Assemblies and Assembling

Dan Whitney

What Limits Rate of Assembling?

- Cost
  - People, machines
- Speed
  - Basic rate, errors
- Complexity
  - Different versions of the product
  - Difficult assembly operations
- Flexibility
  - Different versions of the product

Legostack, Inc.

- How fast can a stack of 10 Legos be built?
- What happens as we try to go faster?
- Relate to what happens in metal cutting when we try to go faster
- Volunteer employees will make some for us.

Main Kinds of Errors

- Use the wrong part
- Use a bad part
- Use the correct part but install it incorrectly so that the product does not work or will fail (sooner)
- Damage the part or the assembly while putting the part in

Some Things to Notice

- Learning effect
- Fatigue
- Adopting best practices
- Value of preparing in advance
- Women are generally more dexterous than men

Basic Arithmetic of Assembly

- Production rate r = # of units finished per unit time
- Takt time t = time interval between finished units
  - Same as residence time in each station of a serial line; then it is the same as the station time
  - Station time = work time + in/out time
- Assembly happens very fast: time to move work in and out of a workstation can be a big percentage of the whole cycle
- Your factory needs a production rate ≥ demand rate

Typical Takt Times

- Automatic assembly machine or robot working with small parts: 3 - 5 seconds
- Person working with small parts: 5 - 10 seconds
- Person or robot working with big parts like car windshields or wheels: 60 seconds
- In general, small things are made in large quantities and short takt times while large things (made of many small things) are made in small quantities and long takt times
- Think of cigarettes and aircraft carriers

Effect of Errors

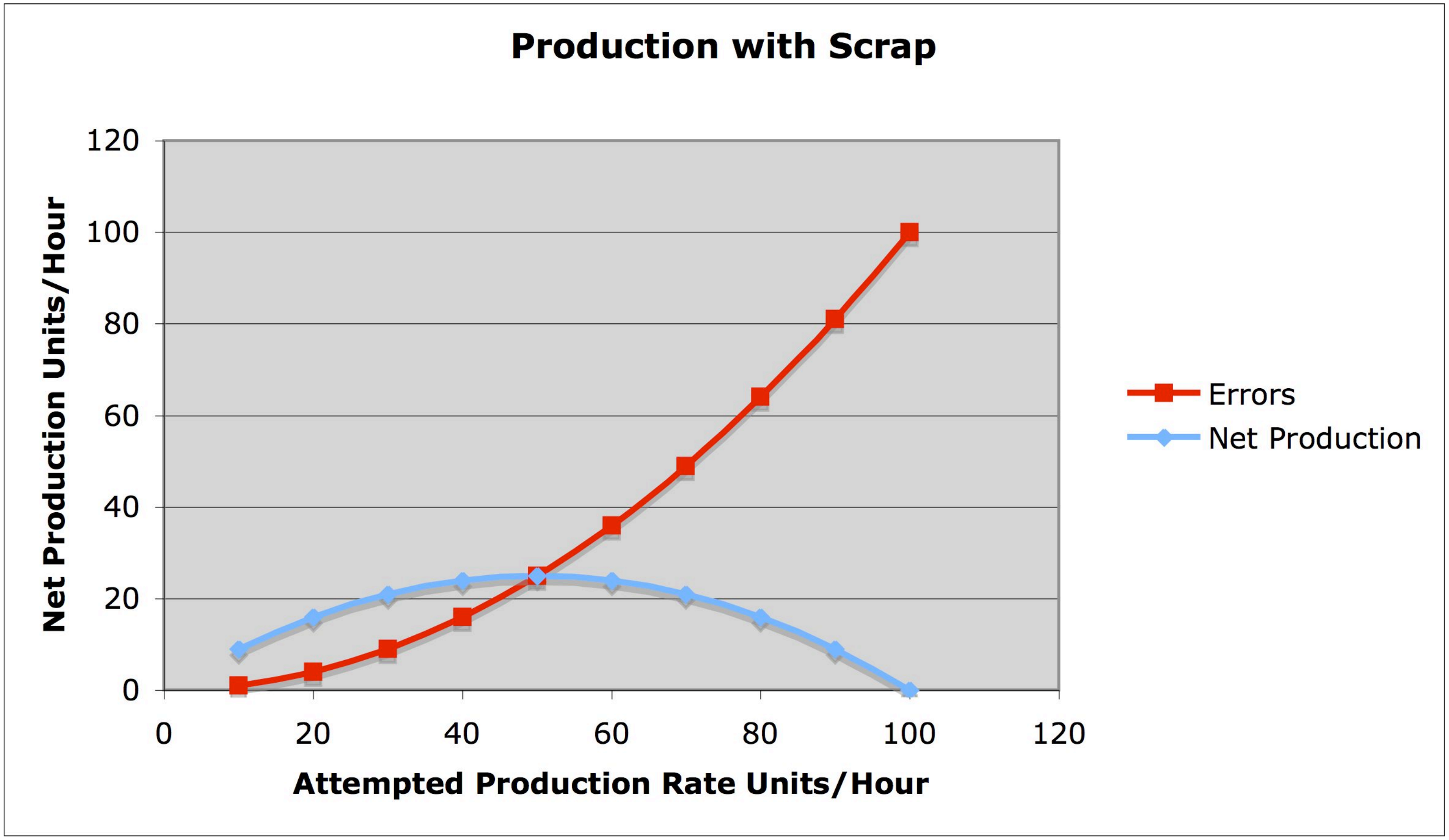
- Production rate = r assemblies per unit time
- Error rate = e scrap assemblies per unit time
- Net production rate = r - e good assemblies/unit time
- Let $e = a\, r^{k}$
- Let $a = 0.01$, $k = 2$
- What is max r? What is best r?
- Max r occurs when $r = e$ or $r = 100$ but $net = 0$
- Best r occurs when $net = r - e$ is max

$$net = r - e$$

$$\text{max } net : \frac{dnet}{dr} = 0 = \frac{d}{dr}\left[r - ar^{k}\right] = 1 - kar^{k-1}$$

