A holistic view of design for manufacture

Dr James Moultrie
Agenda ...

- A brief history lesson!
- Design for manufacture
- Design for assembly
- Product architecture
- Product platforms
A brief history lesson ...
Eli Whitney ...

- Originally a blacksmith: nails and hatpins
- Attended Yale in mid 20s
- Taught
- Worked on a plantation
  - Designed a machine to clean cotton
  - Did work of several people
  - But machine copied
  - Nearly ruined in court cases
- Penniless at 39

Source: www.eliwhitney.org/
Eli Whitney ...

- Took an impossible order to make 10,000 muskets at $13.40 each
- Up to then, all rifles were handmade
- Invented the milling machine
- He created (arguably) standardised and interchangeable components
- Tolerances!

Source: www.eliwhitney.org/
Henry Ford ...

- 1907: assembly line
- divided manual assembly operations into short cycle repetitive steps
- Model T ford - standardised parts, simplification
- Serviceability - easy access for repair

“We start with the consumer, work back through the design and finally arrive at manufacturing”
Value analysis ...

- General Electric 1940
- Systematic review of product costs
- Initially applied to existing products

- Value engineering: applied during design phase

Source: http://dismuke.net/howimages/gerefrig1940large.jpg
1960 onwards ...

- **1960s: Producibility & manufacturability**
  - GE developed internal guide - “manufacturing producibility handbook”
  - c. 1985 DfM came into wider use

- **1968: Systematic methods for Design for Assembly**
  - Boothroyd & Redford: studied automatic assembly
  - Later Boothroyd & Dewhurst
  - Lucas Engineering Systems
1980’s: Concurrent engineering ...

- Idea
- Market development
- Product design
- Manufacturing process design
1990s DfX and Product architecture

- Df ... environment, safety, etc
- Product platforms
- Product architecture
- Modularity
- Reuse
Design for manufacture
DFM elements ...

• Appropriate process selection
  – material, volume
  – tolerances, complexity
  – set up costs
  – expertise (internal / external)

• Reduce the number of process stages
  – eliminate and combining processes
  – reducing set up requirements

• Optimise for the process
  – recognise the process limitations
  – exploit benefits of the process
  – DFM process specific guidelines
Process guidelines ...
## DESIGN FOR MANUFACTURABILITY / ASSEMBLY GUIDELINES

### INJECTION MOLDING

© 2002 DRM Associates www.rpd-solutions.com

### Raw Materials

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Exception/Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use standard material types, colors, and fills.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consider recyclability of the material when selecting.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substitute a material that is more economical.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substitute a material that is easier to process.</td>
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<tr>
<td>Mark the part with the material to be used.</td>
<td></td>
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</tbody>
</table>

### General

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Exception/Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid unnecessary part features &amp; complex shapes - they involve more complex tooling.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avoid unnecessary tolerances &amp; finishes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use lowest cost equipment that provides needed capability.</td>
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</tbody>
</table>

### Part Ejection:

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Exception/Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place gate &amp; ejector pin locations on underside of part where blemishes are least critical.</td>
<td></td>
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</tr>
<tr>
<td>Use draft angles to facilitate part removal. The draft angles should typically be &gt; .5° minimum; typically 1° to 2° for 5° depth. Use a greater angle with texture.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimize surface area perpendicular to part line since greater surface area of walls &amp; projections perpendicular to part line requires increased ejection force. Higher ejection forces require longer cooling times. Since cooling is 70%-80% of mold cycle, ejection force is an important DFM factor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce ejection force requirement by: considering rib &amp; projection height &amp; surface area; use gussets instead of ribs; use larger draft angles, and polish the mold surface.</td>
<td></td>
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</tbody>
</table>

### Wall thickness:

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Exception/Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep uniform - less than 15% variation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make transitions gradual.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thicker walls require more cooling time; consider ribs as a structural alternative.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Corners:

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Exception/Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid sharp corners.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain inner radii &gt; .5 x wall thickness.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain outer radii &gt; 1.5 x wall thickness.</td>
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<td></td>
</tr>
<tr>
<td>Maintain inner &amp; outer radii around common center point.</td>
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</tbody>
</table>
Examples ... machined part guidelines ...

