The Design Process
Embodiment Design and Detail Design

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The Design Process

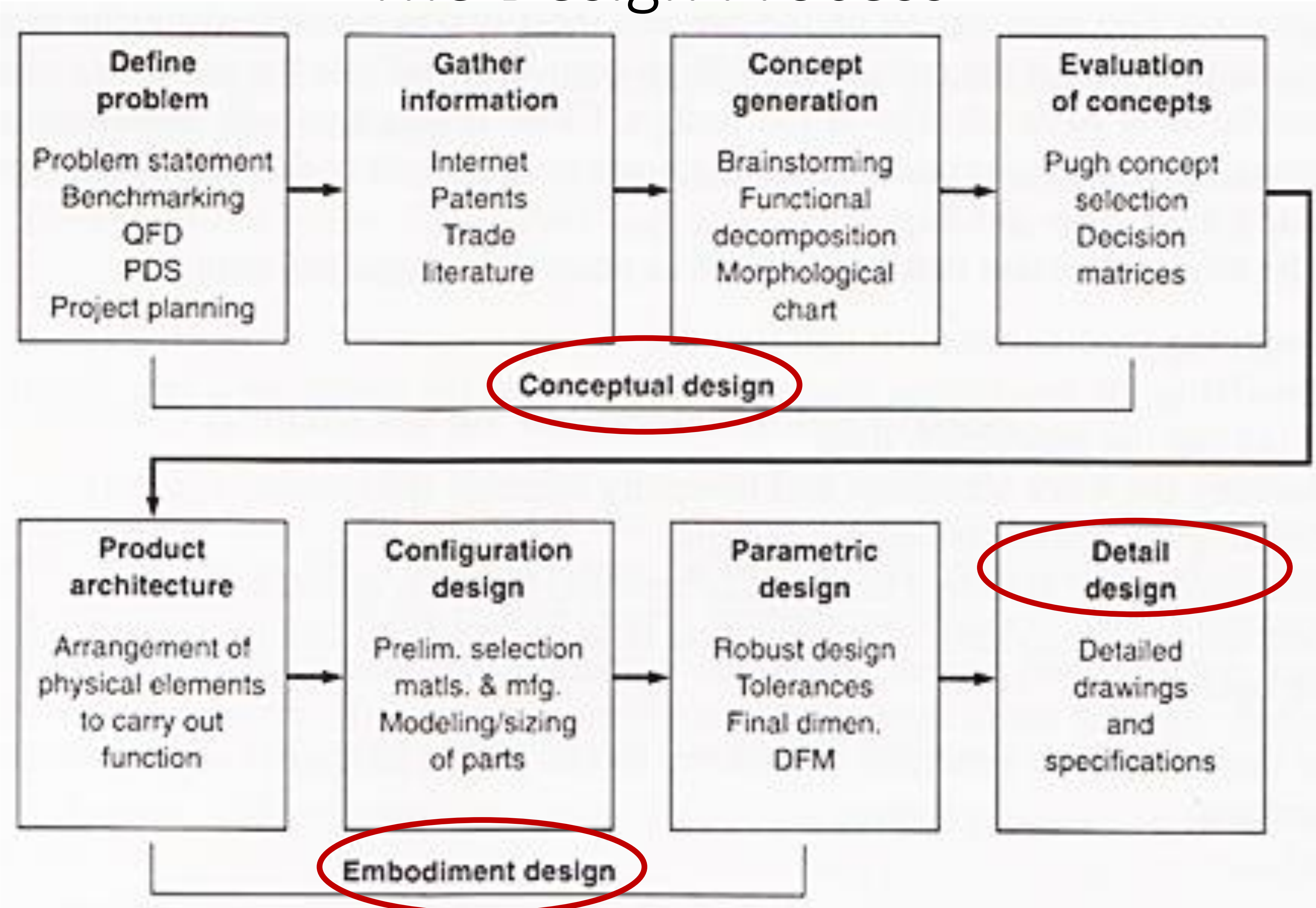
Three Major Phases

1. Conceptual Design
2. Embodiment Design
3. Detailed Design

Others

4. Planning for Manufacture
5. Planning for Distribution
6. Planning for Use
7. Planning for Retirement of Product

The Design Process



The Design Process
1. *Conceptual Design*

- Recognition of a need
- Definition of the problem
  - Includes defining the problem statement, design requirements, constraints, and risks.
- Gathering of information
- Developing alternative design concepts
- Evaluation of concepts and selection

The Design Process

2. *Embodiment Design (Preliminary Design)*

A. **Product Architecture** – arrangement of the physical functions
B. **Configuration Design** – preliminary selection of materials, modeling and size of parts
C. **Parametric Design** – creating a robust design, and selection of final dimensions/parameters and tolerances.

Evaluation: This process must also be accompanied by a series of evaluations to determine if the existing design concept remains feasible. Iteration is often required.

The Design Process
3. Detail Design (final design)

- Creation of final drawings and/or specifications.

- **Example** – final definition of flow rates, chemistries, process time, temperatures, etc. for a extractive metallurgy process.