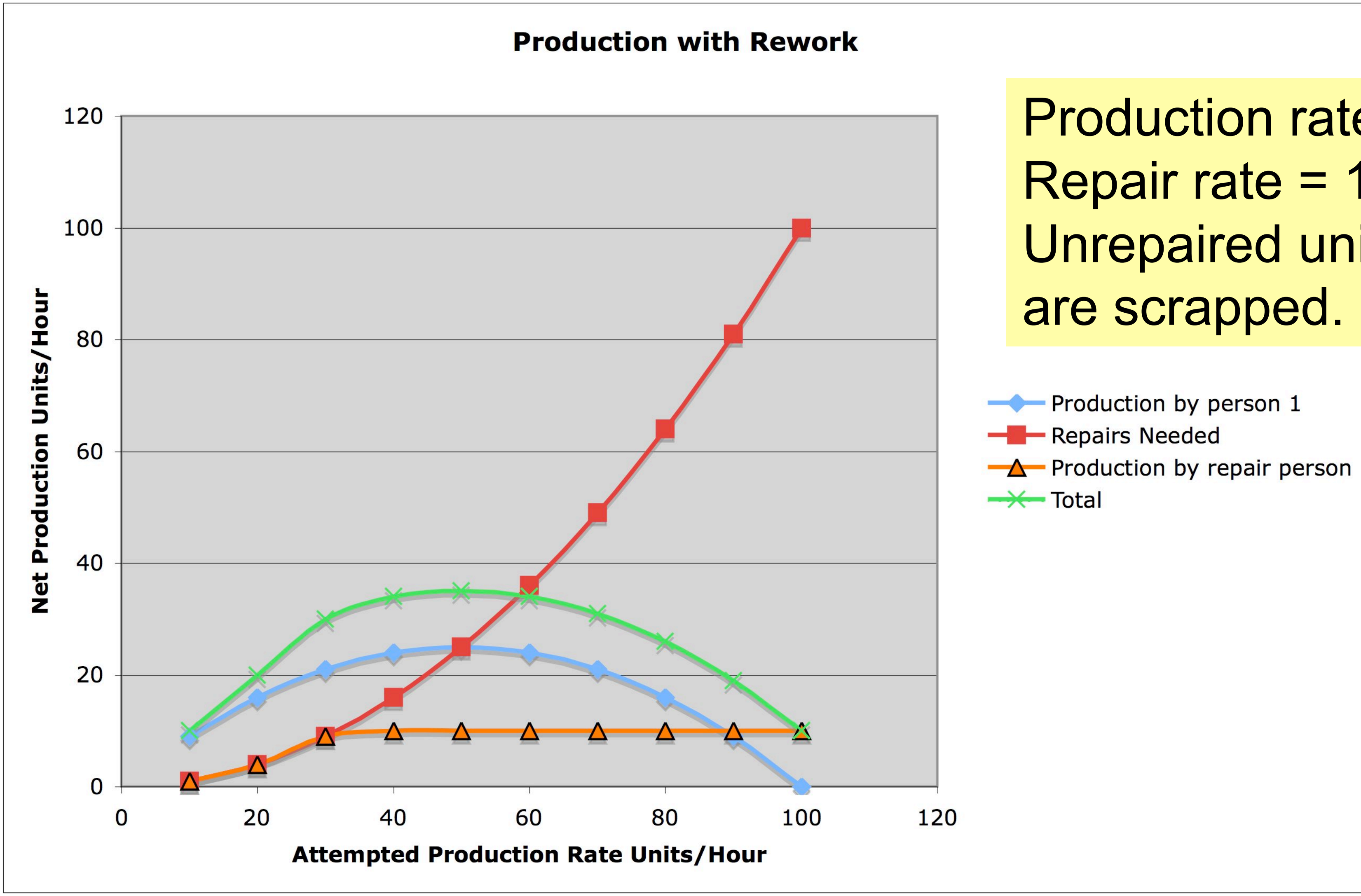
$$\text{For } k = 2, a = 0.01 : r = \frac{1}{2a} = 50, e = 0.01 * 50^{2} = 25, net = 25$$

Effect of Errors with Scrap



"I've run block lines at 20s takt time and gotten 1000 blocks/shift and I've run block lines at 30s takt time and gotten 1000 blocks/shift."

