Assembly Technology

Lecture 1: Introduction to assembly process, models, descriptions and analysis

Outline

- Introduction to Assembly
- Industrial Assembly
- Assembly Model
- Key Characteristic (KCs)
- Assembly sequences and precedencies
- Assembly Motions
- Cost Evaluation
- Elements of System Design

Intended Learning Outcomes

- Position the assembly process withing the manufacturing domain
- Discuss the issue related with the assembly domain using the mainstream conceptualization and jargon
- Produce liaison digaram and feasible sequences from less sophisticated assembly models
- Describe and Perform a basic cost analysis for different approaches to assembly: manual, dedicated and flexible automation.

Assembly Process

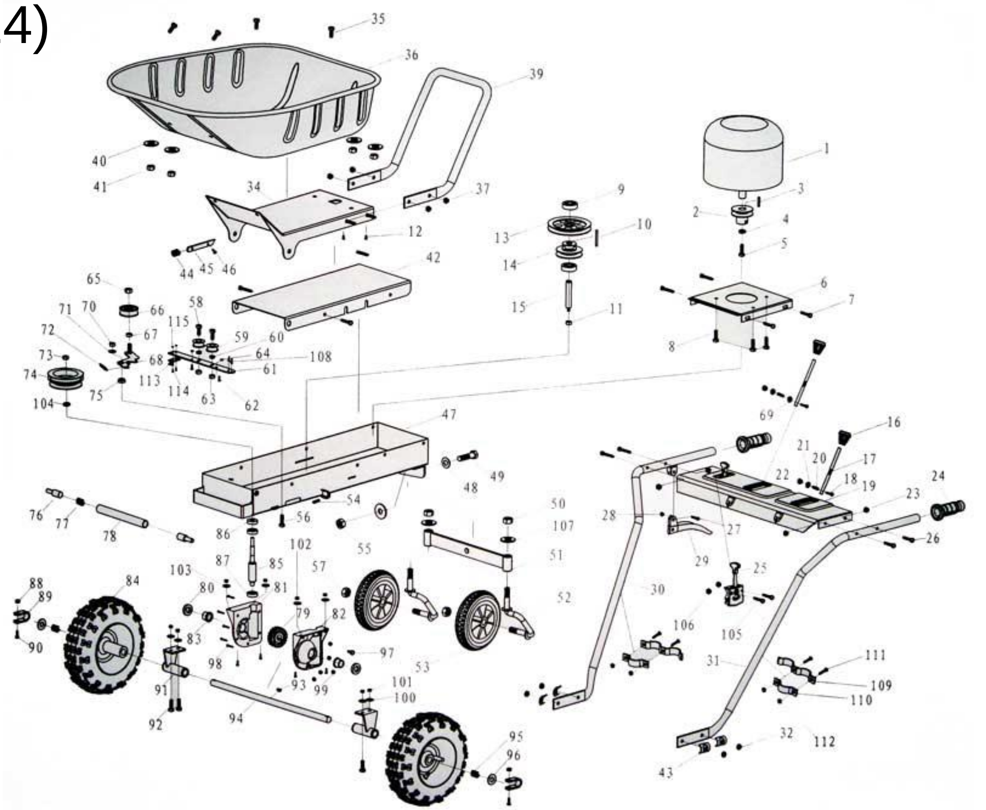
"the process of putting together a number of parts to make a product"

Unlike other manufacturing processes that consist of forming or removing material, Assembly is actually a process of "adding material or energy"

Easy? To understand the scope let's look at the following video

Video

- Assembly of an engine (3:11)
- Manual Assembly (0:24)
- A380 assembly (7:14)
- Toyota Prius (0:55)
- Micro assembly (2:20)



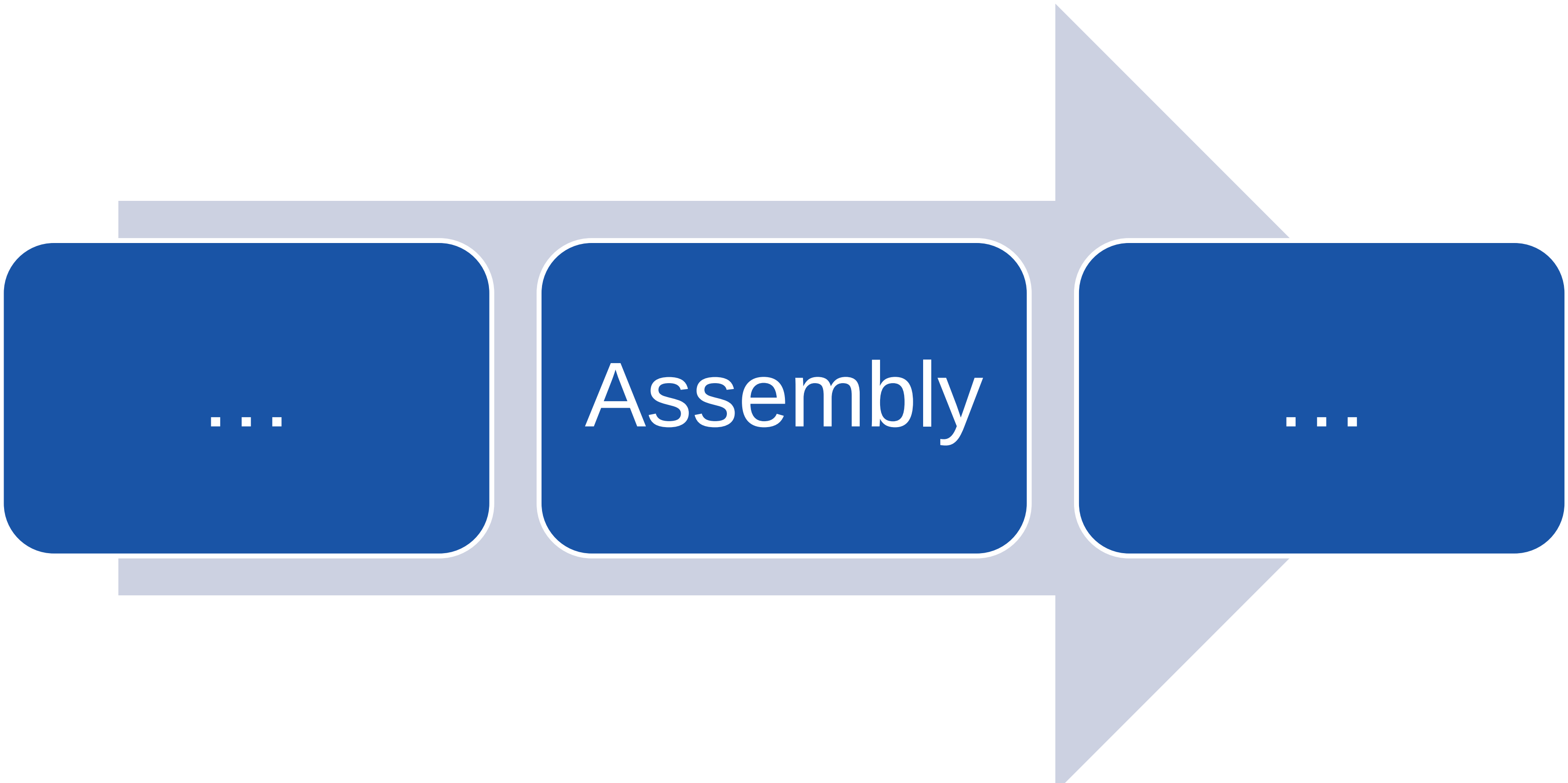
Boundaries of assembly?

- Size
- Materials
- Processes

In this course traditional industrial assembly problems will be described and discussed: metal and plastic.

Other processes like wood and textile will be also touched

Assembly in Manufacturing



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 over 100 years and a lot is known about them