**DO** - Design holes to the shape of the tool. If a hole is to be tapped, provide space for it.

**Don’t**

**DO** - Use standard dimensions wherever possible (NB - these may vary depending on the tooling available)

**Don’t**

**DO** - Provide an undercut for threads in turned components

**Don’t**

**DO** - Provide appropriate fillet radii (matched to tool tips)

**DO** - Place holes away from edges - allow room for tool
Design for assembly
Sub-system optimisation
- Assembly optimisation
- Component minimisation, handling, fitting, feeding

Component optimisation
- Component commonality
- Process selection
- Process optimisation

Assembly

Component
DFA - Design for Assembly ...

- **Design guidelines or design rules**
  - System level
  - Issue specific - handling, fixing etc

- **Systematic methods to analyse an assembly**
  - Lucas Engineering & Systems
  - Boothroyd & Dewhurst

- **Basic philosophy of all approaches**
  - minimise the number of components
  - maximise ease of locating & joining
Don’t fight gravity
Open enclosures

Avoid confined spaces
Don’t ‘hide’ key components
Assemble from a single direction
Integrate components ...
Systematic methods ...

• **Functional analysis**
  – Is each component needed?

• **Handling analysis**
  – Are the components simple to handle?

• **Fixing analysis:** Mapping assembly sequence:
  – *Insertion / holding process*
  – *Securing / fixing processes*
  – *Additional (non-assembly) processes*
Component functional analysis ...

- **Relative movement**
  - Does the part move relative to parts which have already been analysed?  
    - Y
    - N
  - Is the movement essential for the product to function?  
    - Y
    - Y
    - Y
    - N
    - N
  - Must the part be separate to provide this movement?  
    - Y
    - N

- **Different materials**
  - Is the part made of a different material to those with which there was no relative movement?  
    - Y
    - N
  - Is the material difference essential for product function?  
    - Y
    - Y
    - Y
    - N
    - N
  - Must the part be separate to satisfy the different material requirement?  
    - Y
    - N

- **Need for adjustment / replacement**
  - Is the part separate to allow for maintenance, adjustment or replacement?  
    - Y
    - N
  - Is the maintenance, adjustment or replacement essential?  
    - Y
    - Y
    - Y
    - N
    - N
  - Must the part be separate to enable adjustment or replacement?  
    - Y
    - N

- **Non essential ‘B’ component**
- **Essential ‘A’ component**
Component handling & feeding ...

- Handling
  - Presentation of parts in manual assembly

- Feeding
  - Presentation of parts in automated assembly

- Scores based on:
  - size and weight
  - specific handling difficulties
  - part orientation - symmetry
### Component handling ...

*Ease of delivering, handling and orienting each component in preparation for assembly*

<table>
<thead>
<tr>
<th>Component size &amp; weight</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Convenient size</strong>&lt;br&gt;One hand only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Small</strong>&lt;br&gt;Fiddly or requires tools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Large / heavy</strong>&lt;br&gt;2 hands or tools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Very large / heavy</strong>&lt;br&gt;2 people or hoist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Handling difficulties</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No handling difficulties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Need care to grip</strong>&lt;br&gt;Adherence, delicate, sharp / abrasive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Difficult to grip</strong>&lt;br&gt;Flexible, untouchable, awkward</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Tangling &amp; severe nesting</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Beta (rotational) symmetry: about axis of insertion</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Any orientation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Easy to orient:</strong>&lt;br&gt;orientation easy to see and mistake proof</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tricky to orient:</strong>&lt;br&gt;Orient difficult to see but mistake proof</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Difficult to orient:</strong>&lt;br&gt;Orient difficult to see – mistakes possible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alpha (end-to end) symmetry: perpendicular to axis of insertion</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Any orientation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Easy to orient:</strong>&lt;br&gt;orientation easy to see and mistake proof</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

**TOTAL HANDLING SCORE**

20
Maximise symmetry ...
Fitting & fixing ...

- **Insertion / holding process**
- **Securing / fixing processes**
- **Additional (non-assembly) processes**

- **Scores based on:**
  - does it need a fixture?
  - The assembly direction
  - Alignment difficulties
  - Restricted vision or access
  - Insertion force
  - Etc.
Component insertion / holding process ...