2. Embodiment Design

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2.Embodiment Design

A. Product Architecture

Two types of product architecture

1. Integral Architecture
   - implementation of functions is accomplished by only one or a few modules
   - Components perform multiple functions
   - **Example:** crowbar (single component provides leverage and acts as handle)
2. Modular Architecture
   - Each module implements one or a few functions
   - Interactions between modules are well defined.
   - New products or functionality easily developed by adding, deleting, or swapping modules.
   - Benefits from economies of scale and rapid product development (develop new module, get new product)
   - **Example:** Modular hip assembly, Laser drilling/ablation equipment

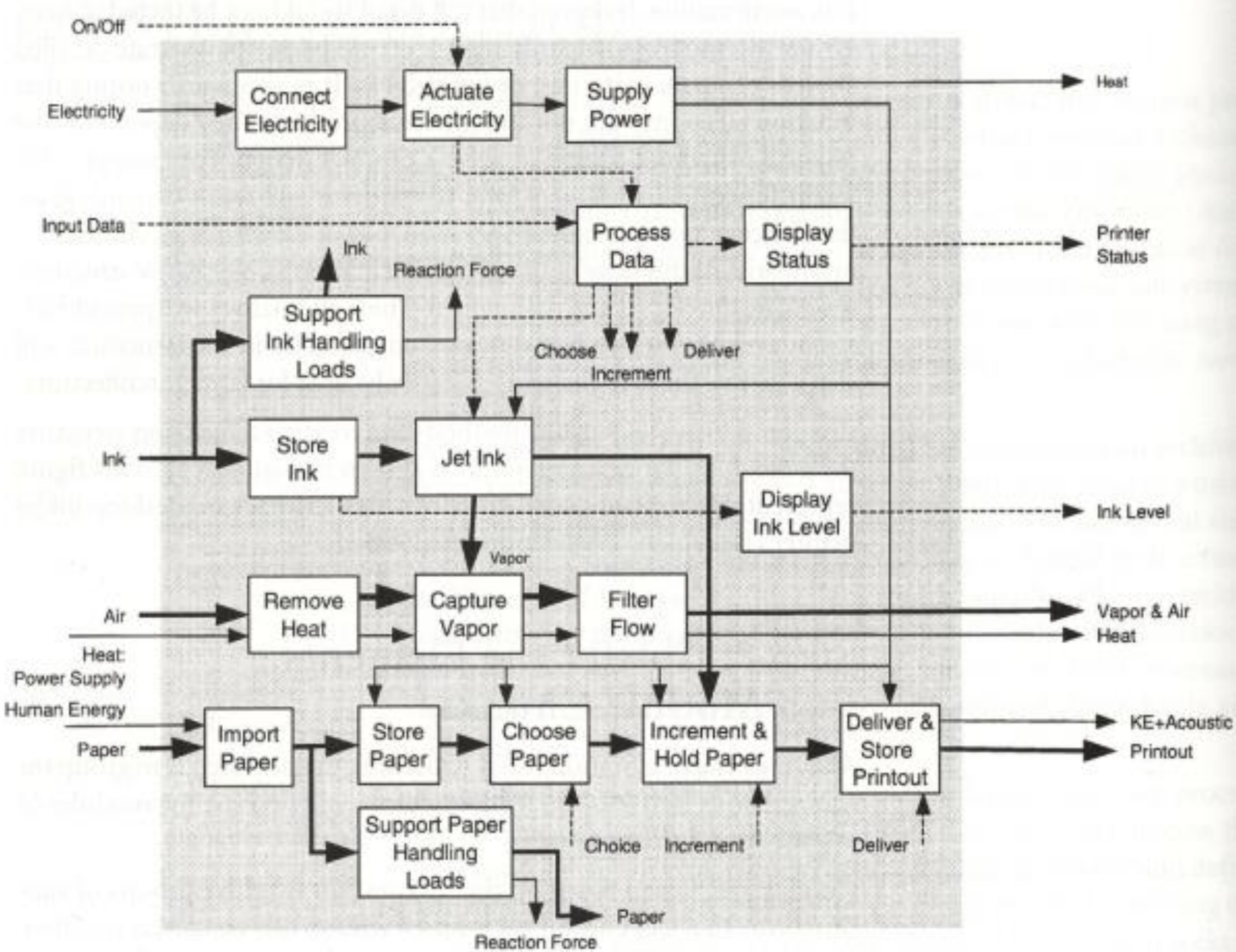
Modular Architecture Example: Hip Joint

2. Embodiment Design
A. Product Architecture

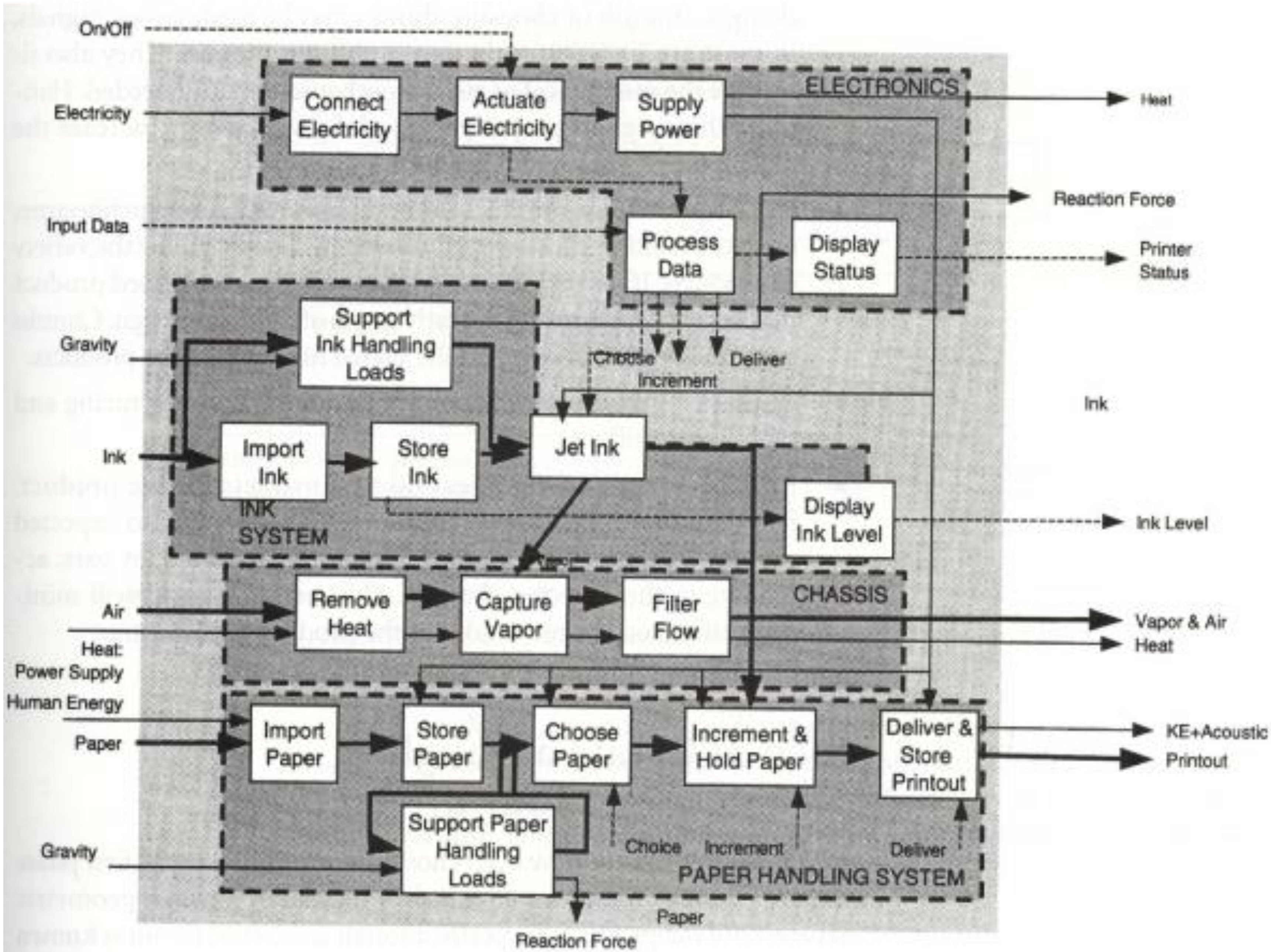
Four steps to developing product architecture

1. Create a schematic diagram of the product (flow chart)
2. Cluster the elements of the schematic
3. Create a rough geometric layout
4. Identify the interactions between modules and performance characteristics

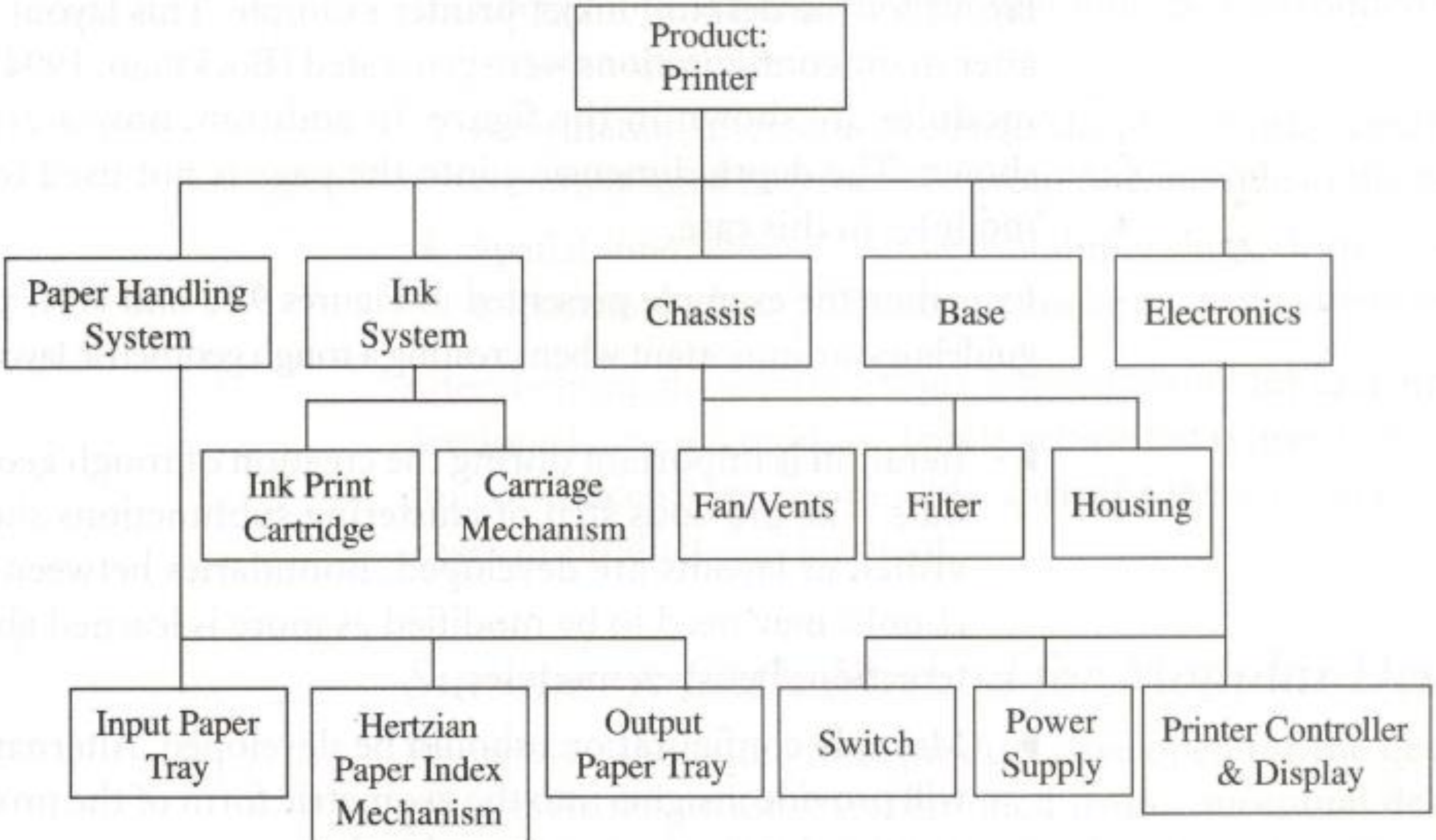
2A. Architecture Schematic (Printer)