•Assembly included fitting, adjustment, and selection until the 1830s and beyond

•Technology and methods to create interchangeable parts evolved during 1765-1900

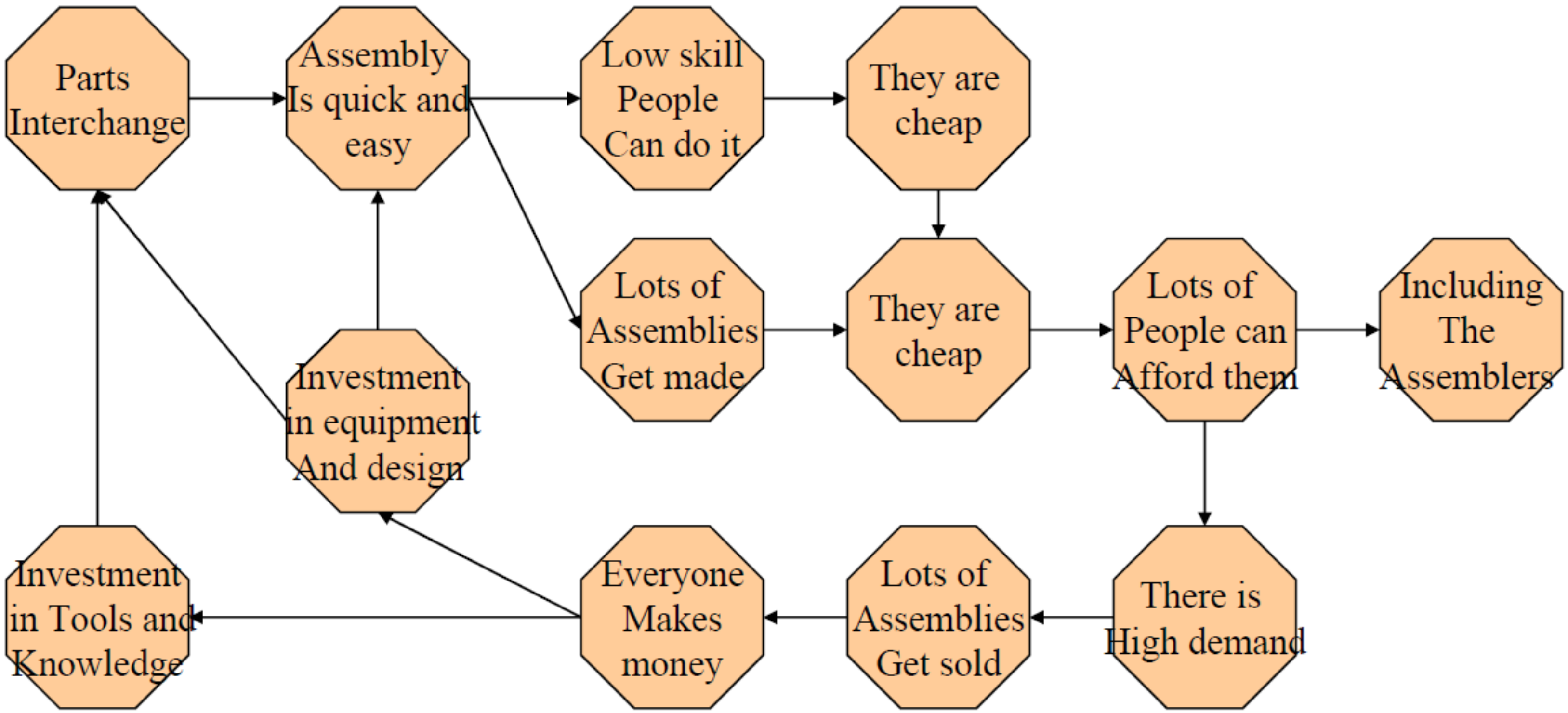
•Mass production requires interchangeable parts

•Interchangeable parts enable use of low skill assemblers

•Supply chain implementation of manufacturing requires interchangeable parts

*this referes to industrial assembly of plastic and metal. Traditional assembly processes have been studied and formalized long before (textile, fabric...)

Interchangeable parts enable mass consumptions



Assembly Process

Assembly is where product come to life and where the "quality" is delivered:

- There aren't many "one part" products
- The quality is determined by how parts come together.

Assembly Process

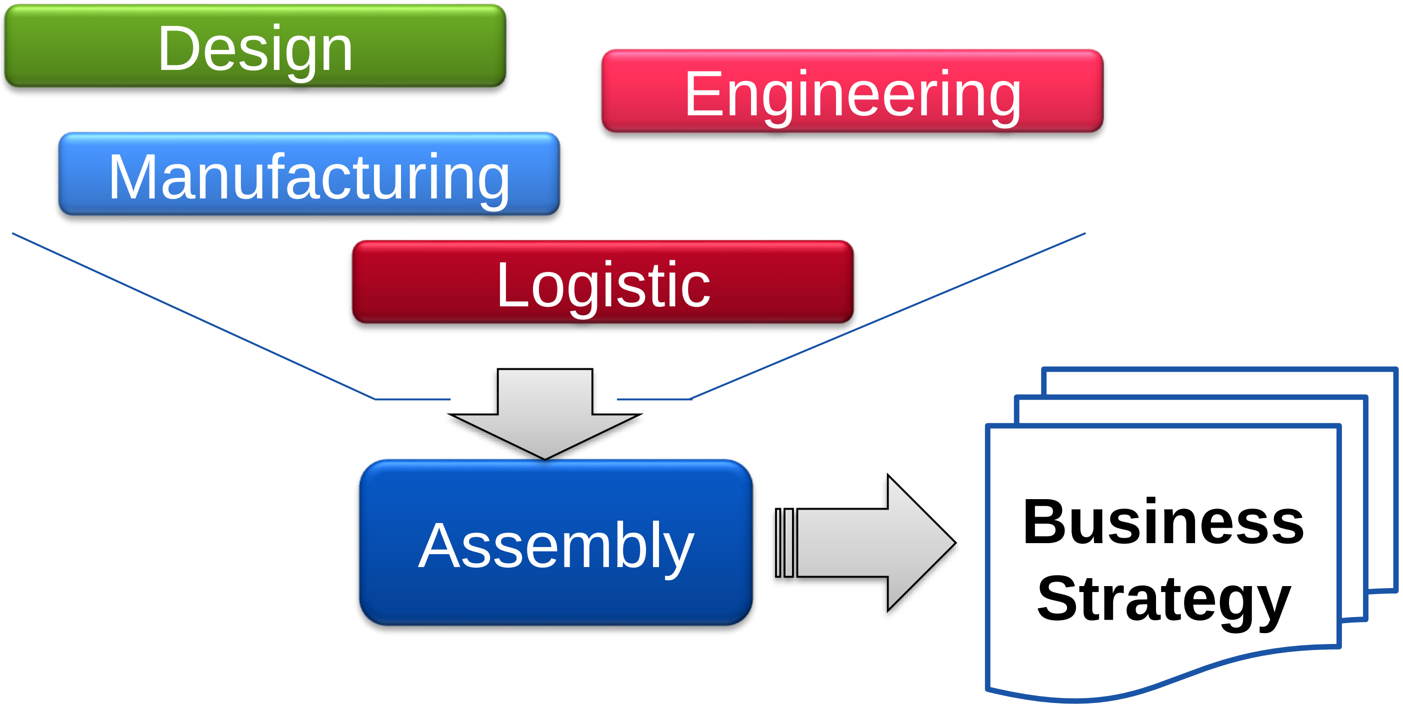
"Having control over the assebly process means having control of the final quality"

A paradox: Assembly is not a big cost element!!!

Is it really "necessary" and convenient to outsource it as many top managers nowadays think?

Introduction to Assembly

Assembly is much more that simply put parts together into a product!



Introduction to Assembly

Assembly is inherently **integrative**: It brings together not only the parts, but also the people and companies who design, make and deliver those parts!

Assembly is the process with the greatest potential to improve **product development** methods and **manufacturing strategy**

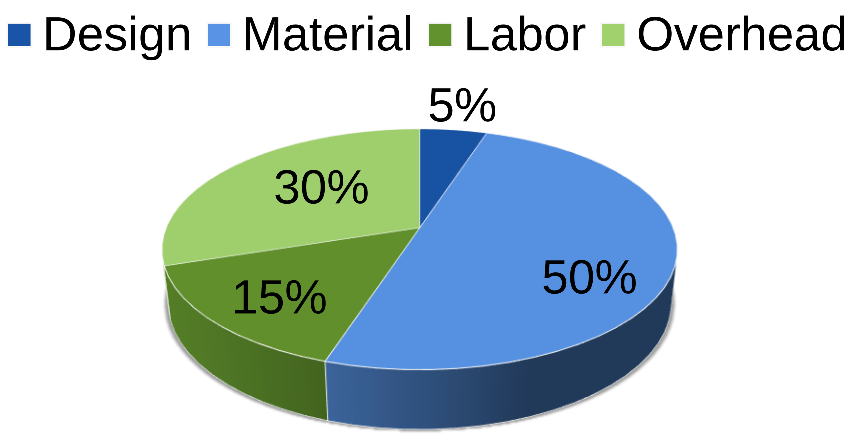
Introduction to Assembly

Traditional attitude of designers:

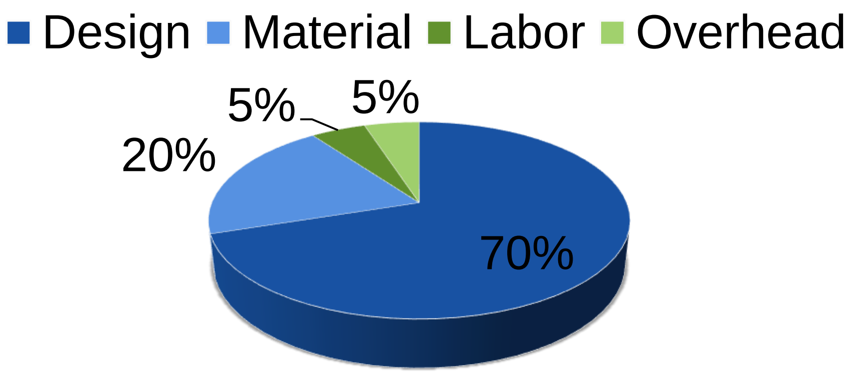
We design it…you build it!

Is that convenient for the company?