Effect of Errors with One Repair Person

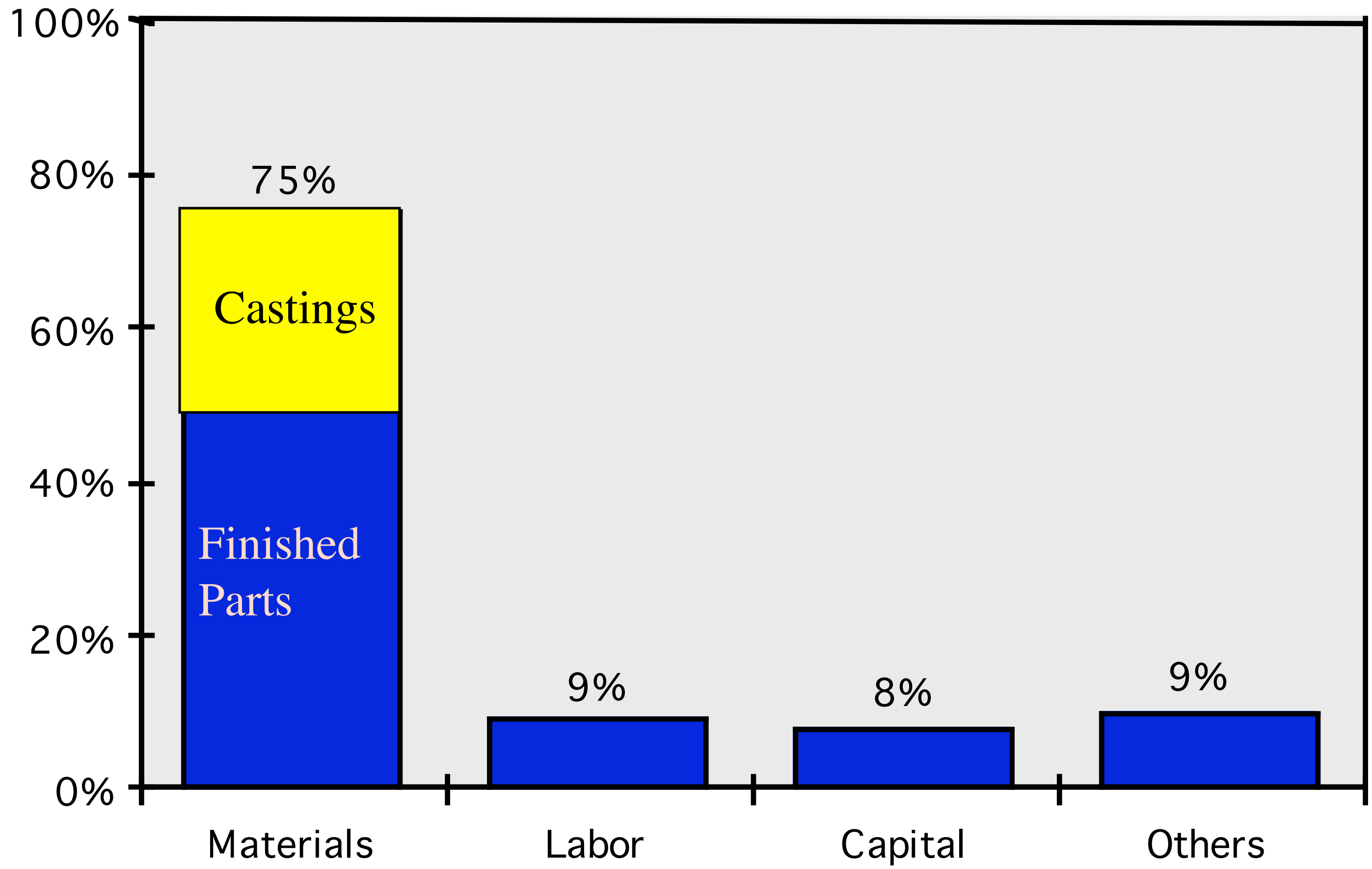


Production rate = r.
Repair rate = 10.
Unrepaired units are scrapped.

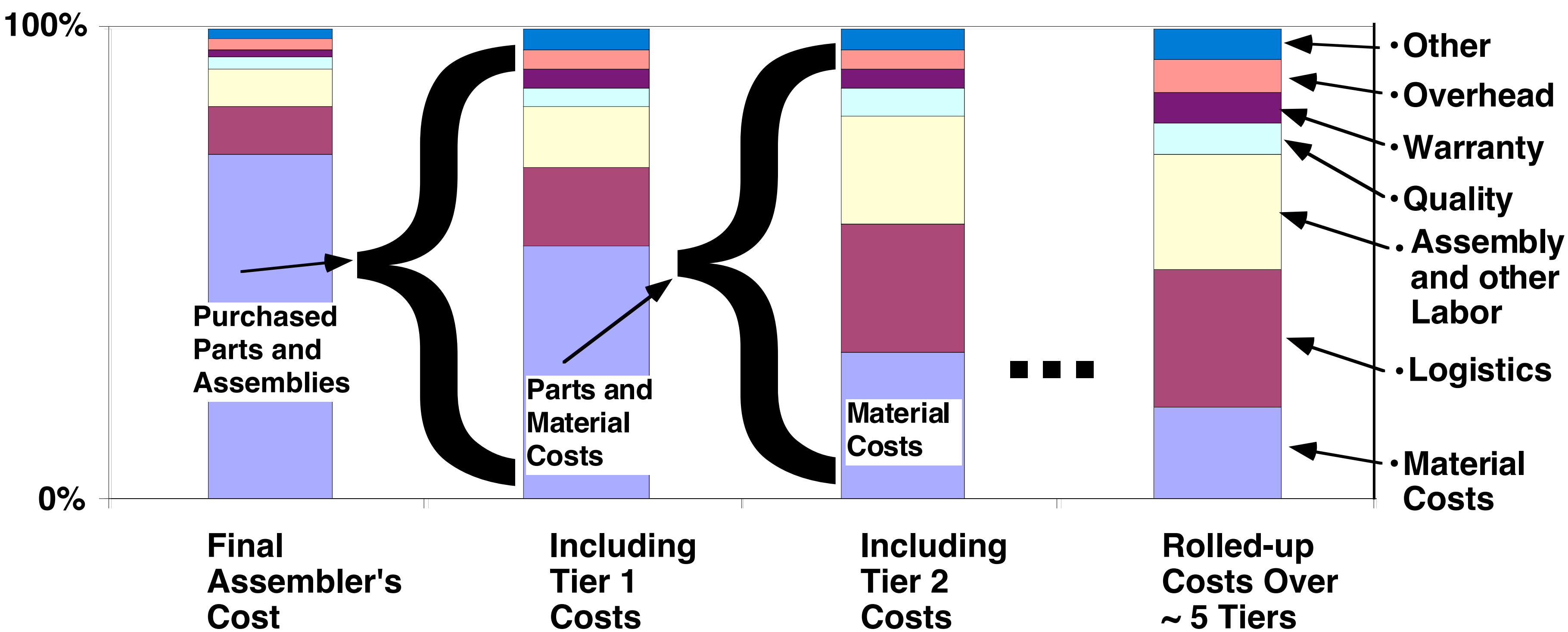
The Question

- Without repair, we get 20 plus 10 scrap from one person. The repair person is able to repair at the rate of 10 per hour. At an attempted rate of 30, we get 30 and no scrap but we need two people.
- At an attempted rate of 50 we get 35 (the max) plus 15 scrap from 2 people
- Should we hire the repair person or not?
- What should *r* be with one repair person?
- If it is worth while to hire one repair person, is it worth hiring another one and seek production of 40?