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gripping / holding during insertion</strong></td>
<td>Holding simple during insertion - no tools needed</td>
<td>Need tools to grip during insertion - but simple</td>
<td>Difficult to hold securely during insertion</td>
<td>No suitable / easy to access gripping surfaces during insertion</td>
<td></td>
</tr>
<tr>
<td><strong>Holding down</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Needs holding in place – secured later</td>
</tr>
<tr>
<td><strong>View during insertion</strong></td>
<td>Clear view during insertion</td>
<td>View partly obscured during insertion</td>
<td>View badly obscured during insertion</td>
<td></td>
<td>No view during insertion – feel only</td>
</tr>
<tr>
<td><strong>Access</strong></td>
<td>Clear access during insertion</td>
<td>Partly obscured access during insertion</td>
<td>Badly obscured access during insertion</td>
<td></td>
<td>No access to insert</td>
</tr>
<tr>
<td><strong>Insertion direction</strong></td>
<td>Straight line from above</td>
<td>Straight line, from side</td>
<td>Straight line from below</td>
<td></td>
<td>Not in a straight line</td>
</tr>
<tr>
<td><strong>Insertion resistance</strong></td>
<td>No resistance</td>
<td>Light resistance</td>
<td>Significant resistance</td>
<td>Large resistance – need leverage</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL INSERTION SCORE**
## Fixing / securing processes ...

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threaded fasteners</td>
<td>No threaded fasteners</td>
<td>Self drilling / tapping screws</td>
<td>Stud / bolt &amp; nut Screw</td>
<td>Nut, bolt &amp; washer (separate loose parts)</td>
</tr>
<tr>
<td>Non-threaded fasteners</td>
<td>Snap fit or light push fit</td>
<td>Rivet</td>
<td>Simple crimping or bending</td>
<td>Difficult crimping or bending</td>
</tr>
<tr>
<td>Soldered / Welded joints</td>
<td>No welded joints</td>
<td>Simple solder / weld</td>
<td>Difficult weld</td>
<td></td>
</tr>
<tr>
<td>Glued joints</td>
<td>No glued joints</td>
<td>Simple glued joint</td>
<td>Difficult glued joint</td>
<td></td>
</tr>
</tbody>
</table>
Fixing & joining ...

- Eliminate / minimise fasteners
  - Separate fasteners of same type
  - Different types fasteners
  - Avoid threaded fasteners
- Carefully position fasteners
  - Away from obstructions
  - Provide flat surfaces
  - Provide proper spacing between fasteners
- Simple fastening
  - Self fastening features
  - One handed assembly
  - Parts secured on insertion
  - Single linear motion
- Minimise assembly tools
- Parts should easily indicate orientation direction
  - Self alignment
  - Self orienting / no orientation needed
## Additional (non-assembly) processes ...

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Additional screwing</strong></td>
<td>No threaded fasteners</td>
<td>Some additional screwing</td>
<td>Significant additional screwing</td>
<td></td>
</tr>
<tr>
<td><strong>Setting</strong></td>
<td>No setting required</td>
<td>Simple / quick setting</td>
<td>Complex / slow setting</td>
<td></td>
</tr>
<tr>
<td><strong>Test &amp; measure</strong></td>
<td>No testing &amp; measuring</td>
<td>Easy / quick testing</td>
<td>Difficult / slow testing</td>
<td></td>
</tr>
<tr>
<td><strong>Fill / empty</strong></td>
<td>No filling / emptying</td>
<td>Simple / quick fill / empty liquid / gas</td>
<td>Complex / slow fill / empty gas</td>
<td></td>
</tr>
<tr>
<td><strong>Re-orientation</strong></td>
<td>No reorientation</td>
<td>Small reorientation</td>
<td>Significant reorientation</td>
<td></td>
</tr>
</tbody>
</table>
Product architecture
System optimisation
Product architecture design

Sub-system optimisation
Assembly optimisation
Component minimisation, handling, fitting, feeding

Component optimisation
Component commonality
Process selection
Process optimisation

Whole product

Component

Assembly
A product’s **architecture** is the way in which the **functional elements** are assigned to the **physical elements** and the way in which these **elements interact**.
Integrated product structures ...
Modular product structures ...
Product change ...

- Integral products
  - Changes to one element can result in changes to many others
  - A functional change demands physical change

- Modular products
  - Changes can be made to isolated elements independently

- Design goal ...
  - Minimise **physical changes** to enable **functional changes**
Types of functional change ...

- **Upgrade**: more memory in a PC
- **Add-ons**: a new flash gun for a camera
- **Adaptation**: different power supplies for different markets
- **Wear / maintenance**: replacement razor blades
- **Consumption**: replacement film, or printer ink
- **Flexibility in use**: changeable lenses
Example: Cooke movie lenses ...