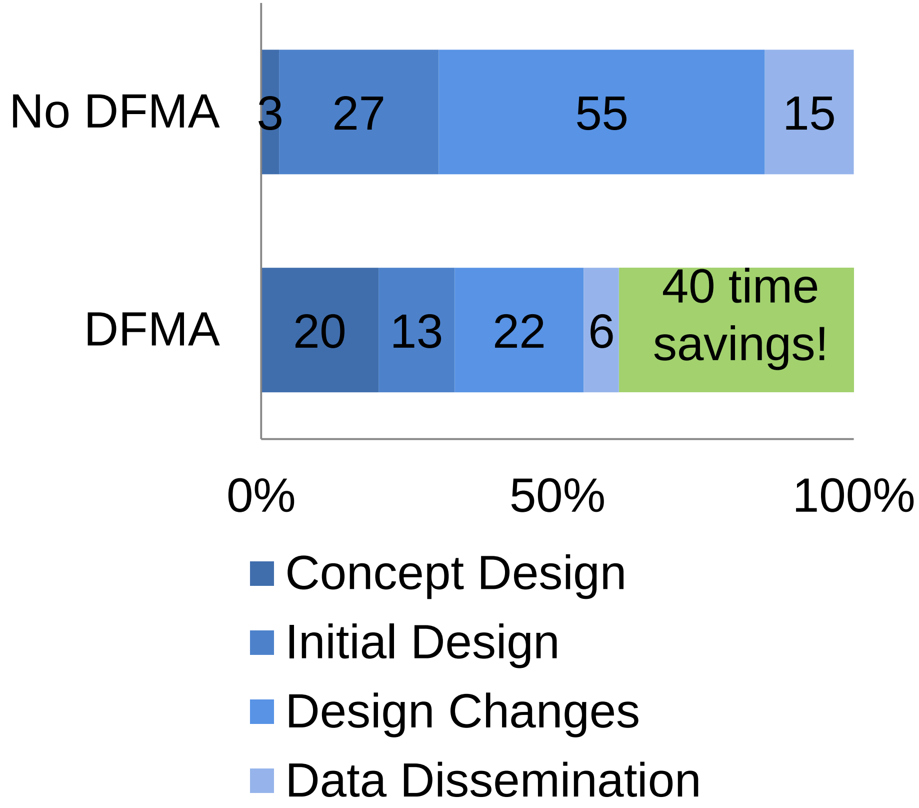
Cost for the company



Influence on final product cost



Introduction to Assembly



An **Assembly-driven** product realization process can greatly improve a company's prospect for the success of its product.

Introduction to Assembly

Overall impact of DFMA on U.S. industry

	Average Reduction	Number of cases
Labor Cost	42	8
Part Count	53	103
Separate Fasteners	57	21
Weight	22	21
Assembly Time	59	68
Assembly Cost	45	20
Assembly Operations	54	25
Product development cycle	45	2
Total cost	50	32

Some facts…

Rational design for manufacturing and assembly is at the basis of some well-known success stories:

- Ford cars
- Allies Victory in WW II [1]
- Sony walkman
- …

1. During World War II, U.S., Russians, and British defense contractors adopted simple standard designs for aircrafts, jeeps, tanks, trucks, and rifles and ground them out in huge quatities. This contrasted sharply with the methods of German industry, which kept «improving» the designs of many of these items with the result that logistics, training, and field repair became difficult. [Overy, *Why the allies won*]

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

Industrial Assembly

Three main categories:

- Manual Assembly
- Fixed Automation
- Flexible Automation

Characteristic of Manual Assembly

Technical

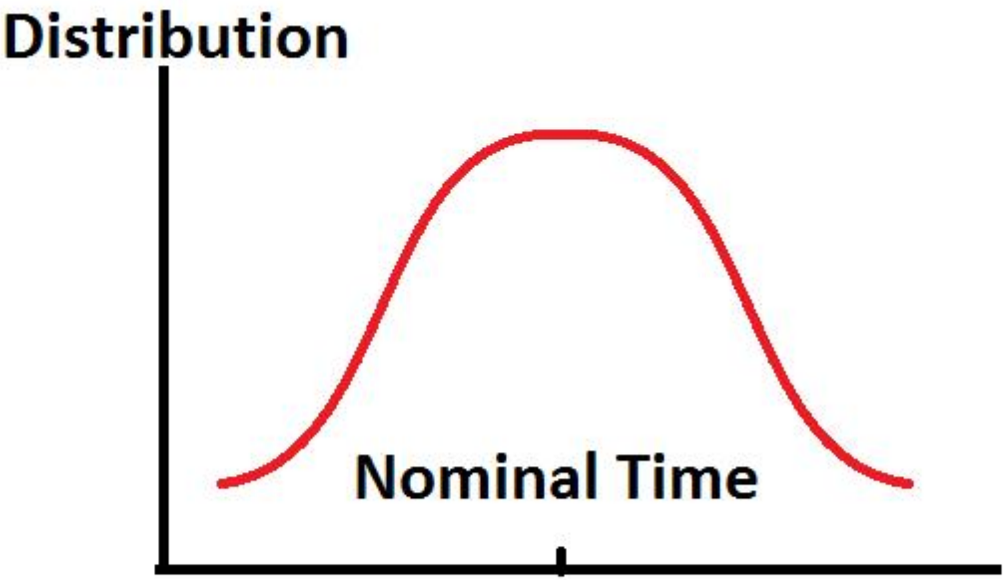
- Dexterous, able to learn and improve, flexible
- Can overlap operations –move+flip+inspect
- May be too innovative, or may be unable to repeat exactly the operation or the cycle time

Economic

- Top speed dictates need for more people to get more output (variable cost*)

* Not really…. According with the unions

Cycle time for assembly stations



For an automatic station instead the cycle time is deterministic!!!

Ergonomics and Job Design

- Manual assembly work is boring due to short takttime
  - "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

Characteristic of Fixed Automation

Technical

- Simple operation with fixed DoF and simple alternatives
- Each station is dedicated to one operation (place/fasten/confirm) built from standard modules strung together
- Small parts, relatively high speed
- Basic architectures include in-line and rotary

Economic

- The investment is in fixed increments regardless of required capacity (fixed cost)
- The payoff is in keeping uptime high

Characteristic of Flexible Automation

Technical

- Multiple motion axes
- Motion (gross and fine) modulated by sensing and decisions
- Multiple tasks with or without tool change

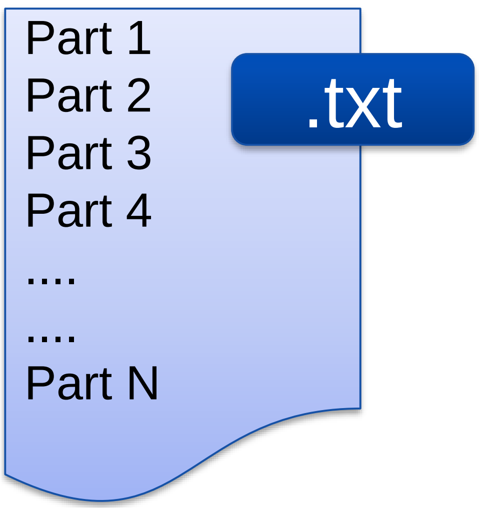
Economic

- Multiple tasks (within a cycle or next year)
- Investment scalable to demand (variable cost)
- Tools and part presentation costly (fixed cost)

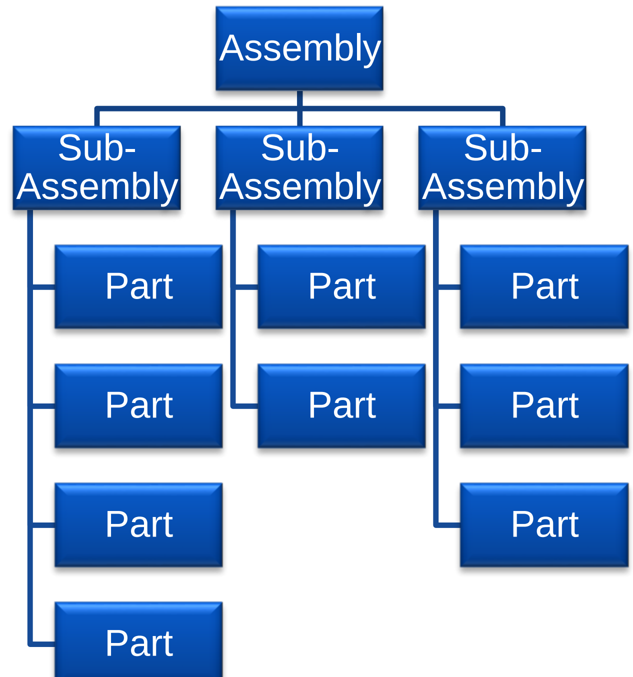
Assembly Model

Different approaches and level of details for different purposes:

Simple list of Part:



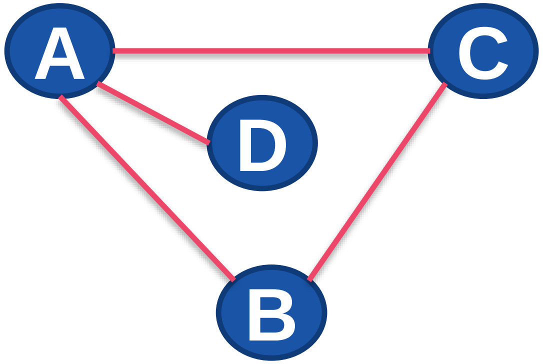
Bill of Material (BOM):



Assembly Model

More interesting and useful for our purpose are the **Liaison Diagram**:

- the nodes represent the parts
- the lines represent connections



This diagram represents 4 parts: A is connected with B,C and D. Other connection can be read analoguosly