Cost Distribution in Engine Plants



Sources of Cost in the Supply Chain

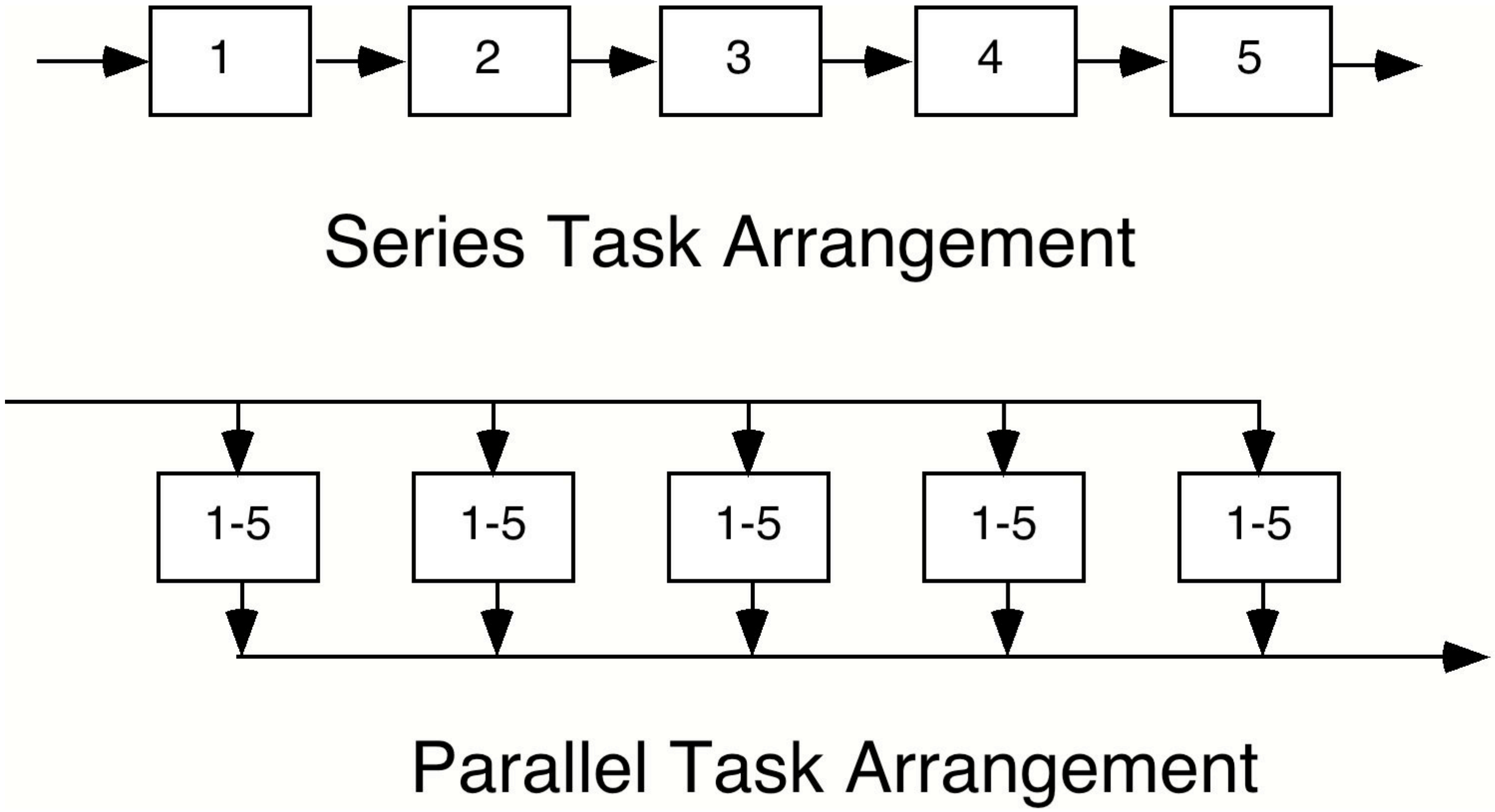


Source: Daimler Chrysler via Munro and Associates

Line Architectures

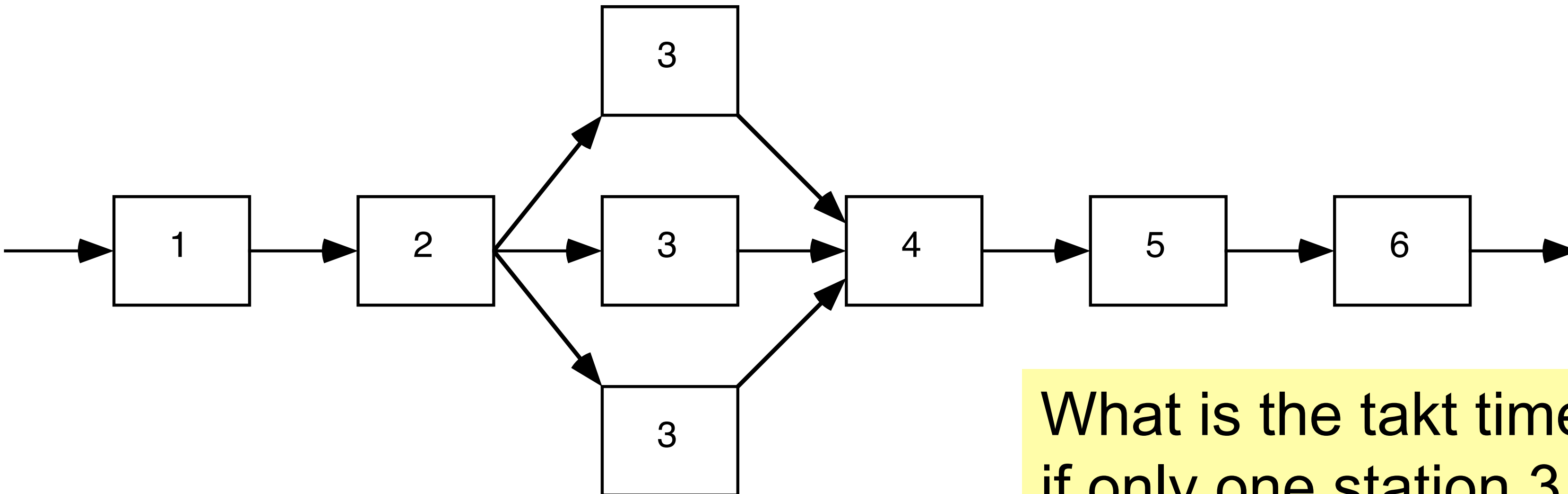
- Single serial line (car or airplane final assembly)
- Fishbone serial line with subassembly feeder lines (transmissions, axles)
- Loop (common for automated lines)
- U-shape cell (often used with people)
- Rotary dial (used for very short production cycle work with a single long task cycle like filling bottles)
- Transport can be synchronous or asynchronous
- Machines break down and have to be repaired.
- While they are down, they do no useful work and possibly neighboring machines also do no work.

