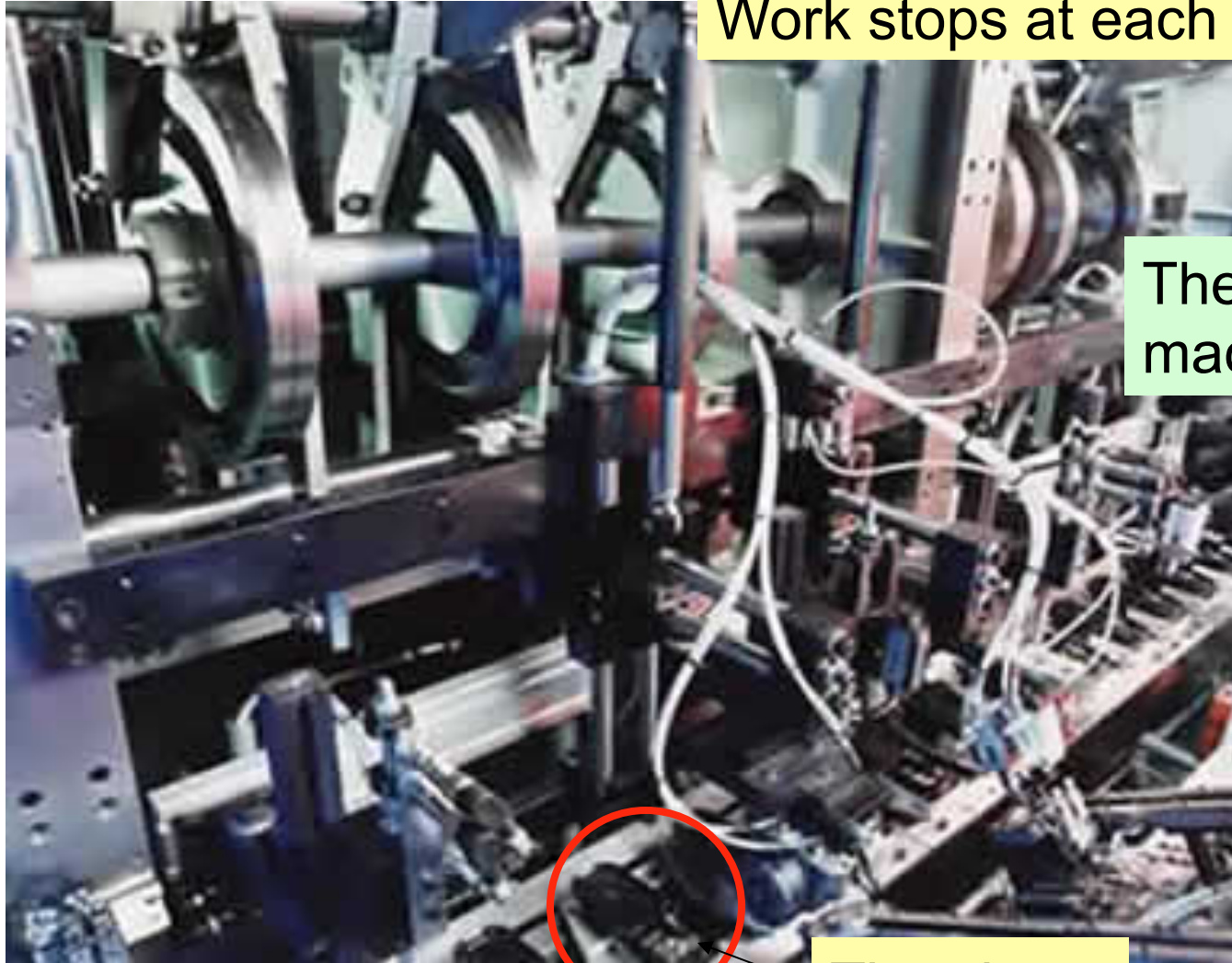


Multiple identical base modules bolted together as needed
Cams cut by NC to do the necessary operations