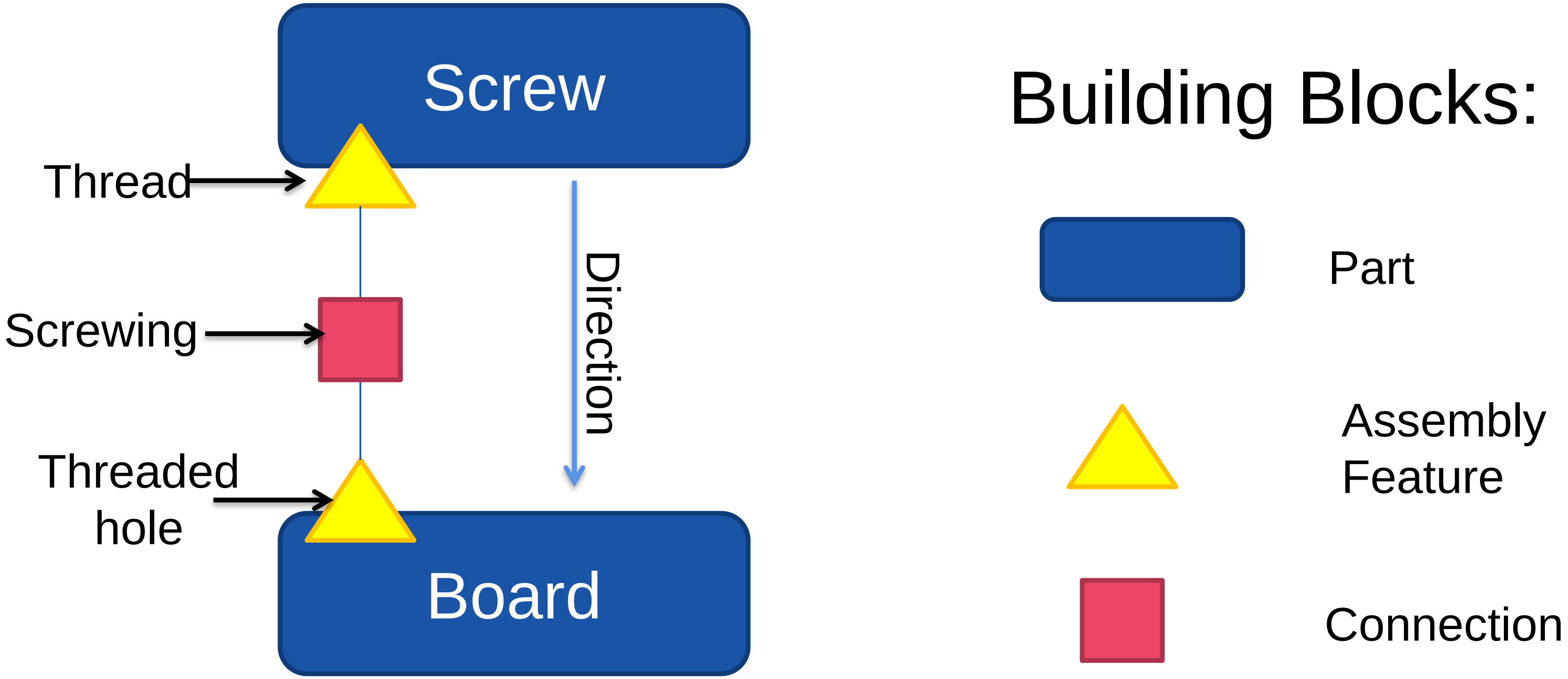
Assembly Model

Liaison Diagrams are very useful to analyze the **assembly sequences** and they can be integrated with:

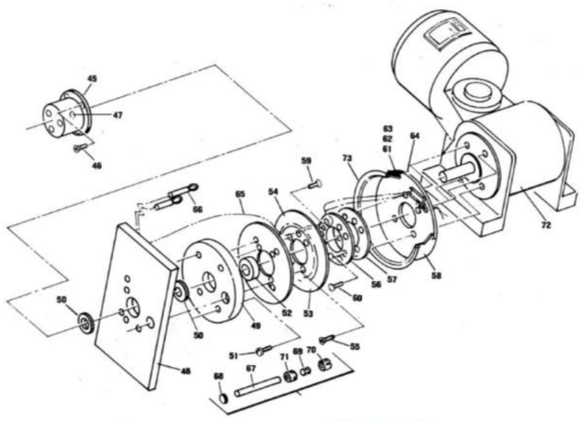
- Graphical and functional **description** of parts or connections. Where the part are in relation with each other
- Numbers to indicate **priorities.** Product sequences and alternative

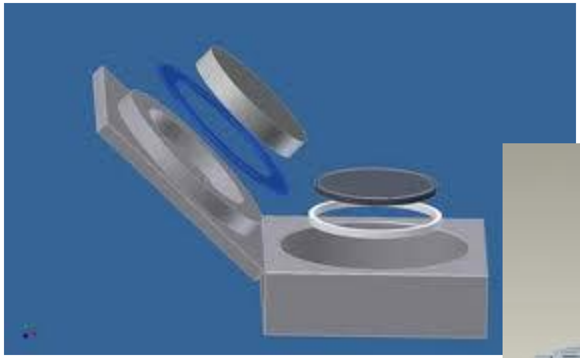
Assembly Model

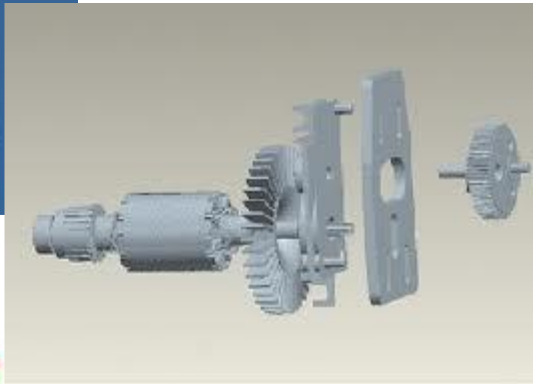
Advanced Liaison Diagram:

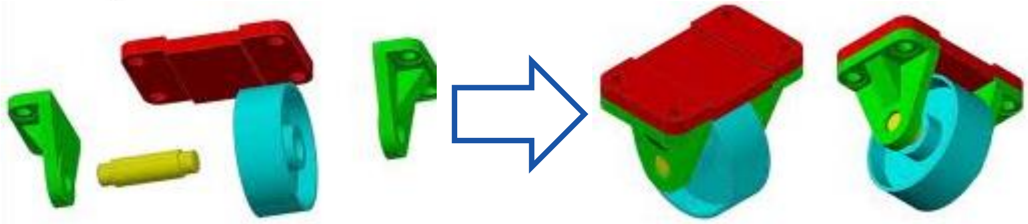


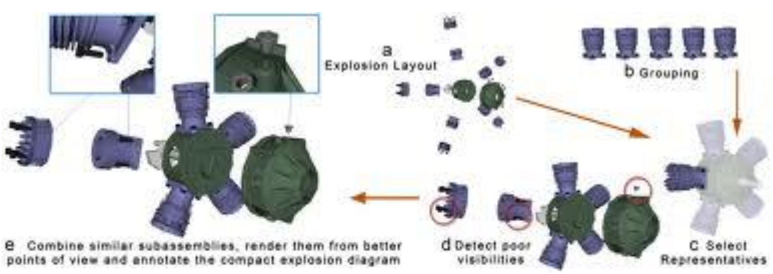
3D and exploded views

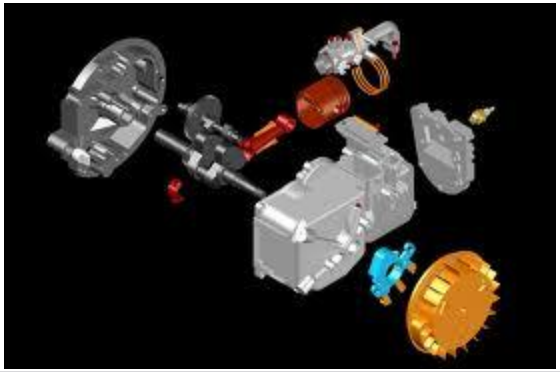












Key Characteristics

Properties of an assembly that delivers the **required** performances and quality

By:

1. The customer
2. The regulations
3. Company standards
4. «Given» properties of high quality products (reliability, durability, safety, fitness for use...)

Key Characteristics

Engineering the design of an assembly is done in three steps:

1. *Nominal Design*: establishing the ideal relative location between the parts.
2. *Variation Design*: how much variation on the nominal design can be **tolerated** and still achieve the KC
3. *Process Design*: fabrication and assembly processes that allow to stay within such tolerances

Key Characteristics

- Establishing the KC of a product is the first step towards an effective design concept.

- Starting from the functional requirements (customer needs) the KCs can be **Flowdown** to the design of single parts and assemblies that are able through their features to deliver them

Key Characteristics Hierarchy

Semiconductor	Copiers/Cameras	Aircraft
Functional	Functional	Functional
Electrical	Physical	Aerodynamics
Mechanical	Dimensional	Dimensional
Process	Process	Process

Variations Risk Management

Dealing with **Nominal**, **Variation** and **Process** design at the same time in order to pursuit economic advantage!!!