Serial and Parallel Line Arrangements



How do they compare on tool cost, reliability, time, flexibility?

Serial Line with Multiple Stations



What is the takt time if only one station 3 is used?

TASK	1	2	3	4	5	6
TIME	3	4	9	4	2	3

(A) THREE COPIES OF STATION 3 ARE NEEDED BECAUSE ITS TASK TAKES SO LONG

Serial Line with Uneven Task Assignment

TASK	1	2	3	4	5	6	7	8
TIME	3	4	9	2	2	3	9	8

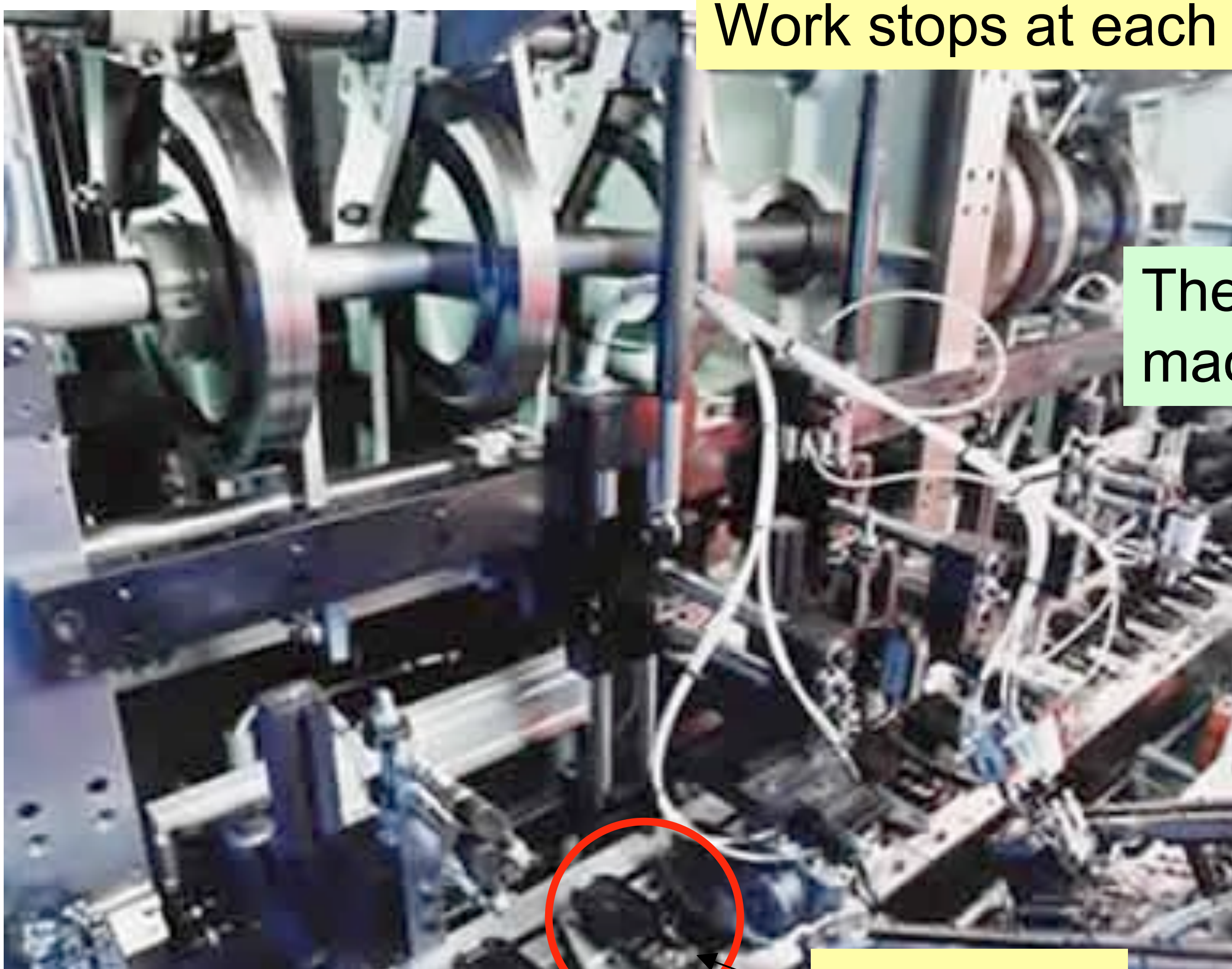
(B) GROUPING WORK AT STATIONS IMPROVES BALANCE OF STATION TIMES

What is the takt time of this line?

Bottlenecks

- The bottleneck station is the one with the longest takt time
- "A cycle lost on the bottleneck machine is a cycle lost forever."
- Assuming you really need that many units, you should keep the bottleneck station going all the time
- But it doesn't matter what the other stations do as long as the bottleneck always has work coming in and has someplace to put the work it finishes.