Synchronous parts transport

Cell Phone Assembly Machine

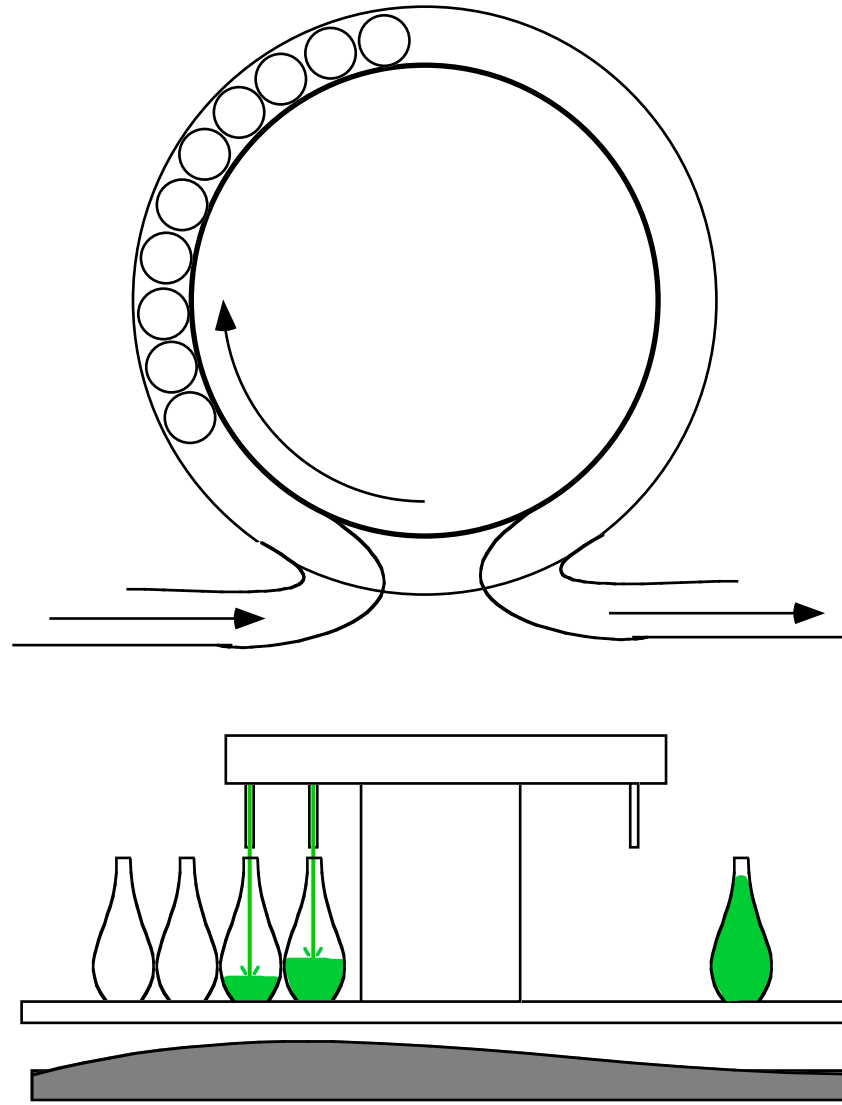
Work stops at each workstation



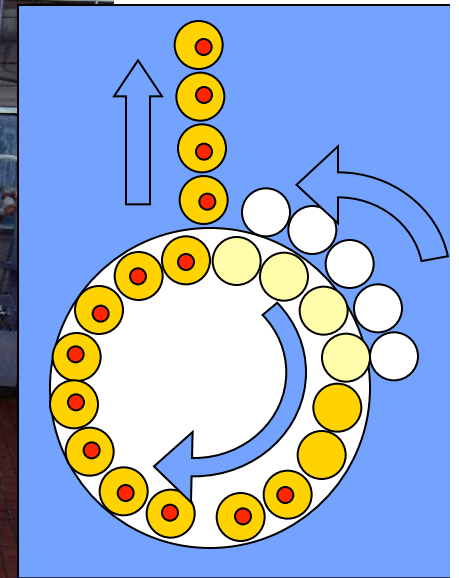
The machine

The phone

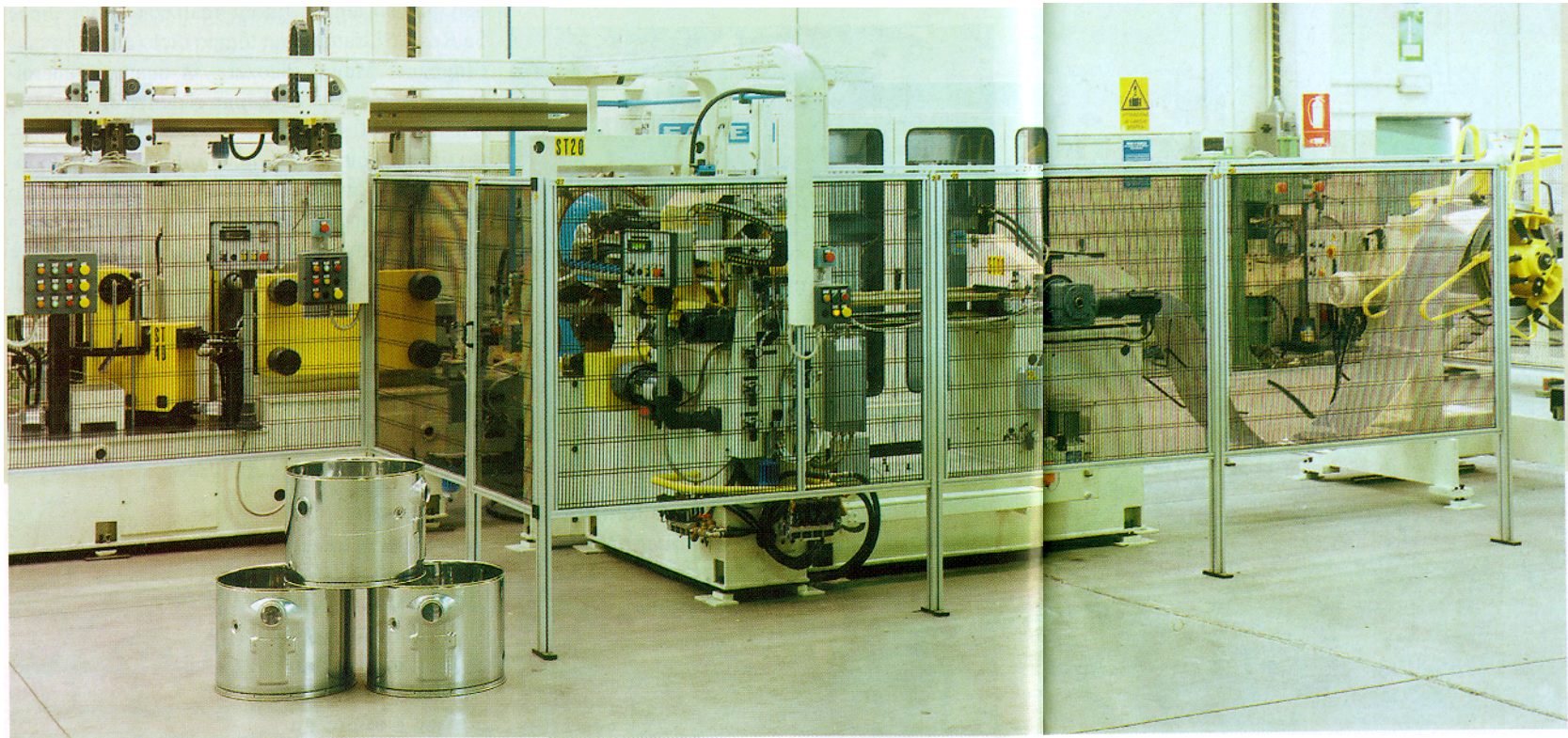
Typical Dial Machine



Bottle Filling Machine



Machine Makes Washer Tubs