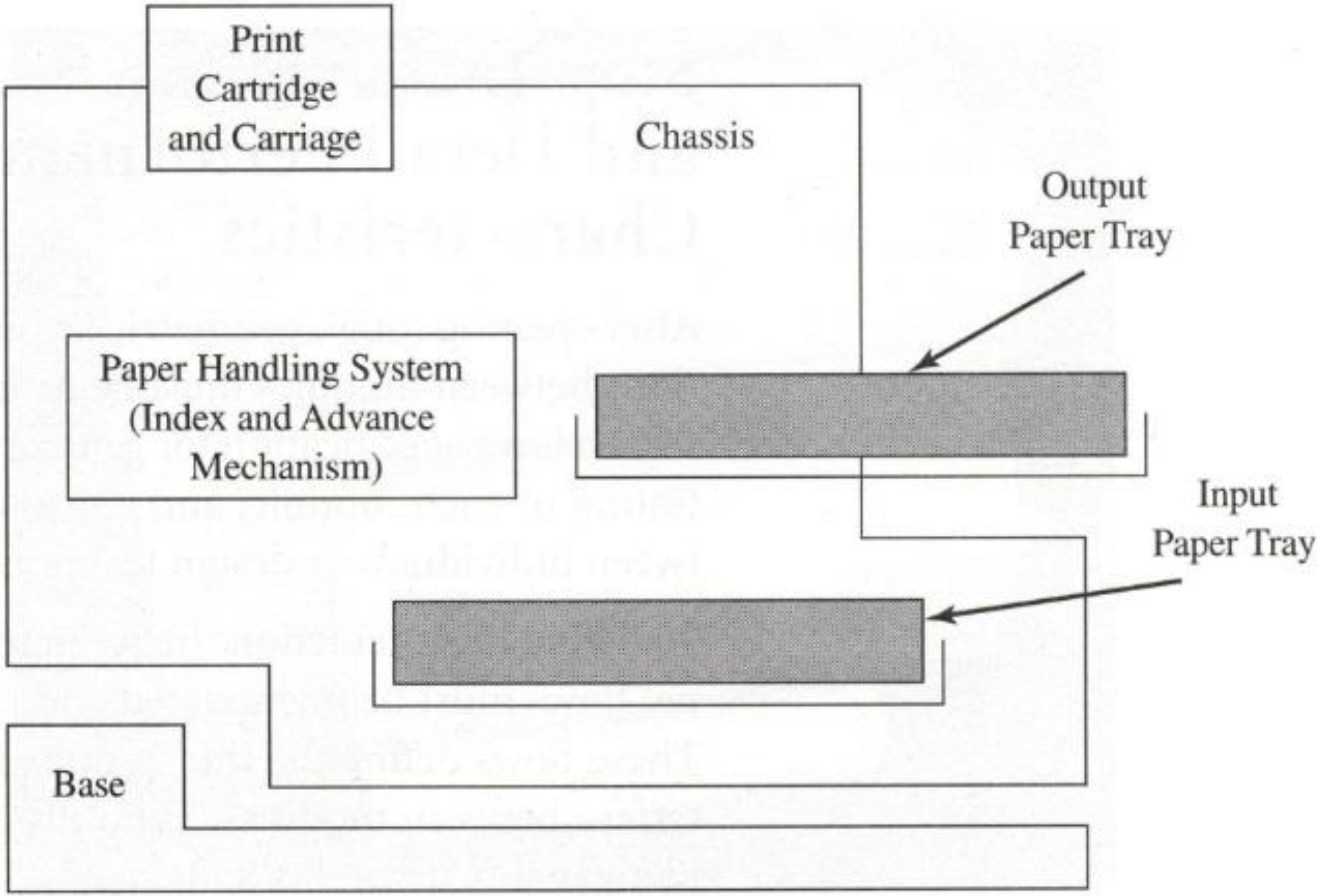
Clustering Elements into Modules/Groups



Physical Decomposition
Module and Subcomponent Definition



Rough Geometric Layout



MET Design Project Example

Rapid Salt Flux Analysis – Al Recycling

- Real Alloy uses NaCl:KCl: Cryolite flux
  - Remove impurities, oxidation protection, insulate melt
- Flux composition is important
  - ~48/48/4 provides the lowest melting point
  - KCl is more expensive than NaCl
- Real Alloy uses a 3rd party for composition analysis
  - 2-week turnaround
  - Flux consumed prior to receiving results

Problem Statement