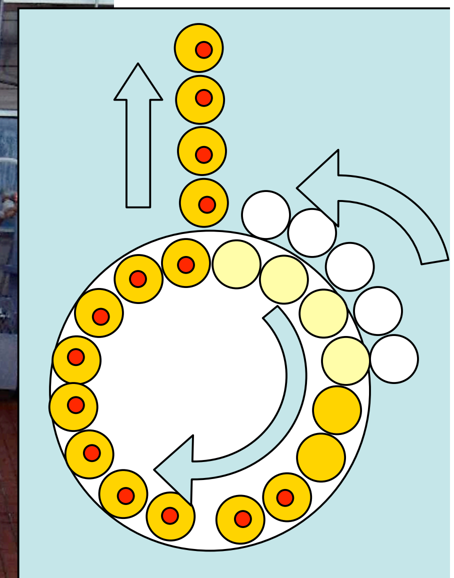
Cell Phone Assembly Machine



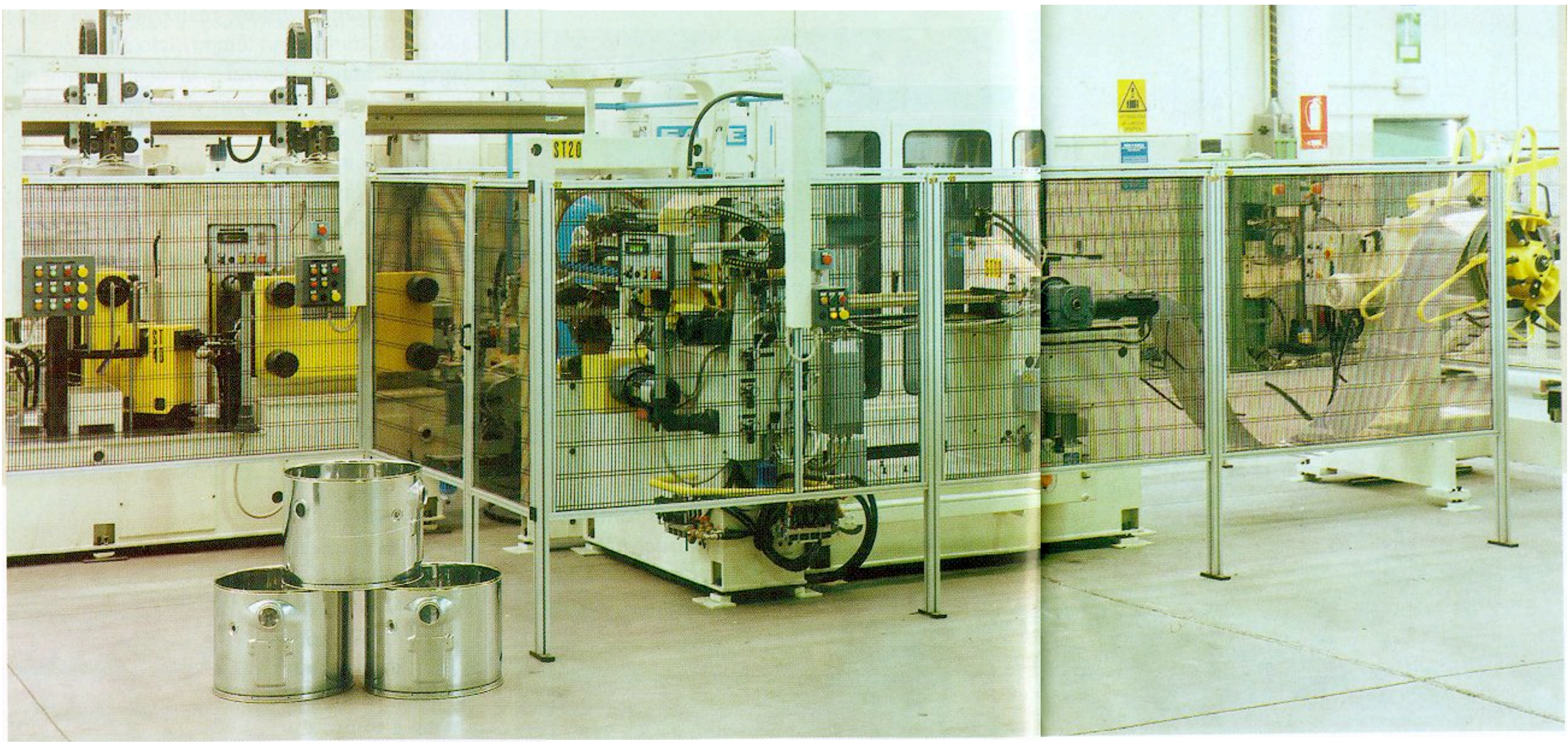
http://www.modular.co.uk/pages/solutions.htm

Bottle Filling Machine

Work does not stop



Integrated System for Washer Tubs



Some Takeaways

- The machines are much bigger than the products they make
- A huge amount of effort and money go into creating the machines and other equipment needed to make things
- It is really worth paying attention to the effect of design decisions on this cost and effort
- This topic is called Design for Manufacture and Assembly

Goals of Design for Manufacturing and Design for Assembly

- 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
  - Broad view inevitably pushes DFM/DFA earlier into the product development process

The Assembly from Heaven*

- Can be assembled one-handed by a blind person wearing a boxing glove
- Is stable and self-aligning
- Tolerances are loose and forgiving
- Few fasteners
- Few tools and fixtures
- Parts presented in the right orientation
- Parts asymmetric for easy feeding
- Parts easy to grasp and insert

*Dr Peter Will, ISI

The Assembly from Hell

- The opposite in each case from the previous slide

The Basic Assembly Errors

- Using the wrong part
- Using the right part but putting it in wrong so that it doesn't work
- Using a bad part
- Damaging the part or the assembly while putting the part in

Characteristics of Traditional DFA

- *DFA in the small* simplifies each assembly step
  - The basic errors are hard to commit
  - Parts are easy to grasp, orient, and insert
  - You can see what you are doing
  - Gravity helps if you put parts in from above
- *DFA in the large* emphasizes part count reduction
  - Advanced plastics and mold technologies make part count reduction more attractive
  - Combining too many parts into one takes away some flexibility

Traditional DFA

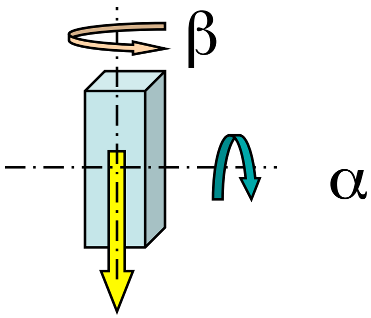
- The issues are:
  - assembling each part -estimating and reducing time
    - feeding/presenting
    - handling/carrying/getting into position
    - inserting without damage, collisions, fumbling
  - reducing part count (originally driven by local economic analysis, now driven by part cost itself)
    - two adjacent parts of different material?
    - do they move wrt each other after assembly
    - is disassembly needed later (use, repair, inspection, upgrade...)
    - if not any of the above, consider combining them
    - What's left are the "theoretically necessary parts"