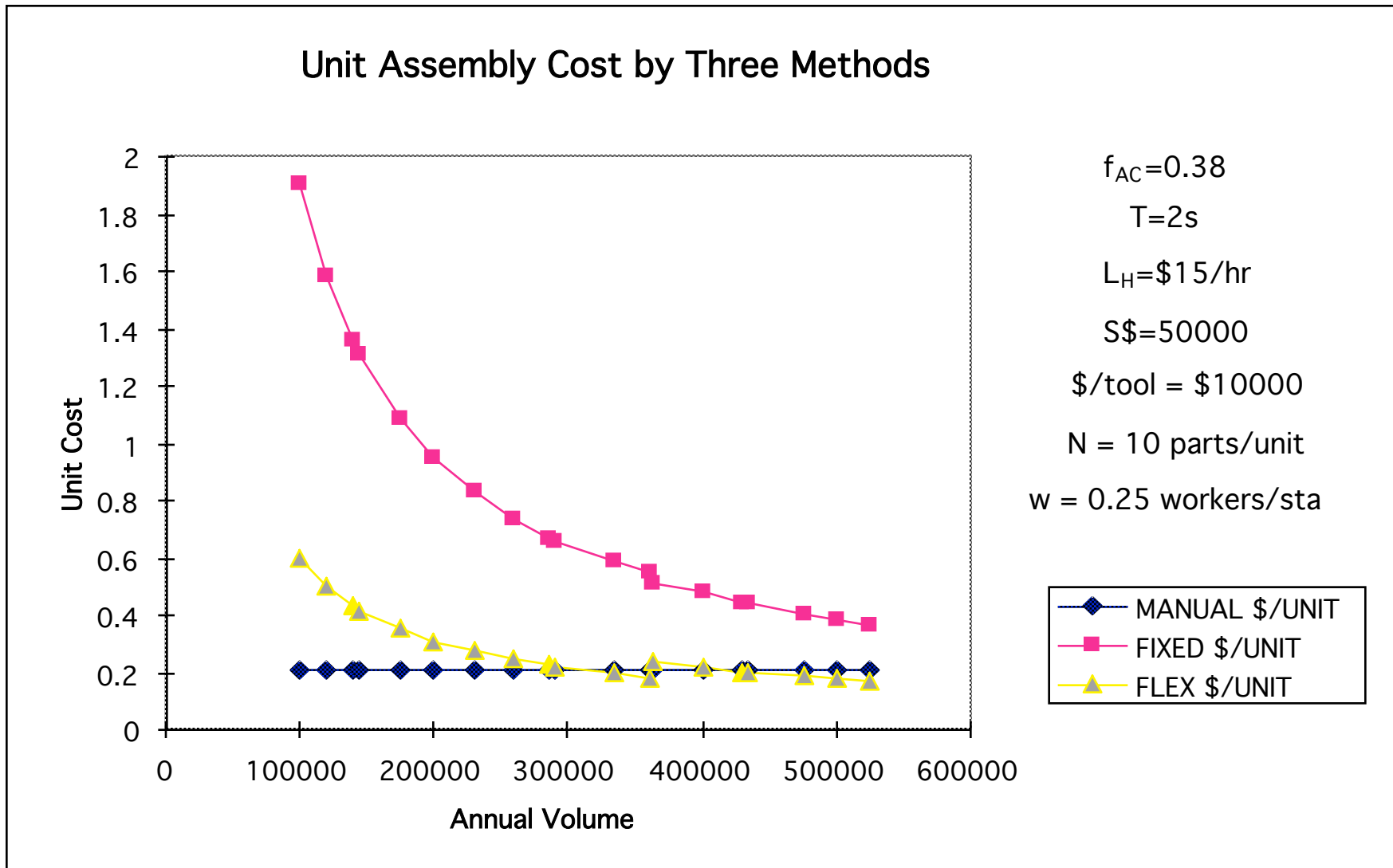
Typical Small Parts Assembly Machine



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

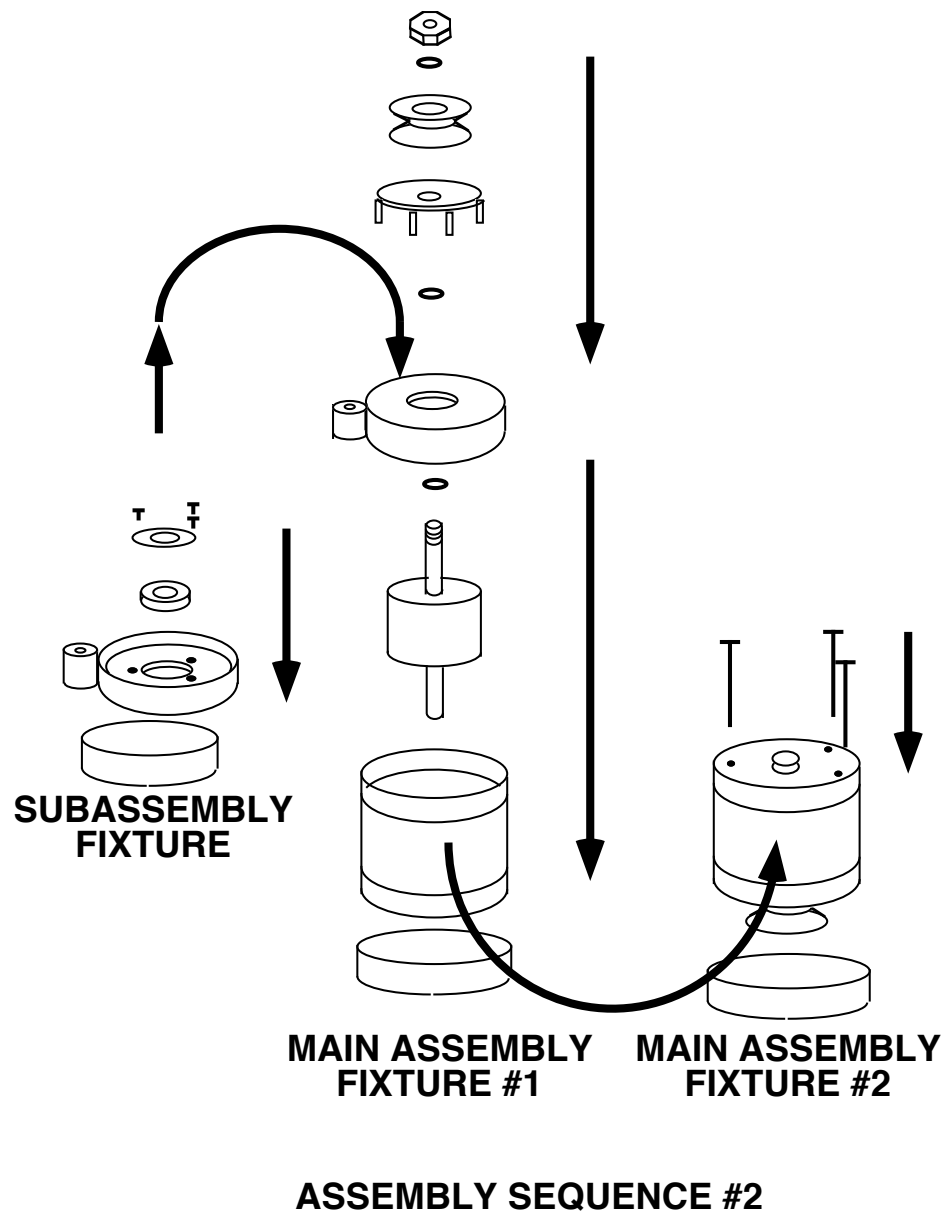
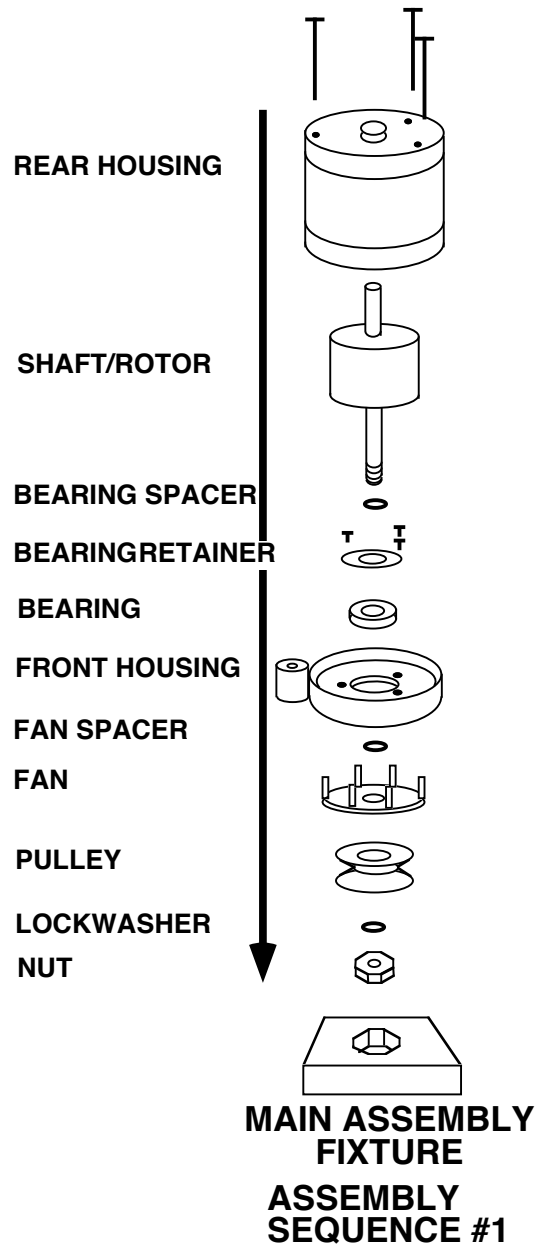
Operational Aspects - Line Balancing

- 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”