The Real Alloy Design Team will design a method to quickly measure the composition of a NaCl-KCl flux.

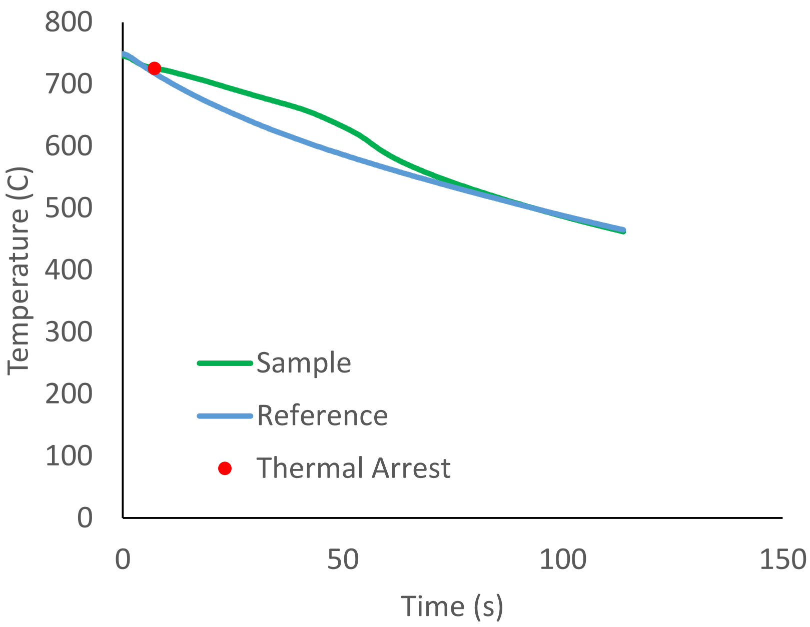
Requirements	Target	Comment
Accuracy	±0.50 wt%	
Ease of use	Little to no training	Use by one technician
Compounds analyzed	KCl and NaCl	Future work, adding cryolite (Na_3AlF_6)
Turnaround time	<1 hr	

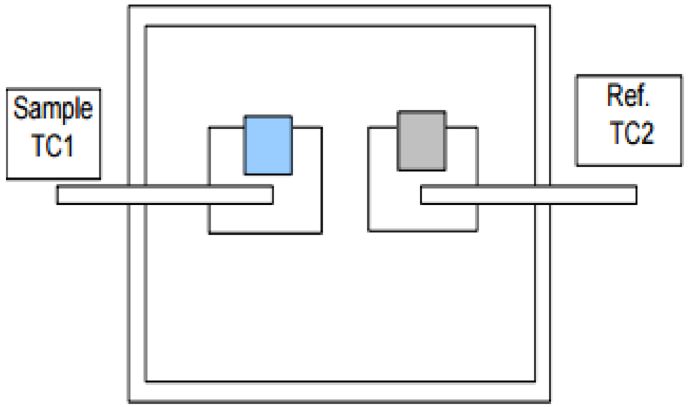
Differential Thermal Analysis

- Compared to AAS, ICP, Gravimetric, Titration
- Pros
  - Fast (less than an hour)
  - Relatively simple to perform
  - Inexpensive (<$2000 start up)
  - Works for all three of the materials
- Cons
  - Lower accuracy (~0.5% accuracy)