How to Do Traditional DFA

- Make a structured bill of materials
- Identify every part mate and understand it
- Choose a reasonable assembly sequence
- Use tables (see next 2 slides) to estimate handling and mating times
- Label theoretically necessary parts, *excluding* all fasteners
- Calculate, using time in seconds

$$assembly\ \ efficiency = \frac{3 *\ \ number\ \ of\ \ theoretically\ \ necessary\ \ parts}{\text{total predicted assembly time using all parts}}$$

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



Handling Times

		No handling difficulties			Part nests or tangles		
		Thickness > 2mm		<2mm	Thickness > 2mm		<2mm
		Size>15mm	6mm<size <15mm	Size>6mm	Size>15mm	6mm<size <15mm	Size>6mm
Symmetry ($S = \alpha + \beta$)		*0*	*1*	*2*	*3*	*4*	*5*
S < 360°	*0*	1.13	1.43	1.69	1.84	2.17	2.45
360°<S<540°	*1*	1.5	1.8	2.06	2.25	2.57	3
540°<S<720°	*2*	1.8	2.1	2.36	2.57	2.9	3.18
S=720°	*3*	1.95	2.25	2.51	2.73	3.06	3.34

For parts needing one hand only

	$\alpha \leq 180°$		$\alpha = 360°$
	Size > 15mm	6<Size<15mm	Size >6mm
	0	*1*	*2*
4	4.1	4.5	5.6

For parts needing two hands

(Courtesy of Boothroyd Dewhurst, Inc. © 1999.)

Insertion Times

		Secured by separate operation or part				Secured right away by snap fit	
		No holding down required		Holding down requried			
		Easy to align	Not easy to align	Easy to align	Not easy to align	Easy to align	Not easy to align
		0	*1*	*2*	*3*	*4*	*5*
No access or vision difficulties	*0*	1.5	3.0	2.6	5.2	1.8	3.3
Obstructed access or restricted vision	*1*	3.7	5.2	4.8	7.4	4.0	5.5
Obstructed access and restricted vision	*2*	5.9	7.4	7.0	9.6	7.7	7.7

Part inserted but not secured immediately, or secured by snap fit

		Easy to align	Not easy to align
		0	*1*
No access or vision difficulties	*3*	3.6	5.3
Restricted vision only	*4*	6.3	8.0
Obstructed access only	*5*	9.0	10.7

Part inserted and secured immediately by power screwdriver. Note: add 2.9 s to get power tool.

DFA Spreadsheet

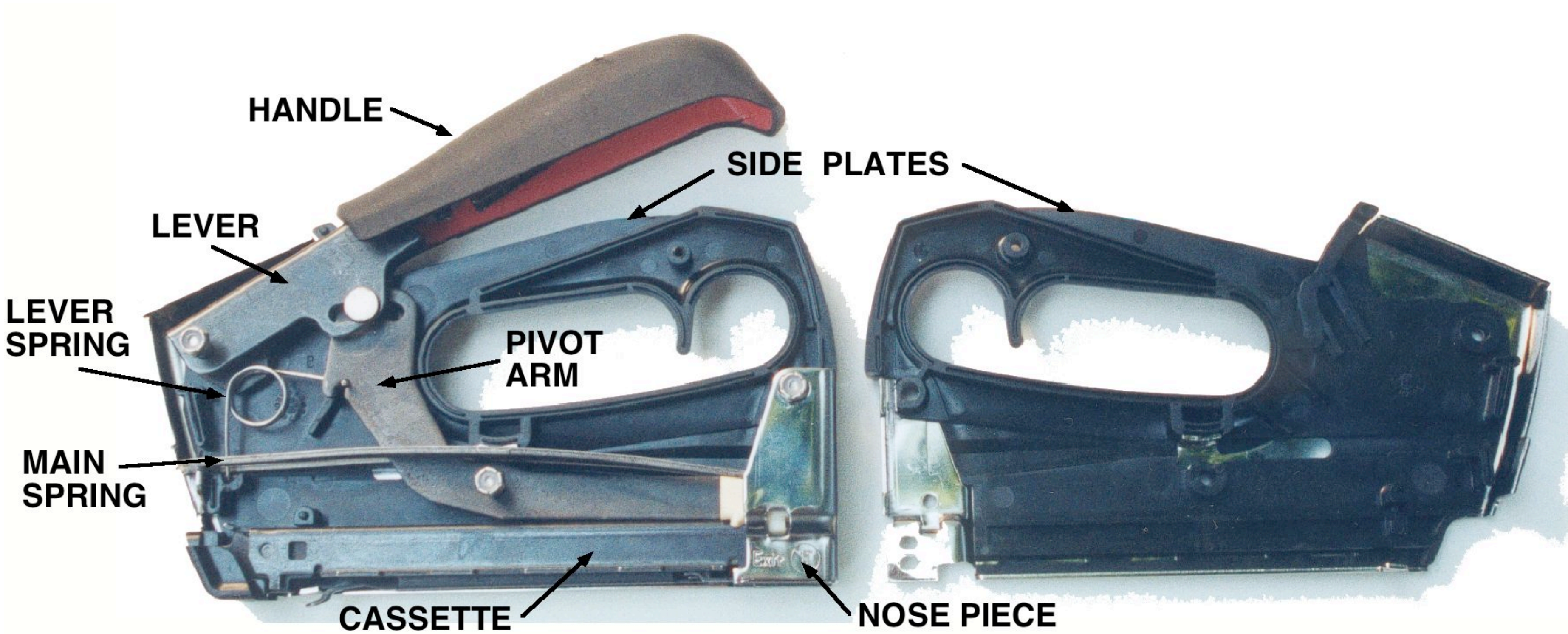
- On class website there is a folder called DFA Software
- In it is DFA05.xls with the handling and insertion data from the previous two slides
- Enter your code numbers and labor rate ($/sec) and the sheet will calculate times and costs