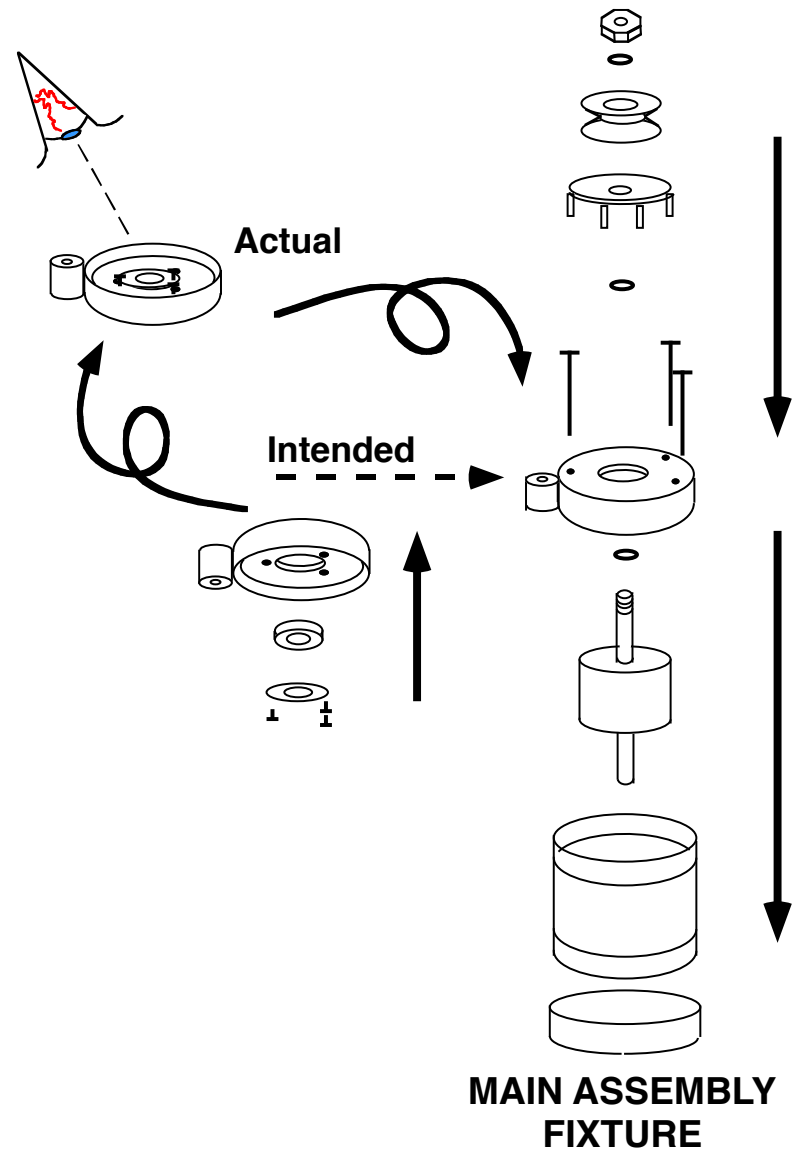
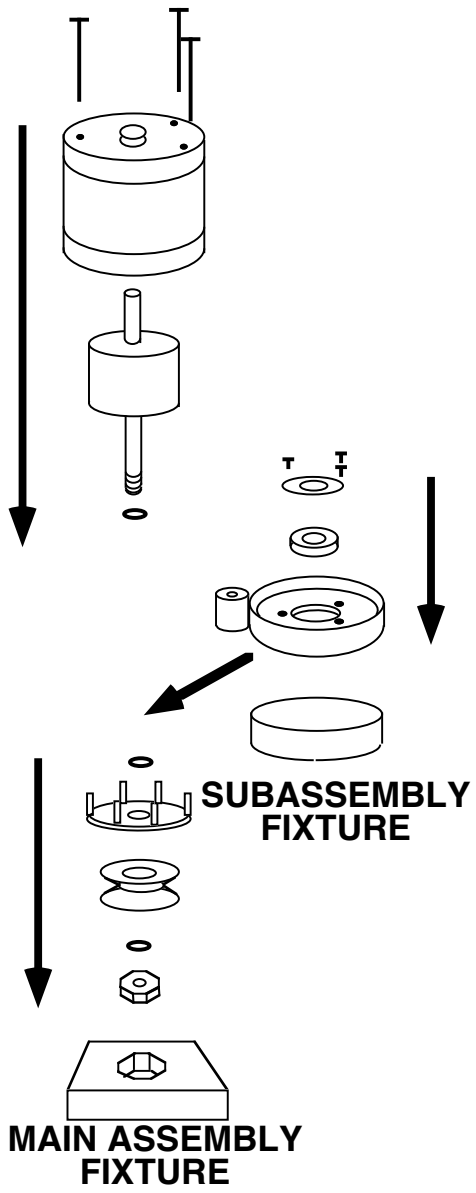
Assembly Sequence Options

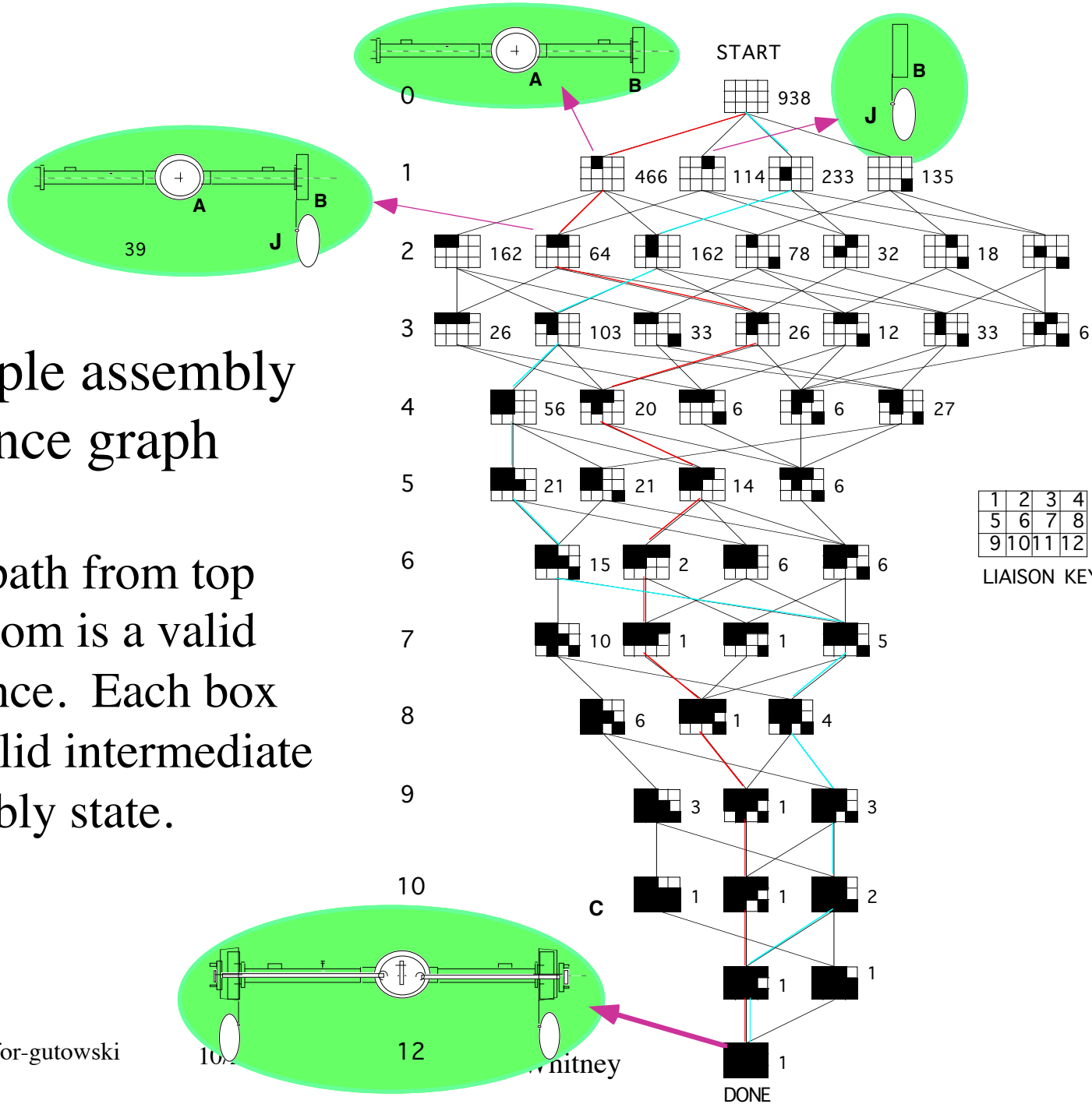
- Typical products have hundreds or thousands of feasible assembly sequences
- Different sequences enable options for
 - Line balancing
 - In-line repair
 - Equipment feasibility
 - Human performance and fatigue
 - Product quality

Two Alternator Sequences



Two More Alternator Sequences





Example assembly sequence graph

Each path from top to bottom is a valid sequence. Each box is a valid intermediate assembly state.