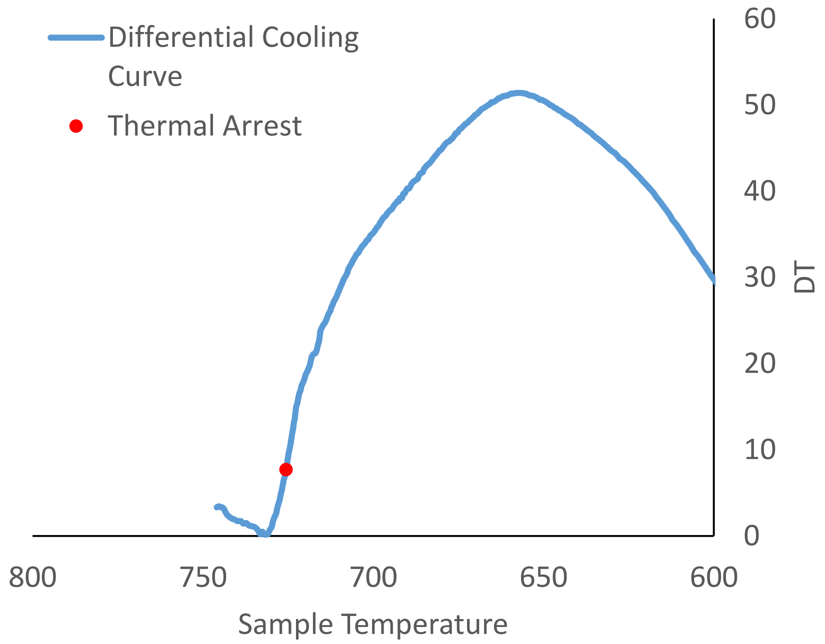
Technical Method

Thermal arrests and Differential Thermal Analysis (DTA)





Silva, Ari F., Nilton Nagem, Edson Costa, Leonard Paulino, and Eliezer Batista. "Implementation of STARprobeTM Measurements & Integrated Pot Control at Alumar." (n.d.): 3. Web.



2A. Design Architecture – Schematic

Relate Functions to Components

Contain molten salt	Crucible
Melt salt	Furnace
Measure Temperature	Thermocouple/reader
Measure Thermal Arrest	Thermocouple Reader, Comparative Thermocouple
Analyze data/estimate composition	Need Thermodynamic Model
Transfer material (to furnace, from furnace)	Need Gloves, Tongs, etc.

Equipment

http://www.tandd.com/product/mcr/index.html

2. Embodiment Design/A. Product Architecture
Define Interactions and Performance Characteristics (step 4)

Types of Interactions

1. **Spatial** – describes physical interfaces
2. **Energy** – how does energy flow between modules (electricity, heat, etc)?
3. **Information** - how does information (signals, feedback, etc) flow between modules?
4. **Material** – how does material flow between modules?

Performance Characteristics

For each module define the following:

1. Functional requirements (what will it do?)
2. Drawings or sketches of the module and component parts
3. Preliminary component selection for the module
4. Detailed description of placement within product
5. Detailed description of interface with neighboring modules
6. Accurate modules for expect interaction between modules

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2. Embodiment Design
B. Configuration Design

Goal: specify the configuration of the design and associated modules to meet their intended function. Involves

- Preliminary selection of materials
- Selecting component manufacturing methods (casting, forging, machining, etc)
- Sizing of parts
- Modeling of system (stress, thermo, heat, fluid, mixing, etc.)

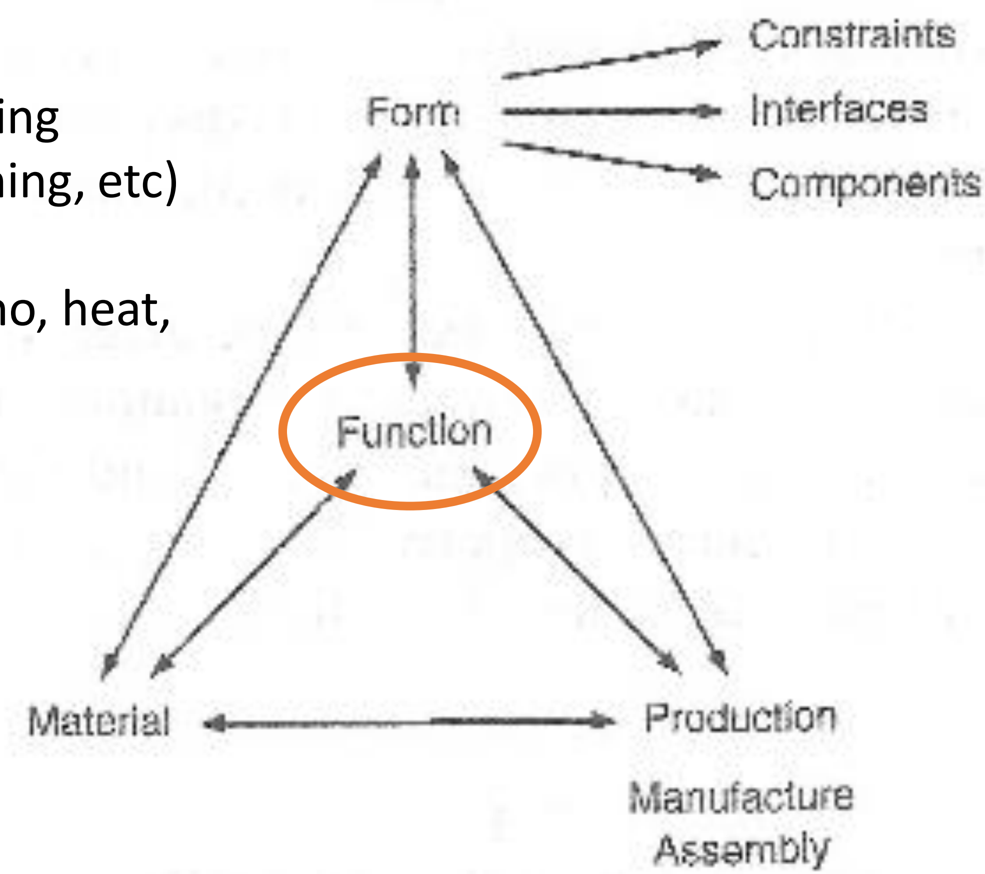

FIGURE 8.7
Schematic illustrating the close interrelationship between function and form and, in turn, their dependence on the material and the method of production. (*After Ullman*)

2B. Configuration Design Process

Starting with the design architecture, the configuration design process involves three basic steps:

(1) Generate alternative design configurations

(2) Analyze Design Configurations

- How does each configuration meet the functional requirements and overall design requirements/specifications?