DFA Spreadsheet

DFA05.xls

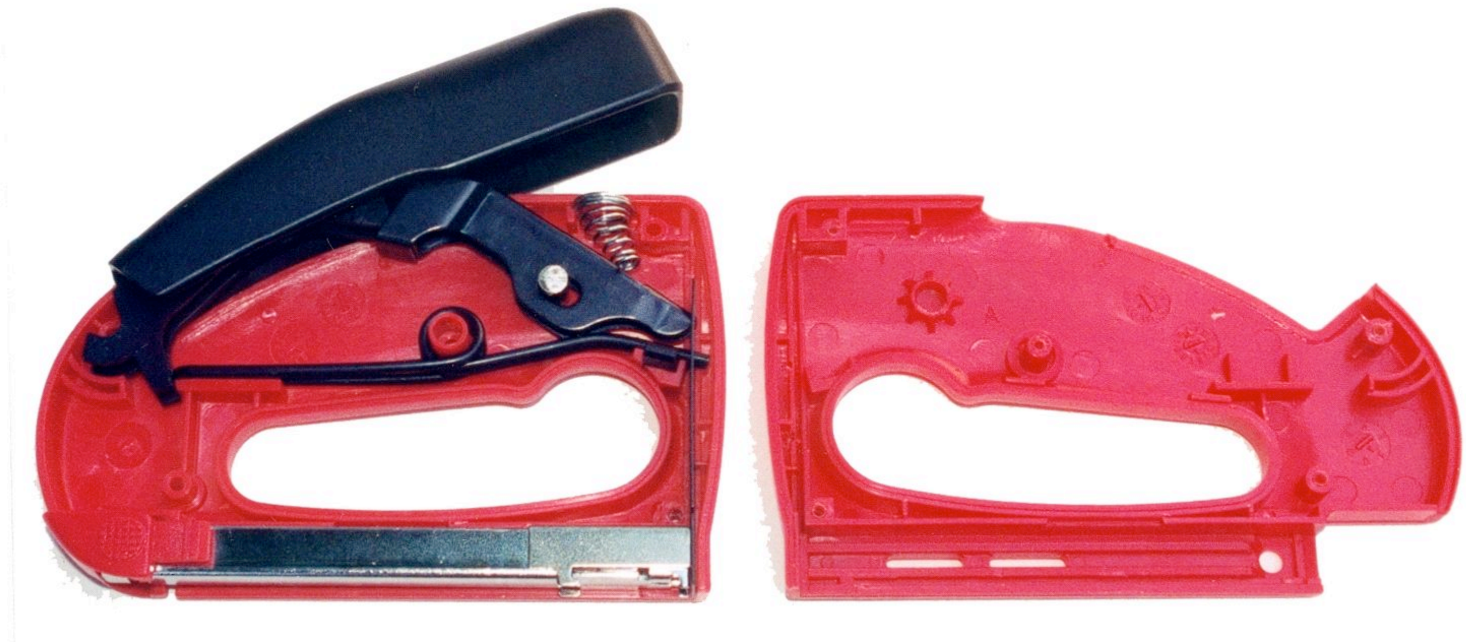
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Cost/hour	Cost per sec		Type cost per hour in cell A2														
2	$10.00	$0.00278			Type handling codes in column E						Type insertion codes in column K							
3	Boothroyd-Dewhurst Data ©				If you type a non-existent code, the value will be #N/A													
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														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															

Heavy Duty Staple Gun



Assembly efficiency = 17% before improvements
= 25% after improvements
= 30% with some functional risk

Low Cost Staple Gun



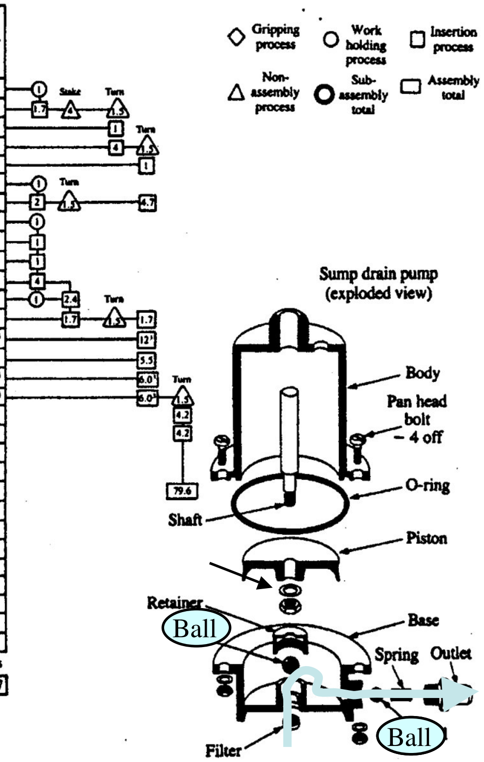
Assembly efficiency = 31%
Contains many of the suggested improvements
But is it a better staple gun?

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

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	B³	3.3³
Bolt	14d	B	1.1
Washer	15 abc	B³	3.0³
Nut	16 abc	B³	3.0³
Washer	15d	B	1.0
Nut	16d	B	1.0
	"A" components		
Totals	25	4	27.7



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

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

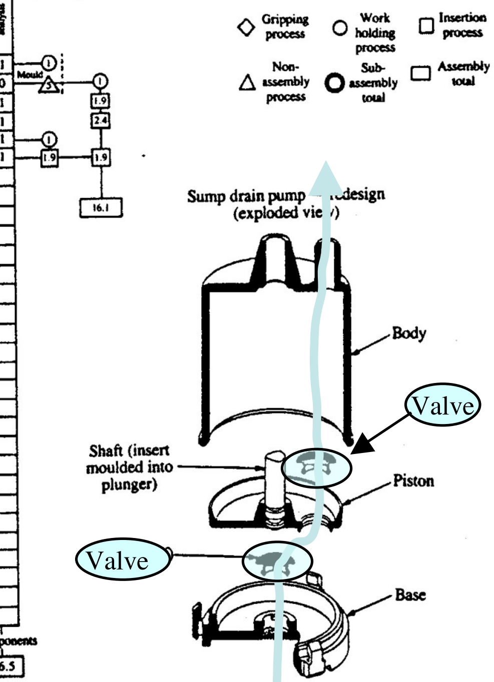
$$\text{Fitting ratio} = \frac{\text{Grip + fit + fix } 79.6}{\text{"A" components } 4} = 19.9$$

	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
	"A" components		
Totals	6	4	6.5



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

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

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

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

Figure 8.6 Lucas method—redesigned example

If You Liked This topic

- I teach a graduate course
- 2.875 Mechanical Assemblies and their Role in Product Development
- Fall term