Architecture Aspects

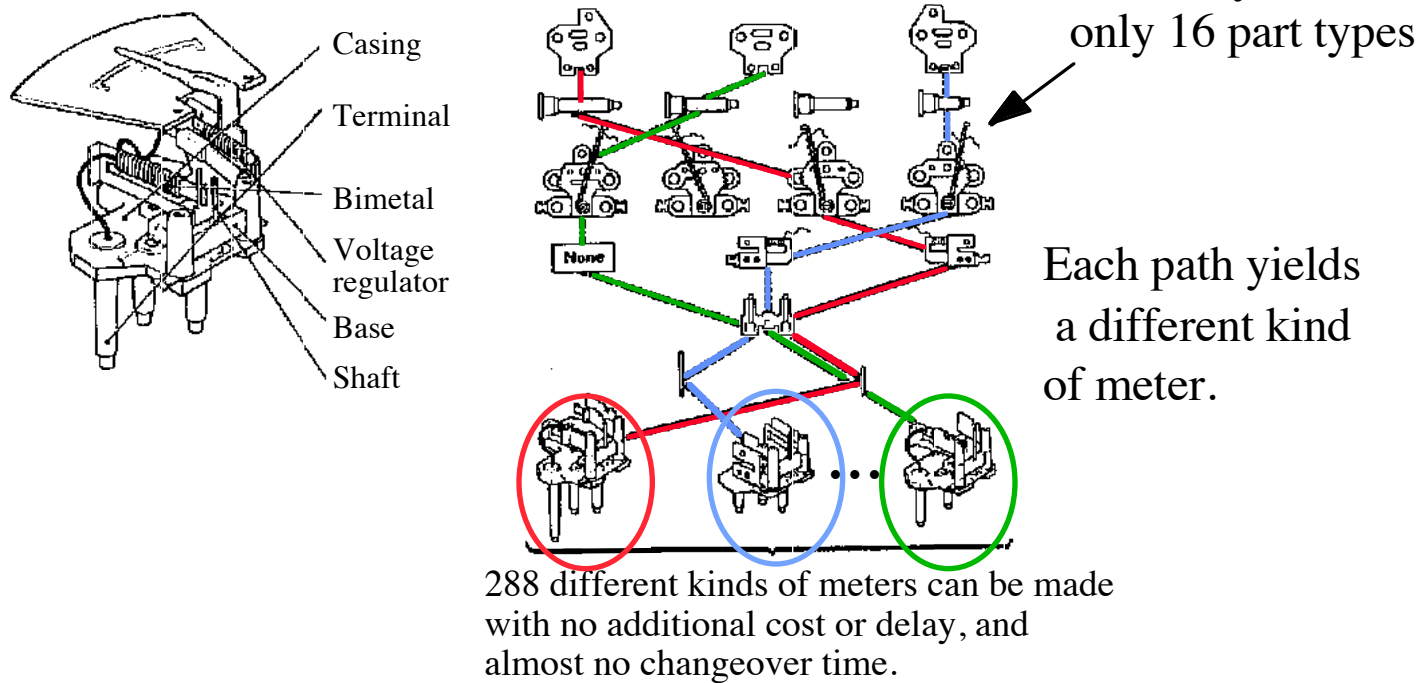
- Architecture is the definition and arrangement of the parts with respect to the product's functions
- Architecture affects
 - Definition of subassemblies
 - Assembly sequence options
 - Testing options
 - Customization and just-in-time operations
 - Design for assembly

Model Mix, Customization, and Changeover Happen During Assembly

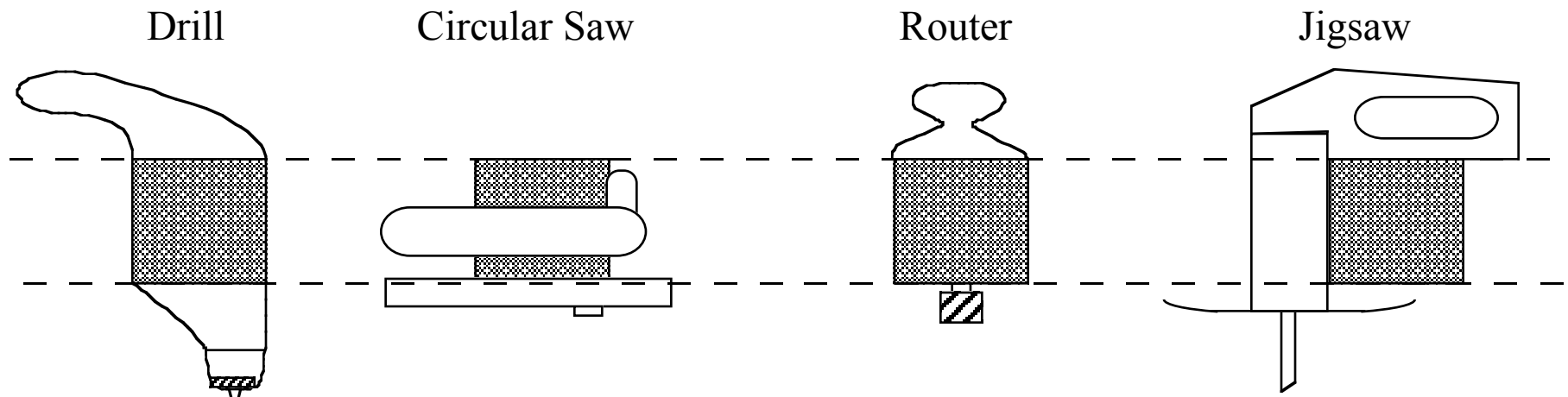
- Marketing wants them in 30 colors while manufacturing wants them all to be white
- “Decoupling point” is the last point where the product is the same for everyone
 - Can be at the beginning of assembly
 - Can be during assembly
 - Can be at a distribution point or with the user
- How much variety to 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.’