(3) **Evaluate Configuration Designs**

- This is a preliminary design evaluation to select between various design configurations. Full design analysis is reserved for parametric design.
- Use decision matrix and module based evaluations/models/tests

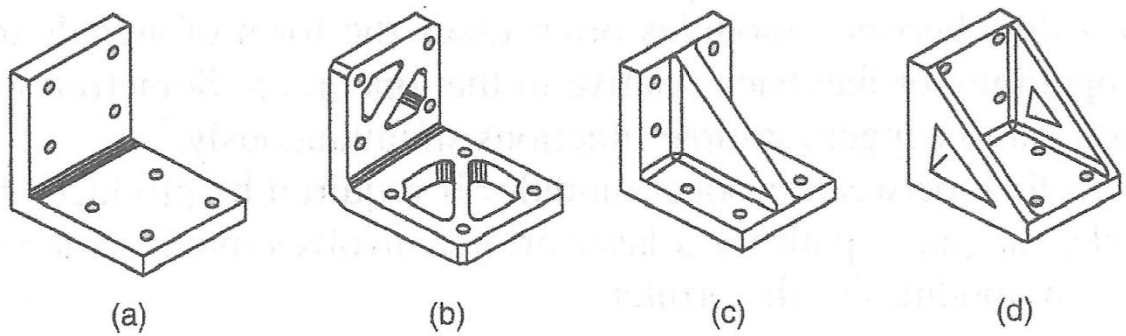

FIGURE 8.6
Four possible configurations of features for a right-angle bracket. (a) Bent from a flat plate. (b) Machined from a solid block. (c) Bracket welded from three pieces. (d) Cast bracket.

2B. Configuration Design (Cont’d)

General configuration design rules

1. **Clarity of Function**
   - The relationship between inputs/outputs (energy, material, signal) and function should be unambiguous and, when possible, functions should be independent
   - Braking system should not interact with steering system (e.g. require same signal or energy input)
2. **Simplicity**
   - Design to the minimum complexity level while still achieving function. (KISS)
   - Design should be easily understood and produced.
3. **Safety**
   - As much as possible, safety should be guaranteed by direct design, not by secondary methods (labels, guards, etc.).

2B. Configuration Design (Cont'd)

More about safety

Safety

- As much as possible, safety should be guaranteed by direct design, not by secondary methods (labels, guards, etc.).

Direct Safety

- Involves design approaches that prevent accidents from happening
- Fail safe, redundancy, visible checks
- Evaluate risk, reliability, availability, cost
- Safety preserved for operator, society, and environment (and equipment)

Indirect Safety and Chain of Failure

- What if ____{breaks, loosens, slips, rusts, fails, etc.}?
- What is the next safety barrier item (in the chain of failure)?
- Warnings are not legally sufficient defense against claims of negligent product design

Scope: Safety design evolves safety of function, working principle, layout, operation (e.g. ergonomics), manufacturability, assembly/transport, operation, maintenance, recycling

2B. Configuration Design

General Design Principles

(1) **Force Transmission** – involves designing with an understanding of how forces will be transmitted within and between components to minimize/eliminate sections of potential weakness (e.g. maintain low nominal stresses, reduce stress concentration, maintain uniform stress distribution) [mechanical design focus]

(2) **Division of Tasks** – similar to clarity of function. Critical functions require components designed for that single function. Resist assigning multiple functions to a single component to avoid compromising performance of individual functions. *Must balance performance vs. cost.*

(3) **Self-Help** – where possible make designs that are "fail safe", self-reinforcing, or self-protecting. For example, O-ring seal that provides better sealing with increased pressure. **Austenitic manganese parts** – improved wear performance in response to heavy deformation.

(4) **Stability** – design should developed to recover appropriately from a disturbance. For example, ship that rights itself in high seas or plating bath chemistry that stabilizes after chemical excursion.

2B. Configuration -Design Checklist

1. Identify how each component/part may fail in service (wear, corrosion, overload, fatigue).
2. Identify ways that component/module functionality might be compromised
3. Identify possible materials and manufacturing issues
4. Identify areas of limited design knowledge base. Are there “unknown” areas of the design

This process typically requires a **Failure Modes and Effects Analysis (FMEA)**

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Evaluation: This process must also be accompanied by a series of evaluations to determine if the existing design concept remains feasible. Iteration is often required.

2. Embodiment Design
C. Parametric Design

- Once a final design configuration is selected the design variables (parameters) must be set through evaluation.
- Design attributes for each component are identified in configuration design and become design variables (component attributes that may be varied by designer)
- This process involves detailed modeling and analysis to determine the final design parameters.
- System level evaluation and parametric analysis.
- Output:
  - Robust design
  - Final sizing of parts, tolerances, flow rates, chemistry, etc.