- Lots of commonality in production:
  - Common external mechanics, different lens and iris assemblies
  - Common parts
  - Common features on parts: different lengths, reuse of CAM
  - Common tool set: radii, thread forms, holes etc
  - Common processes: designed for single M/C tool

- Modularity: optical elements, lens to camera interface, Iris assembly
Product platforms
Product range
- Product range planning
- Platform planning

System optimisation
- Product architecture design

Sub-system optimisation
- Assembly optimisation
- Component minimisation, handling, fitting, feeding

Component optimisation
- Component commonality
- Process selection
- Process optimisation

Assembly

Product range

Whole product

Component
### Volkswagen A-Platform

| Platform | VW | Audi | Skoda | Seat | Rolls-Royce/Bentley | Lamborghini | Bugatti?
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Sportwagen*</td>
<td>W12 Coupé/Roadster</td>
<td></td>
<td></td>
<td></td>
<td>Diablo SL/V</td>
<td>EB 110</td>
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<tr>
<td>D</td>
<td>Luxuslimousine</td>
<td>A8 (Nachfolger)</td>
<td></td>
<td>Silver Seraph/Arnage*</td>
<td></td>
<td>EB 112*</td>
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<tr>
<td>B/C</td>
<td>Passat Plus Passat</td>
<td>A4/A6</td>
<td></td>
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<tr>
<td>A</td>
<td>Golf, Bora, Beetle</td>
<td>A3 TT Coupe/Roadster</td>
<td>Octavia</td>
<td>Toledo (Nachfolger)</td>
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<tr>
<td>A00/A0</td>
<td>Polo, Lupo</td>
<td>Al*</td>
<td>Felicia (Nachfolger)</td>
<td>Ibiza/Cordoba, Area</td>
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</tbody>
</table>

- Aprox 19 vehicles based on A-platform
- VW estimates development and investment cost savings of $1.5 billion/yr using platforms
VW Platform: common components ...

Market segmentation grid ...

Segment C

Segment B

Segment A

Market 1  Market 2  Market 3

Shared product platform / technology - common subsystems and interfaces
No leveraging ...

Unique products targeted at individual segments

Shared product platform / technology - common subsystems and interfaces
Horizontal leveraging ...

<table>
<thead>
<tr>
<th>Segment C</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment B</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Segment A</td>
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<table>
<thead>
<tr>
<th>Market 1</th>
<th>Market 2</th>
<th>Market 3</th>
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Reuse of platform elements across markets, and within a segment

Shared product platform / technology - common subsystems and interfaces
**Vertical leveraging ...**

<table>
<thead>
<tr>
<th>Segment C</th>
<th>Segment B</th>
<th>Segment A</th>
</tr>
</thead>
<tbody>
<tr>
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<table>
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</table>

Share product platform / technology - common subsystems and interfaces

Reuse of platform elements within a market and across segment
Beach-head leveraging ...

Horizontal and vertical reuse of platform elements across markets and across segments

Segment C
Segment B
Segment A

Market 1, Market 2, Market 3

Shared product platform / technology - common subsystems and interfaces
Example: Cooke lenses ...
# System architecture map

<table>
<thead>
<tr>
<th>System architecture (schematic)</th>
<th>2012</th>
<th>2013</th>
<th>2015</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td><img src="image1" alt="Simple 2012" /></td>
<td><img src="image2" alt="Simple 2013" /></td>
<td><img src="image3" alt="Simple 2015" /></td>
<td><img src="image4" alt="Simple 2021" /></td>
</tr>
<tr>
<td>Middle</td>
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## System roadmap ...

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<td>D, E</td>
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<td>F, G</td>
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<tr>
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<td>P, Q, R</td>
<td>S, T</td>
<td>U, V</td>
<td>W</td>
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<td>X, Y, Z</td>
<td>X, Y, Z</td>
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<td>New sensors</td>
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<td>New materials</td>
<td>Communications, RFID</td>
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<td>GPS</td>
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Strategic

Product range
- Product range planning
- Platform planning

System optimisation
- Product architecture design

Sub-system optimisation
- Assembly optimisation
- Component minimisation, handling, fitting, feeding

Component optimisation
- Component commonality
- Process selection
- Process optimisation

Whole product

Assembly

Component

Tactical
When to consider platforms etc ...

- Platform Planning
  - Modularity
    - Component Commonality
      - Feature & Process Commonality
        - Consciously Different components
  - Unconsciously different components

- Product Strategy
- Requirements
- Concept design
- Detail engineering

Design Decisions
Thank you ...