Economics of Materials Competition - Effects of Product Architecture Changes and the Level of Analysis

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Introduction

- Current state of materials competition
  - In the past materials competition has often compared similar designs made from different materials.

- Problem
  This standard approach
  - often results in a part-by-part comparison
  - omits specific advantages of various materials, both primary and secondary

- Research questions:
  - What is necessary to allow a more comprehensive analysis of the competitive position of alternative materials?
  - What role can changes of the product architecture play?
  - How to think about future design/materials choices?

Traditionally, performance vs. cost has been the tradeoff criteria for materials selection

- Performance
  - Functionality
    - Strength
    - Weight
    - Rrigidity
  - ...

- Cost
  - Manufacturing cost
  - Design cost
  - Logistics cost
  - ...

Customer requirements

Function/Part Assignment

Part Definition

Assembly Cost Analysis

Part Cost Analysis

Total Cost

Sum of Part Cost

Function definition

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Conventional cost analysis approach works well for narrowly defined cases - Example: Car Door Outer Panel

Conventional Door:
1. Door Inner - Steel
2. Door Outer - Steel-Aluminum
3. Reinforcement Panel at Hinge - Steel
4. Reinforcement Panel at Latch - Steel
5. Reinforcement Panel at Waist - Steel
6. Intrusion Beam - High Strength Steel
7. Front Door Check (2x)
8. Nut Weld M8 Square (4x)

Frequent result of part-by-part comparison: the tradeoff is reduced to materials' density/cost ratios

Fabrication cost for a steel and an aluminum door outer panel

<table>
<thead>
<tr>
<th>Component</th>
<th>Steel Panel</th>
<th>Aluminum Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Building</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Overhead</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Tooling</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Main Machining</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Energy</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Labor</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Material</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Annual Production Volume: 300,000
Secondary effects may as well be excluded as sufficiently unfamiliar design/material combinations

1. **Focus too narrow**: The fixation on (existing) parts may result in ‘blind spots’ for alternative design/material combinations

2. **Focus too short**: While often manufacturing part cost are compared, a ‘systems’ perspective including several parts, assembly, logistics, data maintenance, etc. would be appropriate

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Suggested approach: extend view beyond parts and existing designs

1. How to broaden the focus?
   - Evaluate changes in the product architectures; they may allow to exploit currently unused advantages of different materials and materials combinations
   - Current trends show that materials compete less and less within traditional boundaries, i.e.
     - more materials combinations are deployed
     - more application dependent material developments

2. How to lengthen the focus?
   - Comparative analysis needs to be extended beyond simple part considerations
     - Include assembly of parts as well adjacent and architecturally affected parts and components
     - Analyze cost effects on non-manufacturing activities as logistics, data management, etc.
Understanding materials’ competitive positions better requires to include more of the design information

- Customer requirements
  - List of customer requirements:
    - Examples (highly aggregation):
      - good acceleration
      - convenient operation and ride
      - high top speed
      - appealing aesthetics
      ...

Function definition assignments

<table>
<thead>
<tr>
<th>Function 1</th>
<th>Part 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function 2</td>
<td>Part 2</td>
</tr>
<tr>
<td>Function 3</td>
<td>Part 3</td>
</tr>
<tr>
<td>Function 4</td>
<td>Part 4</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Function n</td>
<td>Part n</td>
</tr>
</tbody>
</table>

Tradition Cost Perspective

- Analysis of fabrication cost for each single part:
  - Assessment of assembly cost:
    - part 1 $ x
    - part 2 $ y
  - Sum $ z
  - Assembly: $ w
  - Total fab. cost: $ v

Various definitions are used for 'product architecture’ and its characteristics: modular vs. integral

1. Module vs. System view - The industry distinguishes between modules and systems:
   - "Modules" are groups of components or parts arranged in close physical proximity to each other within a vehicle
   - "Systems" and "subsystems" are groups of components or parts which operate together to provide a specific vehicle function

2. Product architectural view - Academia defines ‘integral’ and ‘modular’ as features of the product architecture:
   - "Product architecture is the scheme by which the function of a product is allocated to physical components."
     - modular architecture: a one-to-one mapping from functional elements to the physical components
     - integral architecture: a complex mapping from functional elements to physical components and/or coupled interfaces between components
Modularization is not necessarily contradicting integration: important is the hierarchy level under consideration.

Fragmented, modular and integral product architectures
Different product architectures display different internal constraints and opportunities

Product architecture determines to some extent relationships between process steps

Grouping of functions allows to establish a product hierarchy - but also establishes constraints for the design
**Level 2 module - structure (conventional door)**

Conventional Steel Door:
1. Door Inner - Steel
2. Door Outer - Steel
3. Reinforcement Panel at Hinge - Steel
4. Reinforcement Panel at Latch - Steel
5. Reinforcement Panel at Waist - Steel
6. Intrusion Beam - High Strength Steel
7. Front Door Check (2x)
8. Nut Weld M8 Square (4x)

**Level 2 module - structure (alternative material/design combination)**

Cast Magnesium Door Structure:
1. Door Frame - Magnesium
2. Door Outer - Aluminium
3. Nut Weld M8 Square (4x)
The alternative design/material combination offers about 20% primary weight savings.

On level 1, the scale effects of the steel tooling determines the total cost.
On level 2, the lower assembly cost makes the Mg/Al concept advantageous for low production volumes.

Structure Module Cost
(Annual Production Volume: 30,000)

- Assembly
- Parts Manuf.

On level 3, mechanic, electric and trim contribute 3/4 of the total cost at high production volumes.

Total Door Cost
(Annual Production Volume: 30,000)
Conclusions

Strategic material/design choices need to consider a longer and broader view:

— Entirely different product architectures including modules and/or integrated parts should be considered if they offer potential gains on a higher systems level (to broaden the view)

— Larger chunks of the product can both be better optimized as well as offer through a lower number of interfaces easier ways to introduce entirely new material/design configurations (to lengthen the view)

— On a corporate level, the view should include other product lines in order to determine an efficient level of modularity across the company

![Graph showing the relationship between Complexity of the Module, Total Module Cost per module, and Total units (modules) produced.](graph.png)