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

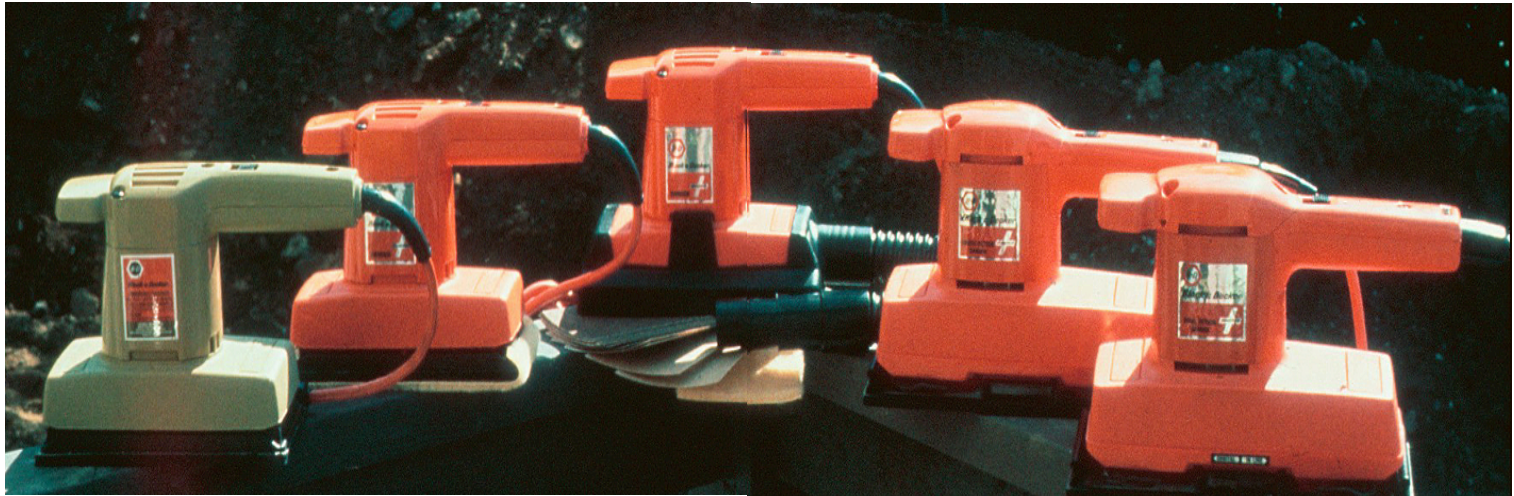


Photo courtesy of Albert Lenherd and James Utterback

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

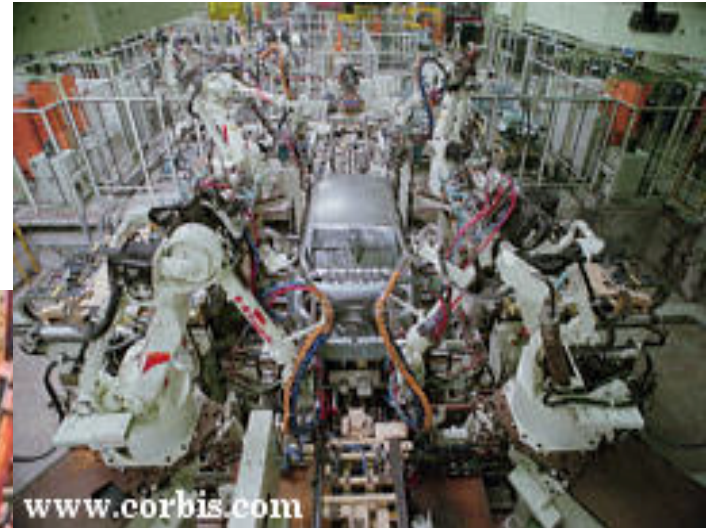
- Manual assembly work is boring due to short takt time
 - “I’ m retiring tomorrow after 30 years. I’ m going to the end of the line to see what we make here.”
- Repetitive strain injuries are possible
- Mistakes are more likely than injuries
 - Wrong part (when there is model mix)
 - Part installed 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

Assy-for-gutowski

1

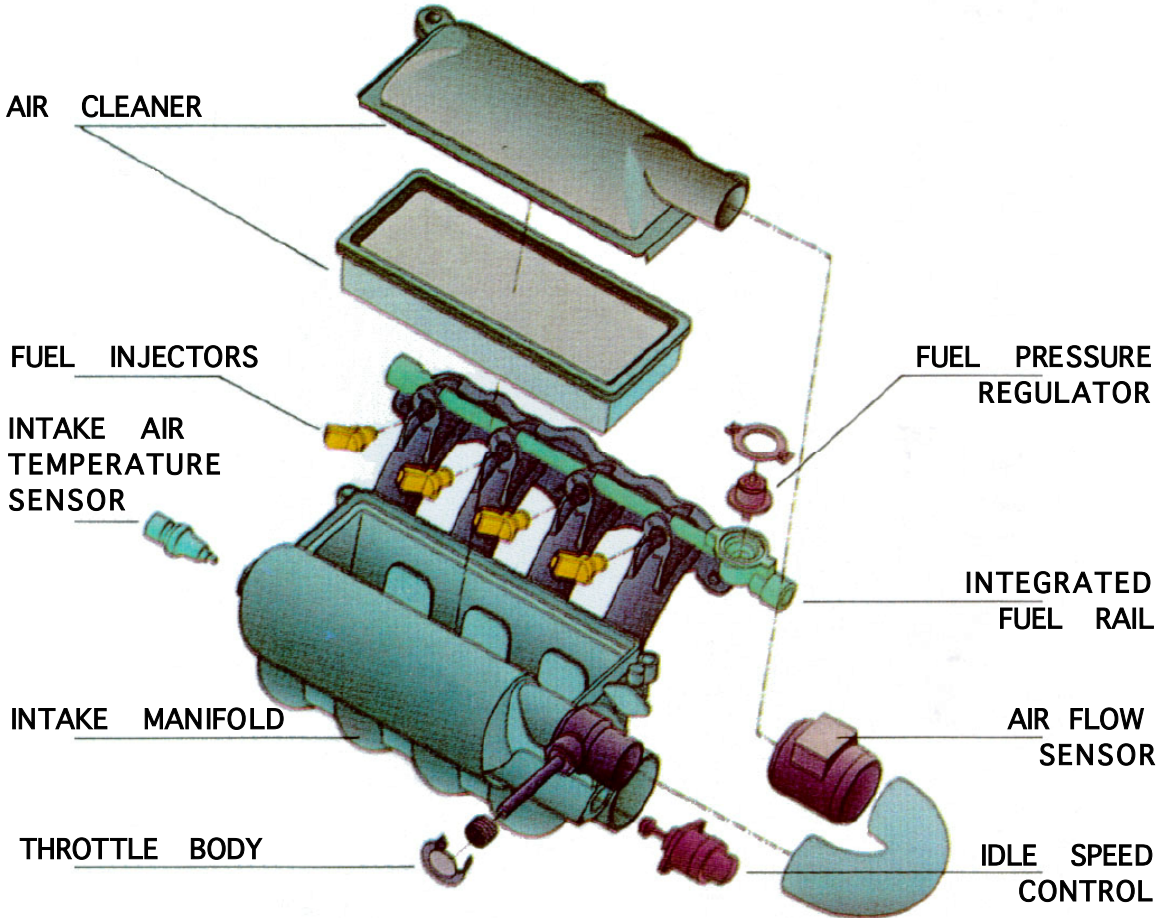
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Goals of DFM/DFA

- Historically, conventionally
 - reduce costs, simplify processes
 - improve awareness of manufacturing issues during design
- More broadly (relevant to 2.875)
 - 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

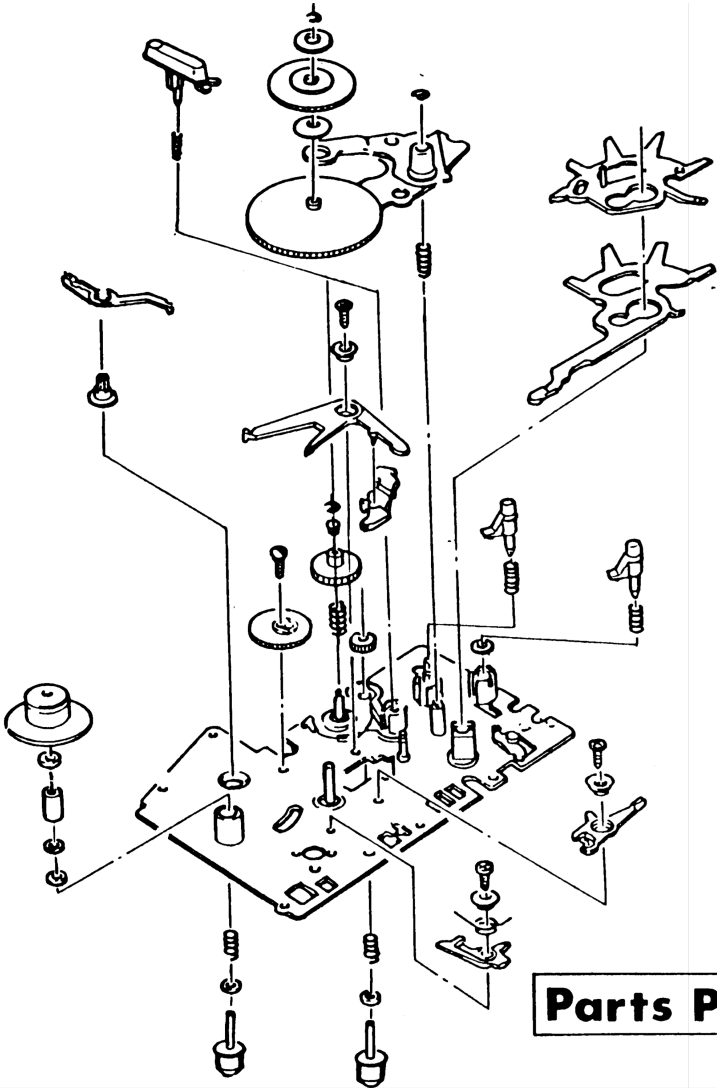
Characteristics of Traditional DFA

- Uses an easy to understand metrics-driven approach (metrics story about dunnage)
- 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