Identify System Requirements

↓

Flow Requirement down to Feature Level

↓

Flow up Process Capabilities

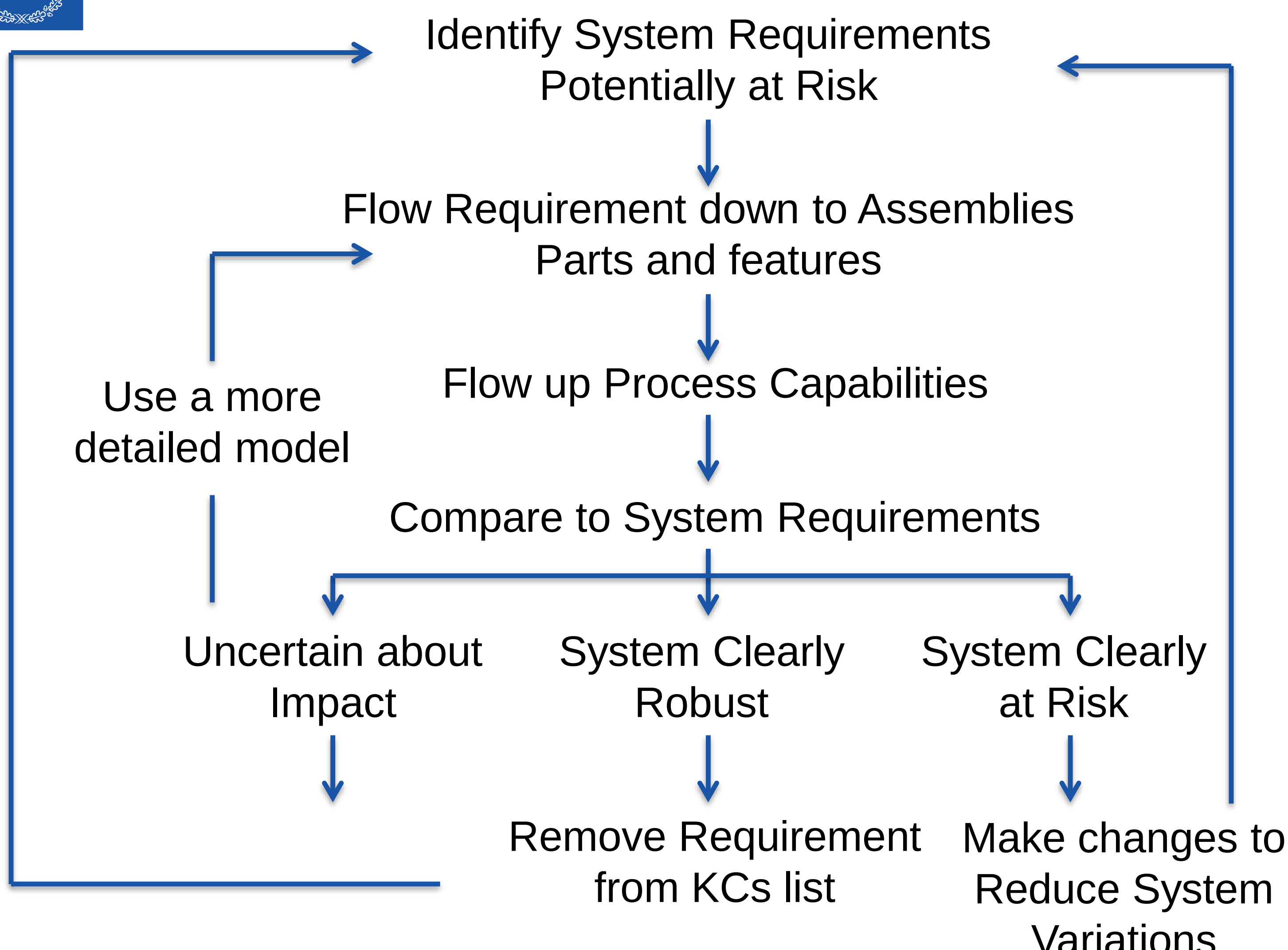
↓

Compare to System Requirements

↓

Make changes to Reduce System Variations

Different levels of Risk



Not all the KCs have the same level of Risk!

Architecture Aspects

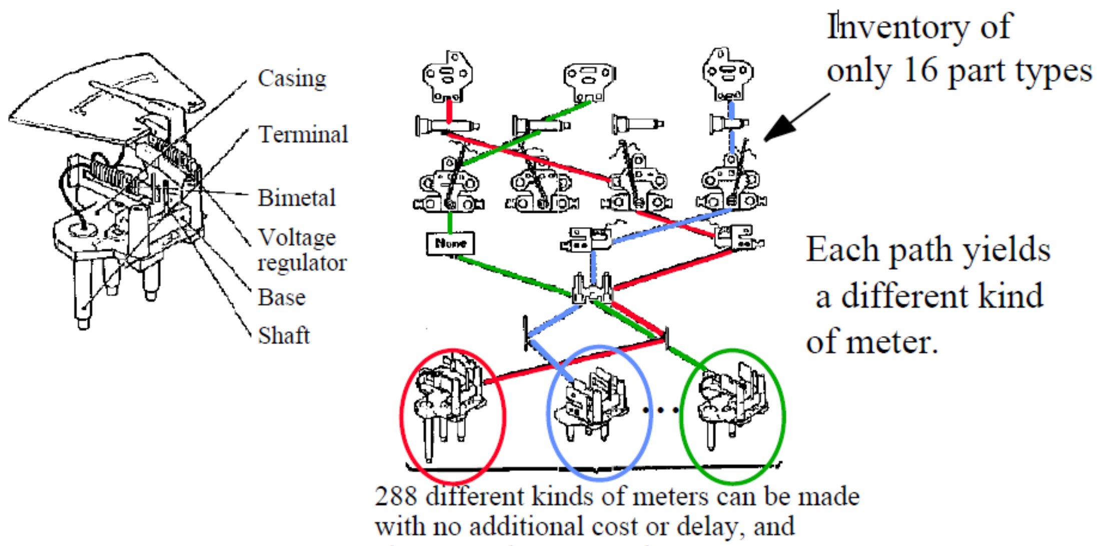
- Architecture is the definition and arrangement of the parts with respect to the product's functions
- Architecture affects
  - Definition of subassemblies
  - Assembly sequence options
  - Testing options
  - Customization and just-in-time operations
  - Design for assembly

Model Mix, Customization, and Changeover Happen During Assembly

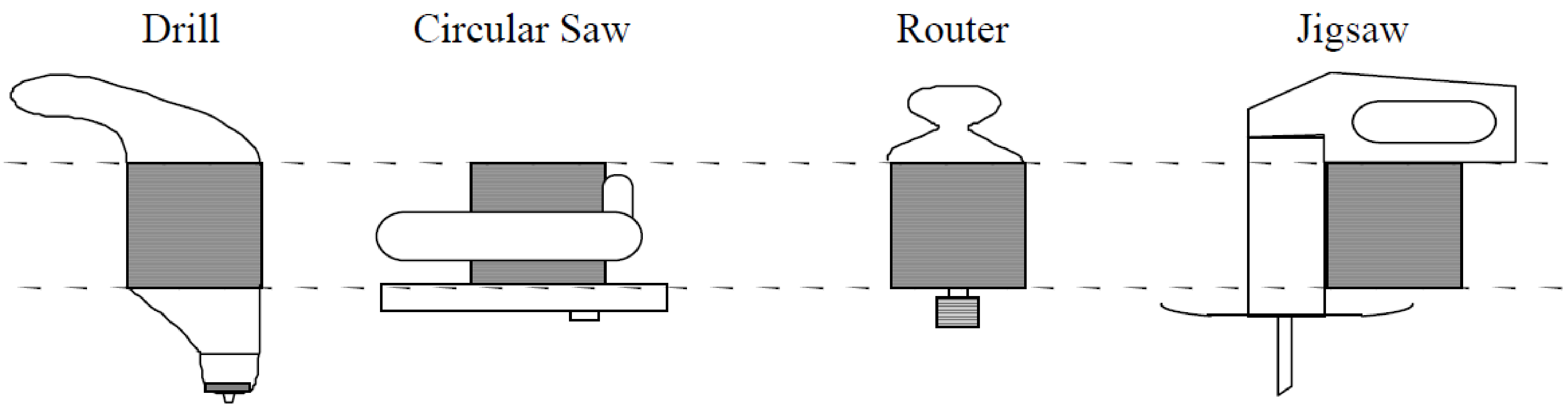
- Marketing wants them in 30 colors while manufacturing wants them all to be white
- “Decoupling point” is the last point where the product is the same for everyone
  - Can be at the beginning of assembly
  - Can be during assembly
  - Can be at a distribution point or with the user
- How much variety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

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.”



Alternate Architecture for Power Tools



AXIAL/STACK ARCHITECTURE WITH COMMON MOTOR MODULE

Black & Decker ~ 1981
(still used)

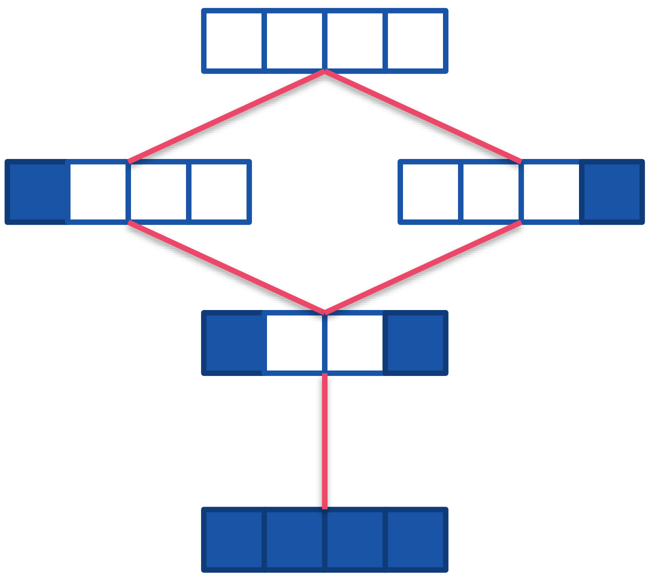
Feasible Sequences

Generated from Liaison Diagrams answering to questions like:

- Is it possible to add this set of part if that set of parts has already been assembled?
- Is it possible to add this set of part if that set of parts has NOT already been assembled?