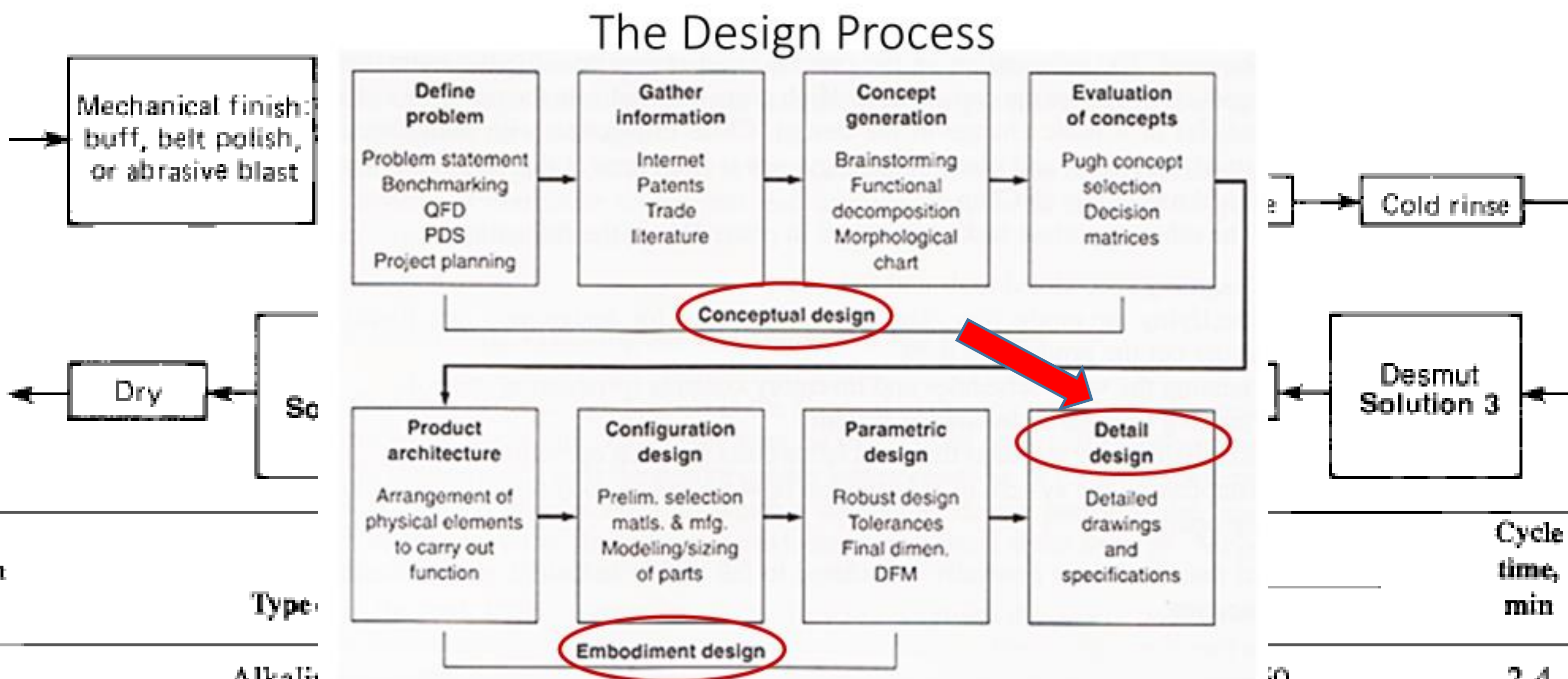
2. Embodiment Design

C. Parametric Design (Cont'd)

Parametric Design Steps

1. Generate alternative designs (combinations of design variables). E.g. part size, materials, flow rates, tolerance, etc.
2. Analyze/evaluate the alternative designs
3. Select best alternative design
4. Refine/optimize

Example: Anodizing
What are the design variables?
How would you analyze/evaluate?



Solution No.	Type				Cycle time, min
1	Alkali			0	2-4
2	Alkaline etching	NaOH, 5 wt%	50-71	120-160	2-20
3	Desmutting	HNO_3, 25-35 vol%	Room	Room	2
4	Anodizing	H_2SO_4, 15 wt%	21-25	70-75	5-60
5	Sealing	Water (pH 5.5-6.5)	100	212	5-20

Fig. 5 Operations sequence in sulfuric acid anodizing of architectural parts

The Design Process
3. Detail Design (final design)

- Detailed design is the phase where "*all of the details are brought together, all decisions are finalized and decision is made to release to production*"
- Creation of final drawings and/or specifications.
- **Example** – final definition of flow rates, chemistries, process time, temperatures, etc. for a extractive metallurgy process.
- The line between embodiment design and final design is often blurred.

3. Detailed Design (Final Design)

Steps

- Make/Buy Decisions
- Finalize selection and sizing of components
- Complete engineering drawings
- Complete Bill of Materials (BOM)
- Verification and Prototype Testing Completed
- Final Cost Estimate
- Prepare Design Project Report
- Final Design Review
- Release to Manufacturing (order material, fabricate, etc.)