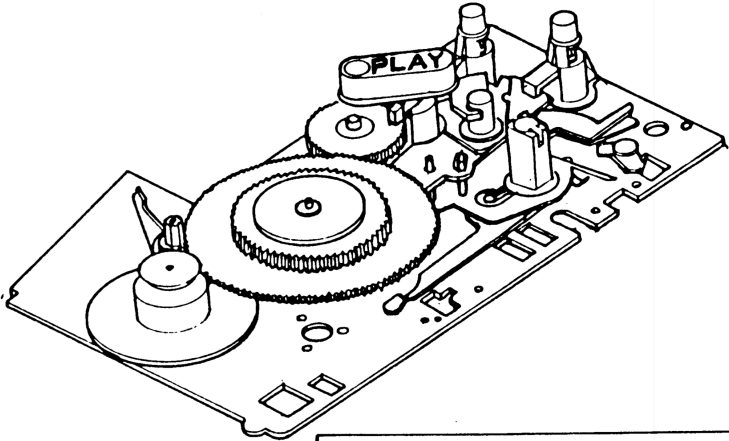
Conventional DFA

- 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



Number of Parts 48



Finished Product

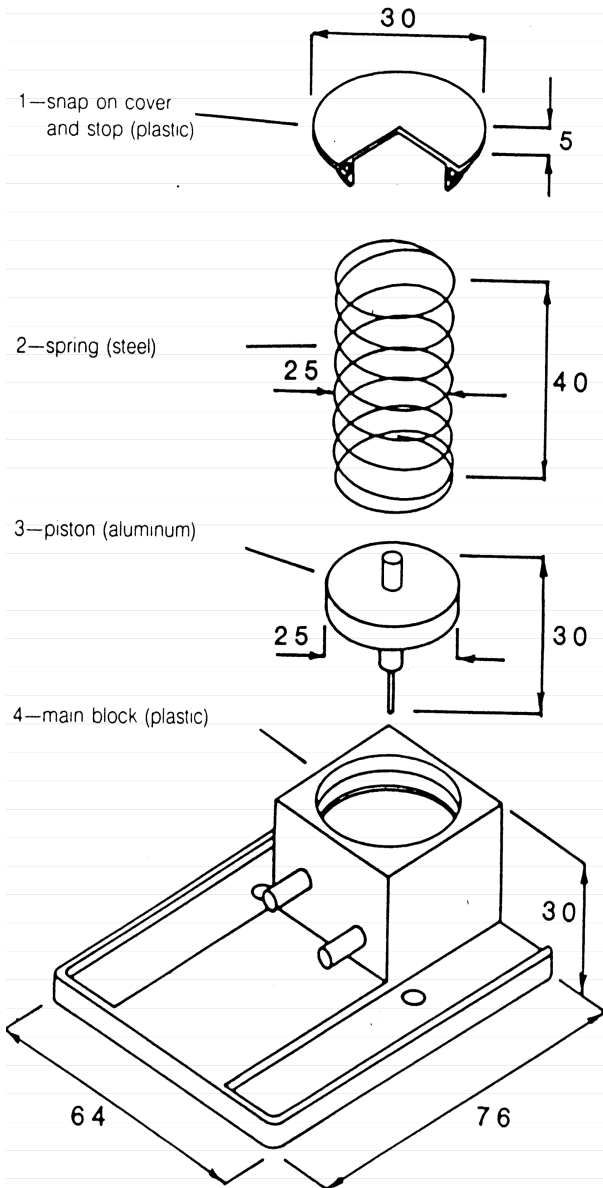
Parts Placement

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
$$\text{assembly efficiency} = \frac{3 * \# \text{ of theoretically needed parts}}{\text{total predicted assembly time}}$$
- This ranges from 5% for kludges to 30% for good designs

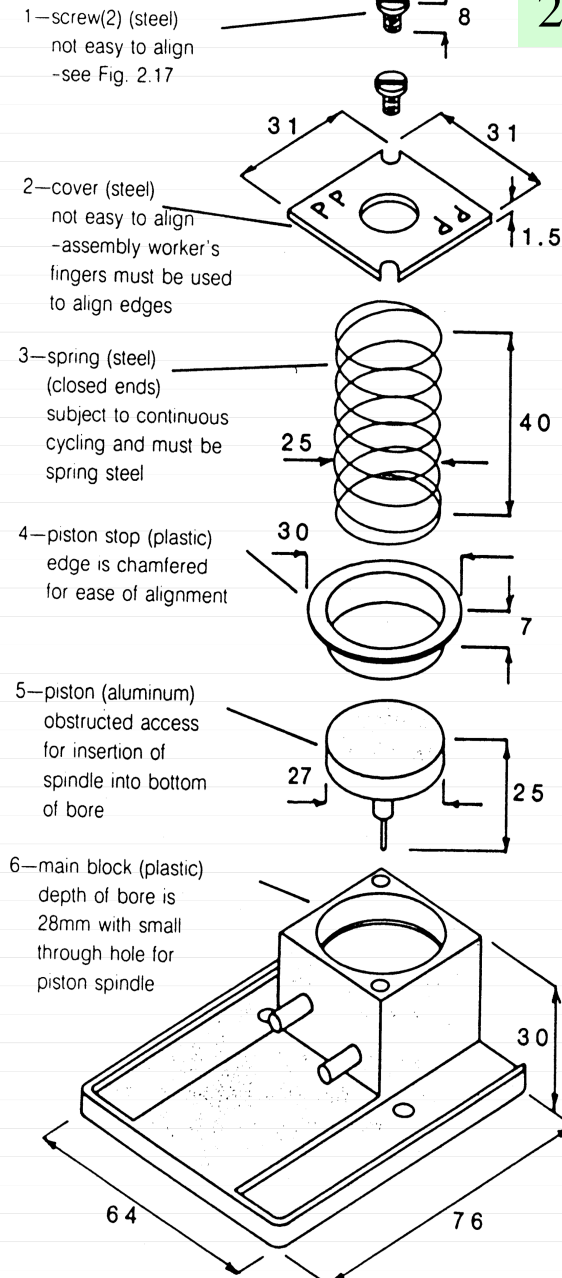
Bore * stroke =
25*17

After



Before

Bore * stroke =
27*20



B&D Pump Redesign

The Water Pump Redesign

- What are the differences between the old and new designs?
 - from the POV of product function
 - from the POV of assembly
- What are we looking at in this example?