The final product is a **Liaison Sequence Diagram**

Liaison Sequence Diagram



Feasible State of the assembly

Liaisons that have not been done

Completed Liaisons

Transition: a liaison or a set of liaisons is done

Good Sequences

While finding the fesible sequences is a mechanic work that can be accomplished through algorithms , finding the good ones requires the **process engineer expertise** in *analysing and evaluating each state and transition in each proposed sequence*.

Criteria for Good Sequences

State:
- Stability
- Fixturing
- Testing and repair

Transition:
- Orientation
- Part Damage

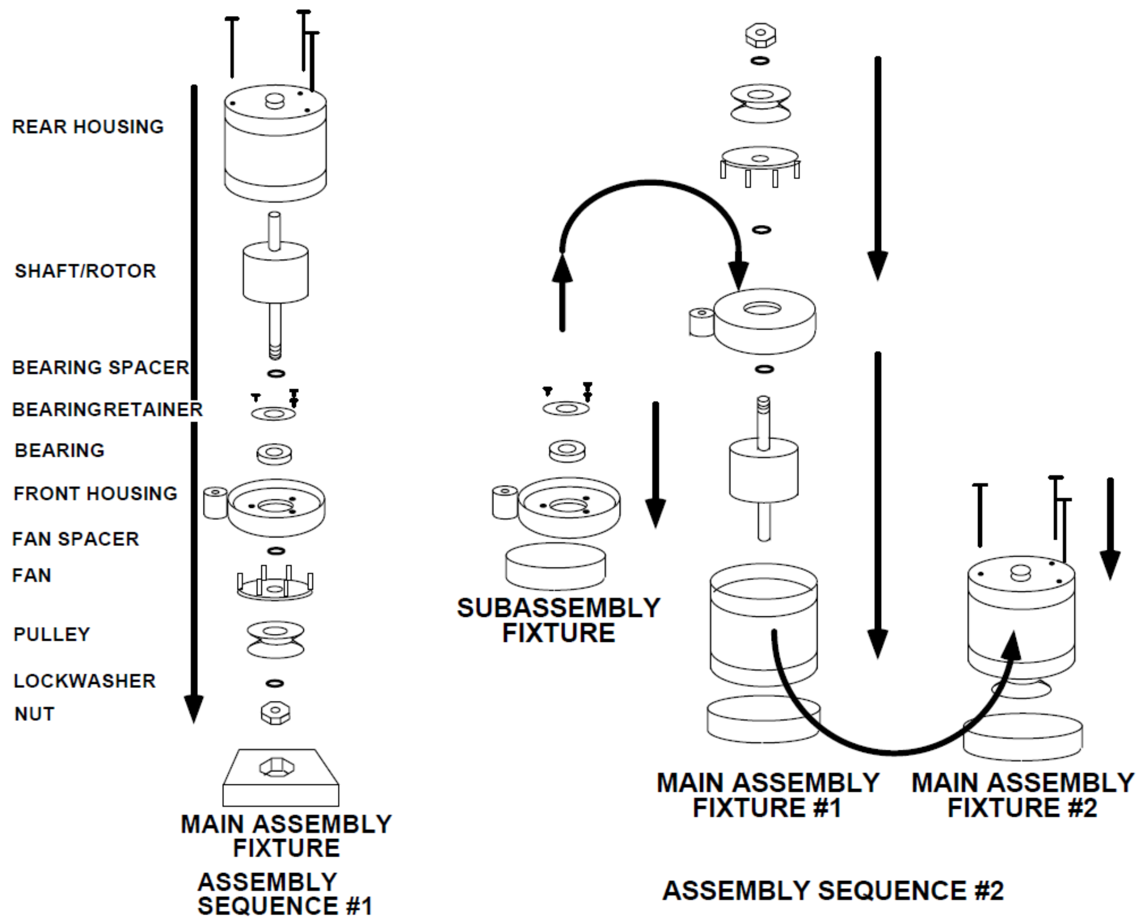
Assembly Constraints:
- No subassemblies
- Specific Partial sequence

Quantitative Data:
- Time
- Cost
- Reliability
- .....

