Modularity and Scalable Manufacturing

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Excellence Across Breadth

- Established in 1817
- 101 graduate programs in the top 10
- Sample University of Michigan “Firsts”
  - First to own and operate its own hospital (1869)
  - First state institution to establish a department of dentistry (1875)
  - First to have a naval tank for study of ship design (1904)
  - First to provide instruction in aeronautics engineering (1914)
- Many interdisciplinary research centers and institutes
- Renowned Institute for Social Research
Prof. Boston (center)
“The machine in the middle was a technical marvel in that it could make large diameter bearing races in the accuracy of $10^{-6}$ inches.”

Professor S. M. Wu, first Anderson Professor of Manufacturing Technology, was a pioneer in applying statistical methods to manufacturing.

Prof. Y. Koren and his team created the science and enabling technologies for reconfigurable manufacturing systems.
Contents

• Evolving Paradigms of Manufacturing
• Mass Customization Enabled by Product Family Architecture
• Reconfigurable Manufacturing Systems
• Delayed Differentiation
• Summary and a Quiz
Craft Production


Lack of systems
Mass Production

Turn of the Century Ford and the automobile

Model-T Production (Highland Park: ~1910)

<table>
<thead>
<tr>
<th>Year</th>
<th>Units per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1912</td>
<td>20-30 per day</td>
</tr>
<tr>
<td>1913</td>
<td>100 per day</td>
</tr>
<tr>
<td>1914</td>
<td>1000 per day</td>
</tr>
<tr>
<td>1915</td>
<td>3000 per day</td>
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</tbody>
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- Interchangeable parts
- Moving assembly lines – Dedicated Manufacturing Systems
- Division of labor/Scientific management
- Vertical integration

Henry Ford assembly line at Highland Park, Michigan
http://www.eyewitnesstohistory.com/ford.htm
Mass Customization

- Un-upholstered
- Latitude upholstery on seat & back
- Latitude on seat only

http://www.hermanmiller.com/

BMW 7 Series
10^{17} possible variants

• Product family
• Management of variety
• Economy of scale and scope
• Demand for responsive manufacturing systems
Volume – Variety Relationship in Paradigms of Manufacturing

Volume per model

Mass production

Craft production

Lean MFG

Mass customization

Future Paradigms

1850

1913

1955

1980
Product Architecture (PA)

A product architecture describes
- what it does (its functions),
- how it is physically realized (its modules), and
- the interactions (interfaces) between the modules.
Types of Product Architecture

• **Integrated:**
  – Single structure or a very small number of interacting units
  – Product functions are all contained in one structure and each component can implement a different function
  – Rigid connections among units such that the boundaries between units are not very clear (taking one of the components out may destroy several portions of the device.)
  – More focused development during system level design phase

• **Modular:**
  – Decomposition of a product into modules or components
  – Each module implements one or a few functions – *eliminate or minimize coupling*
  – Interfaces between modules are well defined – *easy “plug and play”*
Example of Modular vs Integral Product

Example of Integral vs Modular Product

Company A designs 4 products, resulting in 4 variants:

- By adding 1 new design, Company A adds 1 variant:

  5 designs $\rightarrow$ 5 variants

Company B designs 1 modular platform with 3 additional modules resulting in 8 total variants:

- By adding 1 new module, Company B adds 8 new variants:

  5 designs $\rightarrow$ 16 variants

(www.ptcuserworldevent.com/presentations/Modular_Product_Architecture.pdf, 10/17/06)
Product Family

- Platforms: Common components + variant specific components creates a customized solution
Product Family Architecture

Customized Product

Function

F₁
V₁₁ V₁₂ V₁₃

F₂
V₂₁ V₂₂

F₃
V₃₁ V₃₂ V₃₃ V₃₄

Modules

Station 1
Station 2
Station 3

...
Advantages of Product Families

- Economic product variety
- Development risks
- Low system complexity
- Improved ability to upgrade products
- Enhanced flexibility
- Enhanced responsiveness for manufacturing processes
Manufacturing Systems for the three paradigms

DMS: Dedicated Manufacturing System
FMS: Flexible Manufacturing System
RMS: Reconfigurable Manufacturing System
Reconfigurable Manufacturing Systems (RMS)

An RMS is designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family.
Example of an RMS

Scaling of an RMS

When demand grows, the initial system, a, is cost-effectively scaled-up to Configuration b to meet the new demand.

Mitigating the Effect of Variety by Delaying Differentiation

Total differentiation

A1 → B1 → D1

A2 → B2 → D2

Mixed model assembly

A1 + A2 → B1 + B2 → D

Delayed differentiation

By delaying the point in which the final personality of the product is realized,

- Flexibility to handle customer change order increased
- Inventory cost reduced
- Economy of scale: piece cost reduced
- Complexity reduced
An Example of Delayed Differentiation

Modular Designs

- Demand for B/W Printer
- Color Printer
- Demand for Color Printer
- B/W Toner
- Demand for B/W Printer
- Color Toner
- Demand for Color Printer
Design for Delayed Differentiation

Objective: Delay the point in which the final functions of the product are configured

• increases flexibility to handle changing demands of multiple products within the family

• decreases operational and cost savings

• more popular differentiating features designed first (postponement differentiation)

Requirements:

• non-differentiation functions produced first – dedicated mfg. system

• differentiation functions could be added later in the process – flexible and reconfigurable mfg. systems
Summary

- A product *architecture* describes the product functions, physical realization and the interactions between the modules.

- A *modular* architecture is easy to change, allows for variants, allows for parallelization and local optimization.

- A *platform* is the set of components/modules, processes, knowledge and people, shared by a group of products and contributing to product variants in a family.

- *Reconfigurable Manufacturing Systems* are scalable systems with machines in serial/parallel configurations.
Quiz: What are those?
Examples of Modular Products

MoHo – Modular Homes
(Manchester, UK)

Watch out: Your future home might well have wheels

http://www.cnn.com/2015/02/05/travel/gallery/mobile-architecture-homes/