Redford-Chal Pump Redesign

118 DESIGN FOR ASSEMBLY

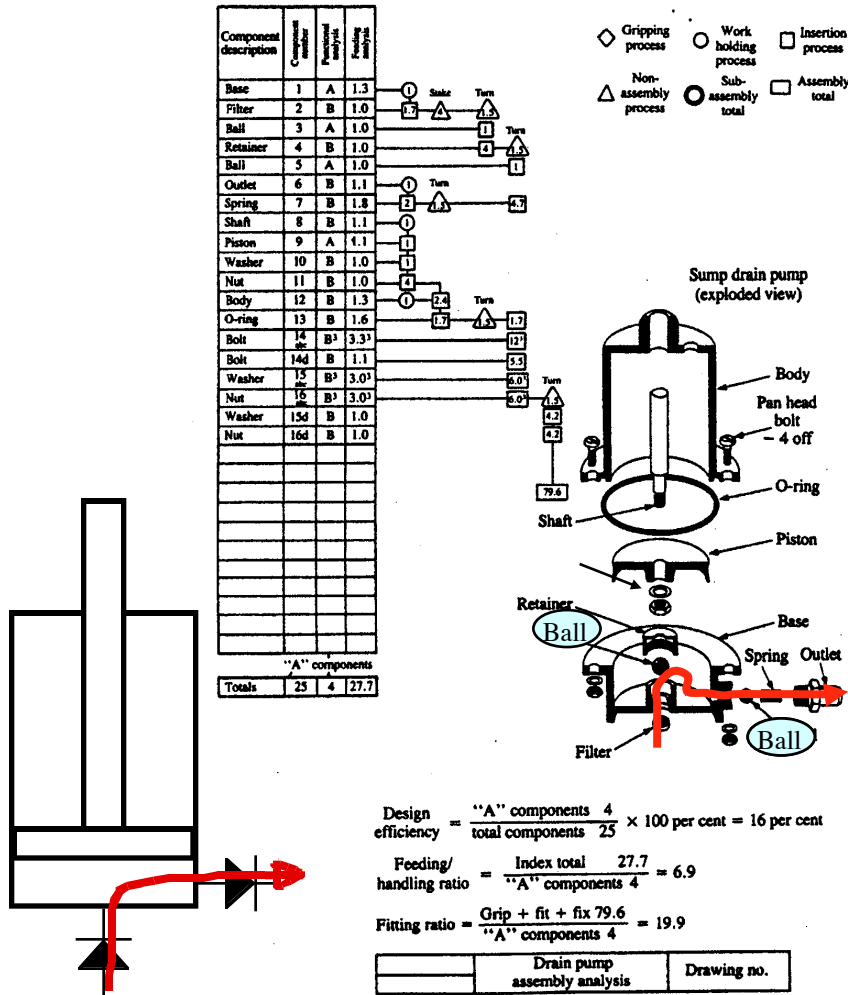


Figure 8.5 Lucas method—assembly sequence flow-chart example

THE LUCAS DFA EVALUATION METHOD 119

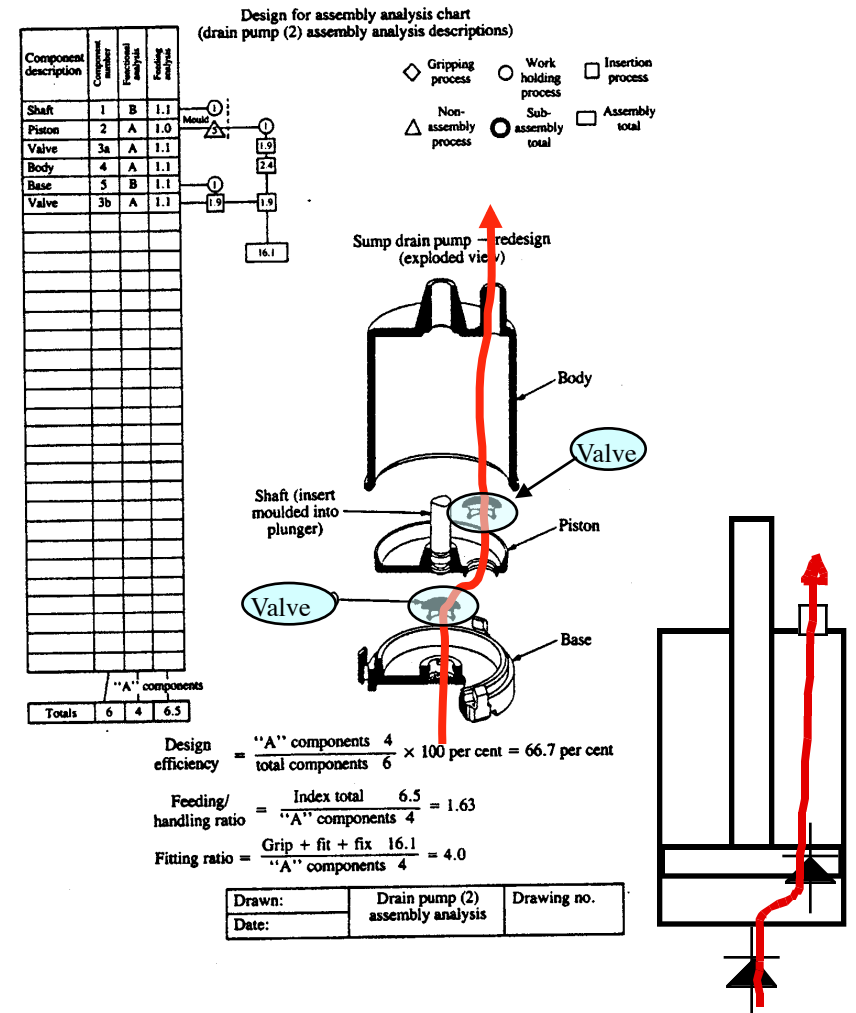


Figure 8.6 Lucas method—redesigned example

Cover

spring

2

Piston

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	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 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	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.96
$(\alpha + \beta) < 360^\circ$	1	1.5	1.8	2.15	2.06	2.55	2.25	2.57	3.06	3	3.38
$360^\circ \leq (\alpha + \beta) < 540^\circ$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$540^\circ \leq (\alpha + \beta) < 720^\circ$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4
$(\alpha + \beta) = 720^\circ$											

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

	parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)					
	$\alpha \leq 180^\circ$		$\alpha = 360^\circ$			$\alpha \leq 180^\circ$		$\alpha = 360^\circ$			
	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	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

	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 heavy (> 10 lb)					
	parts are easy to grasp and manipulate		parts present other handling difficulties (1)			parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	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

ONE HAND with GRASPING AIDS

TWO HANDS for MANIPULATION

TWO HANDS required for LARGE SIZE

Boothroyd-Dewhurst Handling Times

Assy-for

MANUAL INSERTION — ESTIMATED TIMES (seconds)

Piston

Spring

Key:
 PART ADDED but NOT SECURED

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
		1	4	5	5	6	8	9	9	10
		2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

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	part and associated tool (including hands) cannot easily reach the desired location or tool cannot be operated easily	due to obstructed access or restricted vision (2)	due to obstructed access and restricted vision (2)	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 (5)	
					easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly (5)	plastic bending or torsion		rivetting or similar operation		easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
							easy to align and position during assembly (4)	not easy to align or position during assembly (4)	easy to align and position during assembly (4)	not easy to align or position during assembly (4)		
0	1	2	3	4	5	6	7	8	9	6	8	
3	2	5	4	5	6	7	8	9	9	10	11	
4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10	10.5	
5	6	9	8	9	10	11	12	13	10	11	12	

PART SECURED IMMEDIATELY

assembly processes where all solid parts are in place	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				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.)
	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.)	additional material required	weld/braze processes				
0	1	2	3	4	5	6	7	8	9		
9	4	7	5	3.5	7	8	12	12	9	1.2	

SEPARATE OPERATION

Boothroyd-Dewhurst
 Insertion Times

Assy-for-

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

	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 non-existent code, the value will be #N/A														
4	Used in book by permission			Don't change values in yellow cells														
5	Handling	Code	Time, sec	Part handling codes		Part handling times		Handling Cost	Part Insertion codes		Part insertion times		Insertion Cost	Repeated this 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	-1	0			-1	0		1	0	\$0.0000					
34						#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