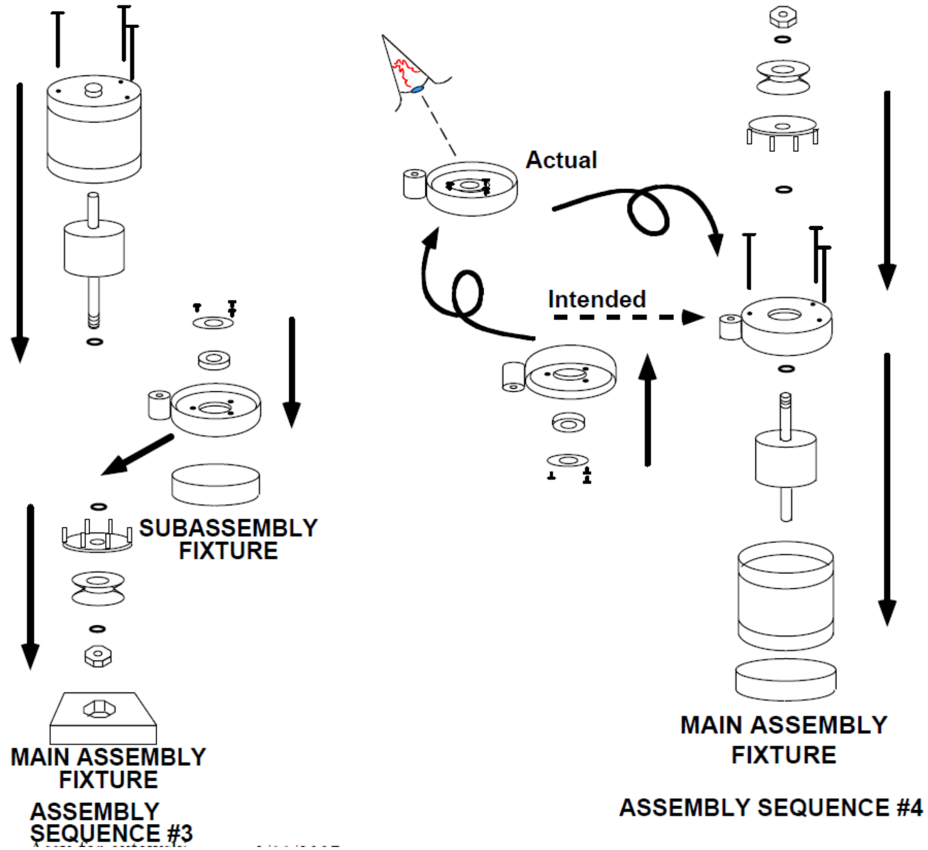
Assembly sequence options

- 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

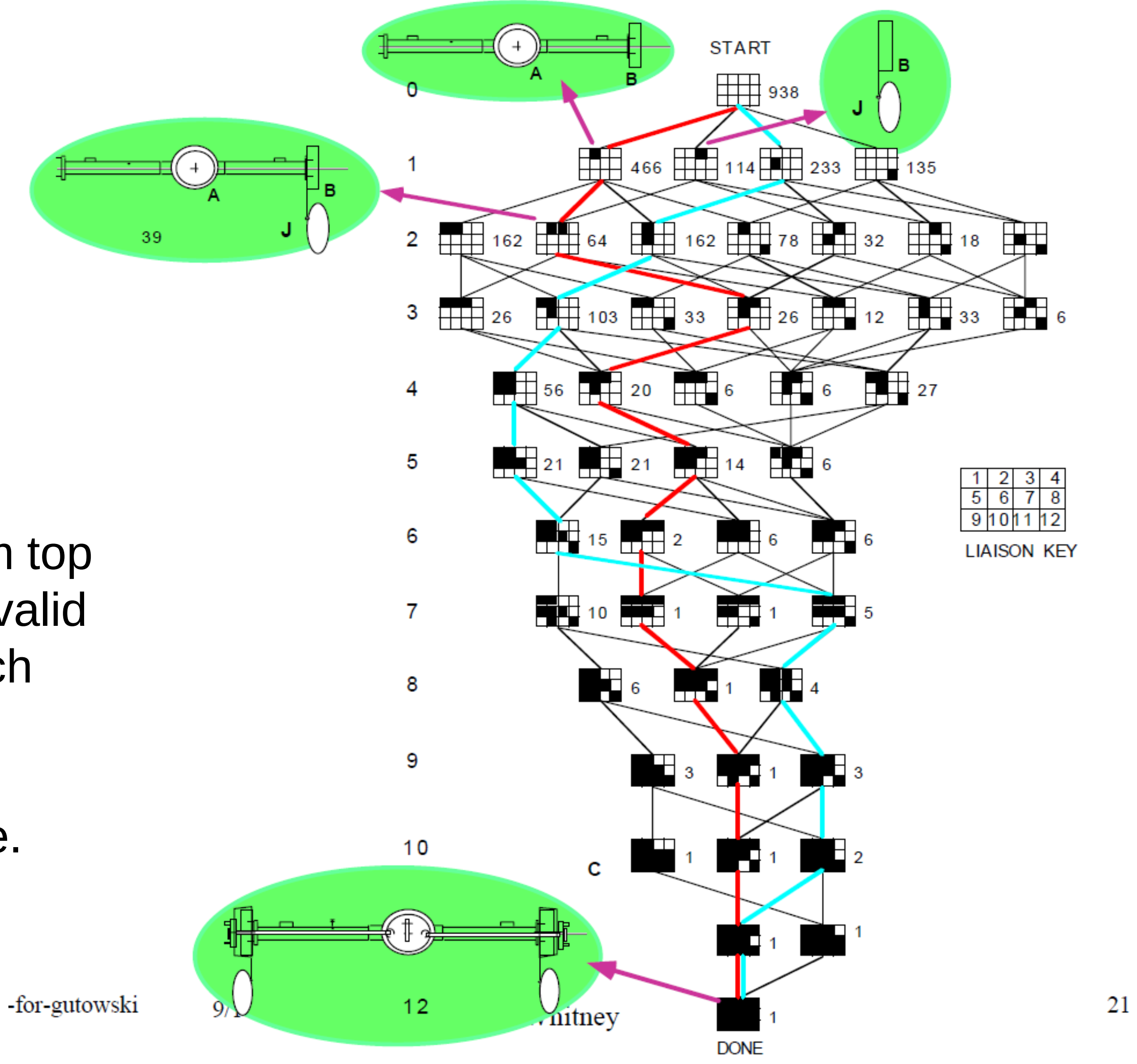


Two more Alternator Sequences



Example

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

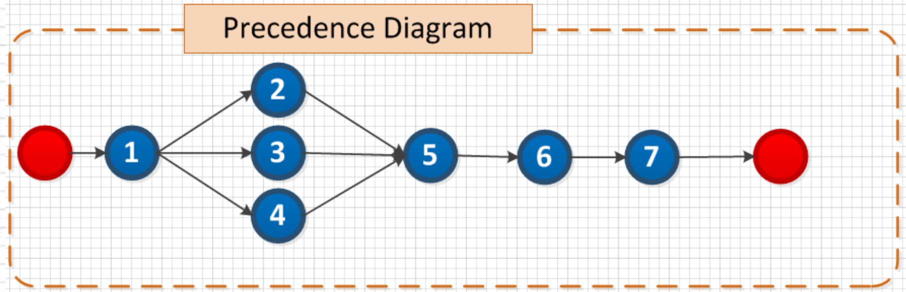


Precedencies Table

Part ID	Part Description	Precedencies
1	Base Object	First part
2	....	1
3	....	1
4	....	2,3
.	....	...
.	....	...
N	....	...

Precedencies Table and Diagram: an example

	Task	ID	Precedencies
 Tube- Base Object	Put in Fixture	1	-
 Main Mirror	Snap Fit	2	1
 CO2 Mirror	Snap Fit	3	1
 Component Block	Snap Fit	4	1
 Flexible Circuit Board	Soldering	5	2,3,4
 PBA Set	Soldering	6	5
 PBA Shield	Guided Fit	7	6



Project

- Description of the object
- Liaison diagram
- Precedence diagram

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

Kinds of cost categories

Fixed cost= what you pay to set up (usually investment in facilities)

Variable cost= what you pay that depends on how many you make per unit time:

- Labor*, both direct and indirect (maintenance, supervision)
- Materials cost
- Expendables: energy, lubricants, tool, etc..
- Scrap, rework

Institutional Cost= all other cost of doing business

* In many cases labor is considered a fixed cost, due to the contracts or the inability to lay people off for short periods when business fluctuates

Main Issue with the economic analysis

Fixed costs are usually expended all at once, mostly before the production takes place

Variable costs are incurred as production runs

How should we combine this to costs to assess the **UNIT COST** of a product?

Main Issue with the economic analysis

The usual method is to allocate the fixed costs to the units by choosing a time period during which the investment is “recovered”

Unit cost= variable cost + η*fixed cost

Where “η” depends on the units of products in the reference period

Some consideration on “η” in fixed and flexible automation

- If a piece of equipment is **dedicated** (like a fixture or an aptly designed pick and place non reprogrammable device) to an operation on a particular product, chances are that you will only be able to use it for that product*.
- **Flexible** devices like robots can be reused for different production**

* Unless you re-engineer them, but often this process costs more than buy a new device!

**Still you will have to cope with the cost of reintegrating the device that are not neglectable

Simplified Cost for manual assembly

You can use this formula to evaluate the cost of the current solution used for the product proposed for the project, and for evaluating the manual cost in the solution you propose (with investment cost neglectable)

$$COST_{Unit\ Manual} = \frac{A\$ \ \#People}{Q}$$

$$\#People = \left[\frac{T\ N\ Q}{hr_{year} * 3600} \right]$$

A$ = annual cost of a person

Q = annual production volume

T = assembly time per part

N = number of part per unit

3600 = sec/hr

$$A\$ = \overline{L}_H * 2000$$

$$L_H = \text{labor cost, } \$ / hr$$

Simplified Cost for Fixed automation

$$C_{UNIT\,FIXED} = \frac{f_{AC}\, N\, S\$}{Q}$$

where Q = annual production volume, units / year

f_{AC}=fraction of machine cost paid for per year

$S\$$ = cost of one station in the machine

(assumes one station per part)

(also assumes no people required)

Simplified Cost for Flexible automation

$$C_{UNITFLEX} = \frac{f_{AC} I}{Q} + \frac{L\$}{Q}$$

where I= total investment in machines and tools

L$ = annual cost of workers associated with the system

$$I = \#\,MACHINES * \$ / MACHINE + \#\,TOOLS * \$ / TOOL$$

$$\#\,MACHINES = \left[\frac{T\,N\,Q}{2000 * 3600} \right]$$

$$\#\,TOOLS = N$$

$$L\$ = w \bar{L}_H \;\#\,MACHINES * 2000$$

where w = number of workers / station

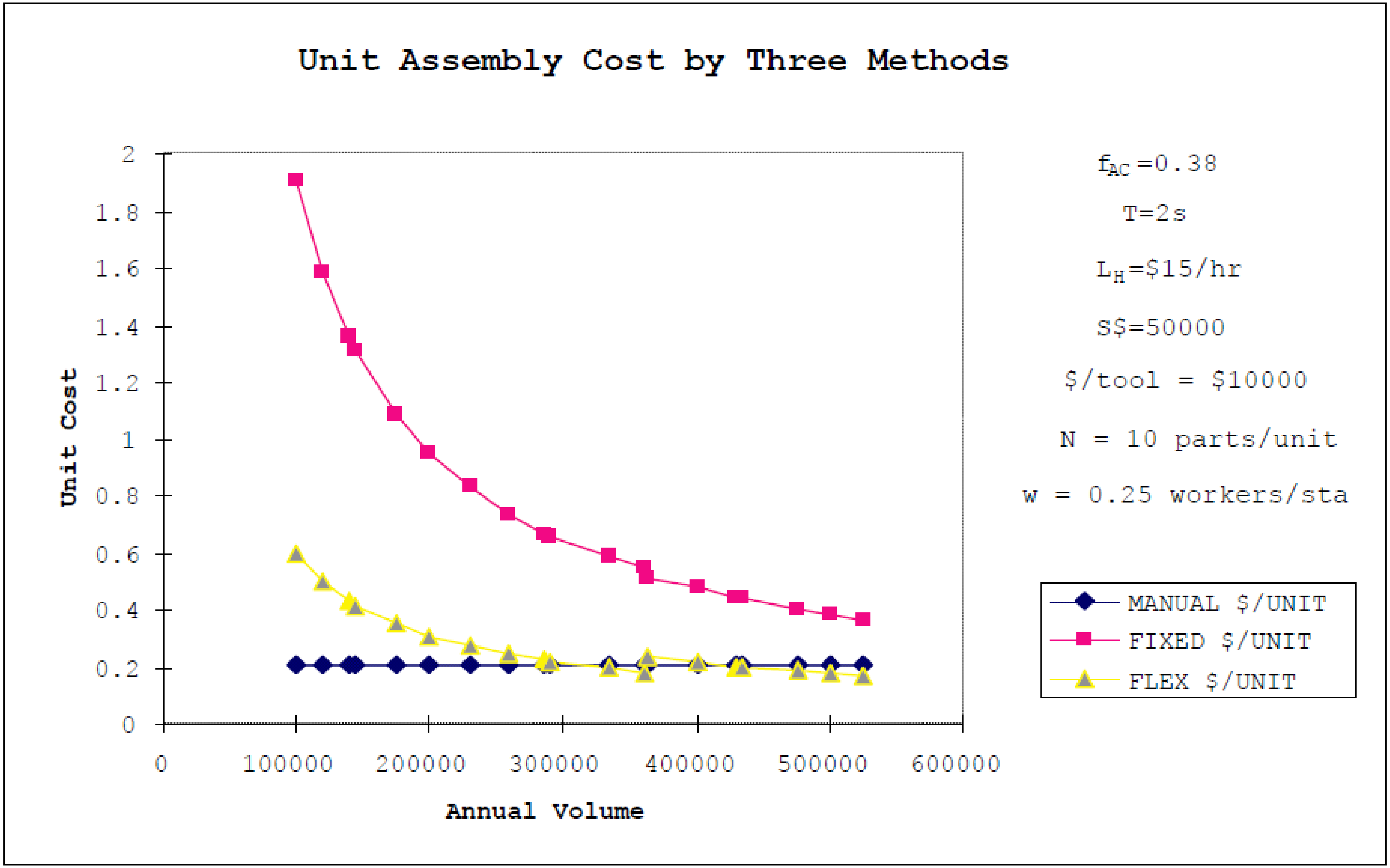
Simplified Cost for Flexible automation

Combining the above yields:

$$C_{UNIT\ FLEX} = \frac{f_{AC}}{Q}\left[\#\ MACHINES * \$\ /MACHINE + \#\ TOOLS * \$\ /\ TOOL\right] + \frac{L\$}{Q}$$

$$C_{UNITFLEX} - \frac{f_{AC}\ \$/\ MACHINE\ T\ N}{2000 * 3600} + \frac{f_{AC}\ \$/\ TOOL\ N}{Q} + \frac{w\ T\ N\ \overline{L}_H}{3600}$$

Unit Cost example



Basic Steps of System Design

- Capacity planning -required number of units/year
- Resource choice -assembly methods (description of the assembly process)
- Task assignment
- Workstation design
- Floor layout
- Material handling and work transport
- Part feeding and presentation
- Quality
- Economic analysis
- Personnel training and participation

Capacity Planning

24 Hours per Day

Scheduled Operating Time (Utilization)

Unscheduled Downtime:

- Part Jams
- Queue/Block/Starve
- Machine Broken

Scheduled Downtime:

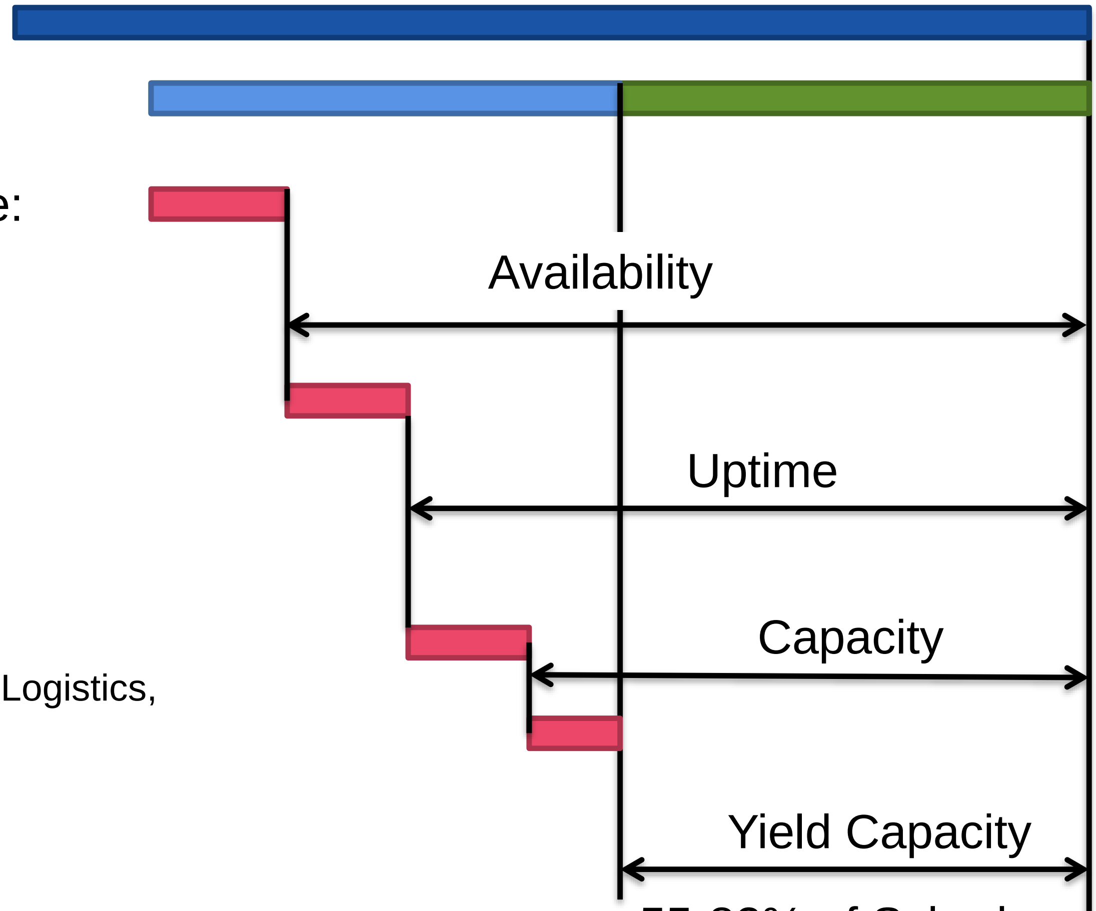
- Tool Change
- Variety Change
- Preventive Maintenance
- Employee Breaks

Proces Efficiency:

- Task Time, Line Balance, Logistics, Scheduling

Proces Quality:

- %bad Parts of Cycles



55-82% of Sched Time!

Volume

- High Volume = 100K/yr or over???
  - High Volume
    - Machines are feasible Economically
    - Manual assy may be necessary technically
  - Low Volume
    - Manual assy is feasible Economically
    - Machines may be necessary technically

Takt time	
Airplane	3 days
Car	48 s
Cigarette	10 ms

Size ↓

Operational organisation 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 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

Line Architectures

- Single serial line
- Fishbone serial line with subassembly feeder lines (transmissions, axles)
- Loop (common for automated lines with reworks)
- U-shape cell (often used with people)
- Rotary dial (for short production cycle with a long production task

Balancing

The balancing of the assembly system can be achieved through:

- Re allocation of the work to different work station (to meet the desired cycle time!)
- Parallel station (to shorten the cycle time of each atomic task!)

•Buffers (to decouple stations from each other, useful in integrating human and automatic stations!)

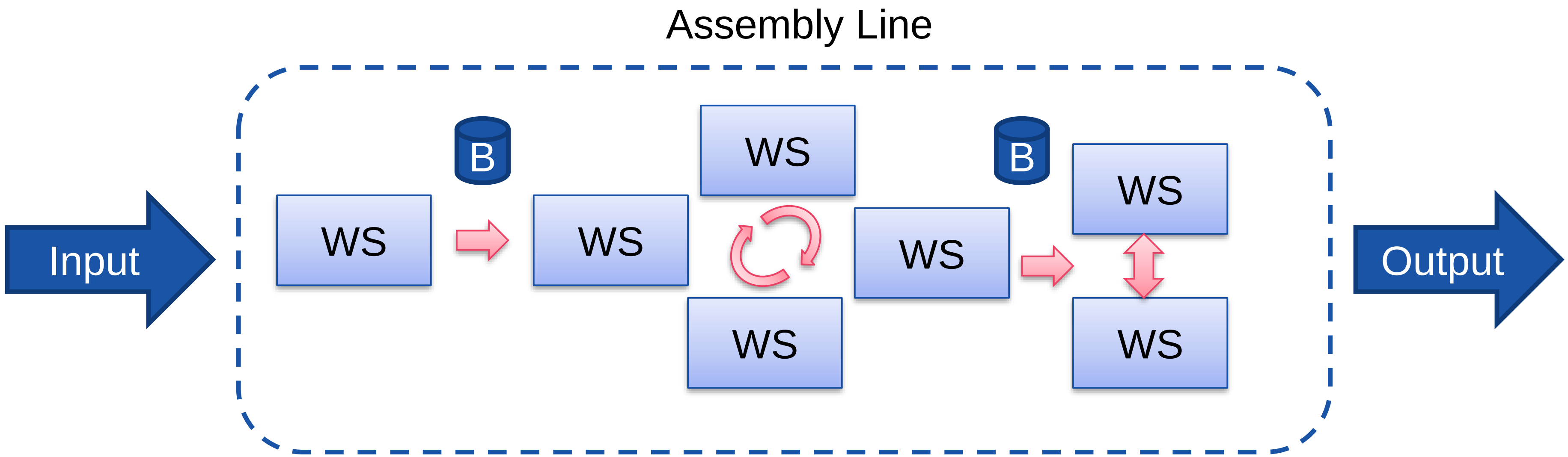
Operational aspects line balancing

- 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”

Balancing

Workstations deployment

- Internal and External Logistic
- Buffering



Automatic Assembly Equipment

- Industrial Robot
- Grippers
- Feeder
- Fixtures
- Transport unit
- ….

Question for the formative assessment

1. Define the assembly process and characterize it in relation with the manufacturing domain. List the technical aspects of an assembly operation.
2. What is the impact of a assembly-driven product realization in term of design and dissemination time and which are the main areas of companies cost/effort affected?
3. List and describe (technically and economically) the three main categories of industrial assembly in respect to human participation.
4. What are the products key characteristics and how do they relate to the architectural aspects of assemblies.
5. List the assembly models you know from the simplest to the most sophisticated. Provide a short description for each model.

Question for the formative assessment

5. What is the difference between a feasible sequence and a good sequence and which are the criteria that link them.
6. Which are the economic aspects of assembly in general and with respect to different kinds of assembly processes (manual, fixed automation and flexible automation) and related costs. Present the typical costs that are encountered in economic analysis of assembly systems and report the specific formulas used for the analysis of such approaches by using the supporting concept of unit cost. Sketch a graph confronting the three approaches.
7. Which are the basic steps in assembly system design?
8. How do you calculate the available time in an assembly system?