Manufacturing as a System of Design

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The Architecture - Capability Framework

1 Design-Information View of Manufacturing

2 Organizational Capability -- Controlling Design Flows

3 Performance Measurement -- A Multi-Layer Approach

4 Product-Process Architecture

5 Capability-Architecture Fit -- Explaining Competitiveness

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1 Design-Information View: Interdisciplinary Background

- Technology and Operations Management (Innovation Management)
- Evolutionary Theory of Firms
- Resource-Capability View of the Firm in Strategic Management
- Product-Process Architecture in Engineering
- Combining Design Concept in Engineering and Trade-Industry Policy
- Fit between Organizational Capability and Architecture
  - Design-Based Comparative Advantage

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A firm’s products and processes are artifacts that has been designed.

Manufacturing is essentially creation and transmission of design information to customers.

A firm’s manufacturing (monozukuri) capability is its distinctive ability to handle flow of design information toward customers.

Product-process architecture is designers’ basic way of thinking when creating design information for the product and processes.

“Design” is the common denominator for these analyses.
Reinterpreting Manufacturing Activities as a System of Design Information Processing

*Product* as design information that is embodied in a particular medium
Body Exterior Design

0.8 mm thick steel sheet

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Body Exterior Design Embedded in Press Dies

Product Development

Production

Purchasing

Meria (Material)

0.8 mm thick steel sheet

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Product = Design Information + Media

Body Exterior
  Design
  Embedded in
  Press Dies

0.8 mm thick steel sheet

Production = Marriage of Design Information Media

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What is Going on at the Press Shop

Body exterior design information, embedded in press dies (steel block), is transmitted to 0.8 mm thick sheet steel (media)

Information transmission time = value-adding time

Information non-transmission time = MUDA
Sheet Steel (Media) Absorbs Design Information through the Press Operation

Design information, embedded in press dies, is transmitted to sheet steel

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Goods and service as flows of design information

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2 Organizational Routines and Capability of Manufacturing

Organizational routine of manufacturing

Repeated control of design information flow between productive resource

Organizational capability of manufacturing

A system of organizational routines for fast, efficient and accurate flows of design information to customers

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Toyota’s Manufacturing Capability as Effective Information-Processing

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Value adding time (transmission)  Value adding time (reception)  Non-value-adding time  Inventory, waiting, transporting, etc.  Productive resource

Value adding time (transmission)
Value adding time (reception)
Non-value-adding time
Inventory, waiting, transporting, etc.
Productive resource

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Organizational Capability Regarding Productivity and Throughput Time (Toyota)

(1) Higher Productivity and Shorter Throughput Time

- **Customer**
  - Pull system
  - Short-term levelization of production volume
  - Levelization of product mix (heijunka)
  - Reduction of finished goods inventory
  - Process step 2: mixed-model (small lot) assembly

- **Supplier**
  - JIT delivery
  - Reduction of raw material inventory

- **Worker and Equipment**
  - Multi-skilled worker
  - Flexible task assignment (shojinka)
  - Maximizing value-adding time
  - Communication
  - Regular pace of information transmission (levelization, small lot)
  -Process step 1
  - Designing process flow prior to work & equipment design

- **Product Design** (M+A+B)
  - Workers participate in Kaizen (improvements)
  - Product design for manufacturability

- **Parts Design** (M)
  - In-house design of equipment
  - Incremental improvement of equipment
  - Low cost automation
  - Flexible equipment
  - Quick set-up change
  - Preventive maintenance

- **Supplier’s Kanban**
  - JIT delivery

- **Communication**
  - Worker and Equipment
  - Customer

- **Revision of Work Designs by Supervisors**
Higher Manufacturing Quality

Toyota-style system as an integrative manufacturing capability

Figure 10  Organizational Capability Regarding Manufacturing Quality (Toyota)

Key:  
- information flow
- material flow
- A,B,M information content
- inspection
- transformation
- productive resource

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Efficient/Accurate Information Processing at Toyota
Integration-Based Manufacturing Capability

Production --- Dense and Accurate Transmission of
Design Information from Process to Product

Development --- Early and Integrative Problem Solving Cycles
For Fast Creation of Design Information

Purchasing --- Long-Term Relationship,
Capability-Building Competition, Bundled Outsourcing
for Joint Creation of Design Information with Suppliers

Toyota’s Manufacturing capability -
Smooth, dense and accurate transmission of design information
between flexible (information-redundant) productive resources.

--- Integration-Based Manufacturing Capability
Three Levels of Toyota’s Capabilities

1. **Routinized Manufacturing Capability**
   
   Ability to Achieve Speed / Efficiency / Accuracy of Repetitive Information Transmission from Process to Product (e.g., Kanban, Multi-Task Work Assignment, Self-Inspection)

2. **Routinized Learning Capability (Kaizen Capability)**
   
   Ability to Achieve Speed / Efficiency / Accuracy of Repetitive Problem Solving Cycles (e.g., Kaizen, QC Story, Product Development Routines)

3. **Evolutionary Capability** (Capability-Building Capability)

   Ability to “Learn Anyway” in the Long Run --- or

   Ability to Establish Competitive Routines Despite Complicated *Multi-Path System Emergence*
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Capability, Competitiveness, and Profitability

other factors of environments and strategy

Organizational Capability
- organizational routine

Productive Performance
- productivity
- lead time
- conformance quality
- etc.

Market Performance
- price
- delivery
- perceived quality
- etc.

Profit Performance

Arena of Capability-building Competition
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Example: Productive Performance of Japanese Auto Firms
-- Development Productivity (Adjusted Person-Hours per Project) --

Adjustment scheme:
(1) # of body types=2, (2) New design ratio=0.7, (3) Supplier’s contribution=0.3, (4) Product class=compact/sub-compact

Example: Productive Performance of Japanese Auto Firms
-- Assembly Productivity (Adjusted Person-Hours per Vehicle) --

Source: M. Howleg & F.K. Pil, *The second century* (IMVP Survey)
Example: Productive Performance of Japanese Auto Firms
-- Assembly Throughput Time (from Welding to Assembly) --

Data: IMVP2000yr. Survey, made by Jeweon Oh, MMRC

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Multi-Layer Evaluation of Performance

Operational Capability (JIT, TQC, etc.) → Productive Performance (productivity, lead time, etc.) → Market Performance (price, brand identity, etc.) → Profit Performance (ROE, ROS, etc.)

Strategy, Environment (e.g., exchange rate)

Estimated Relative Performance in the Late 1990s

Japanese

European

American

Who Gets these Four Performances in a Balanced Way?

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4 Architectural Thinking and Industrial Classification

Supplementary industry classifications
-- based on product-process architecture

*Product architecture*,
Basic way of thinking of engineers when they design *functions* and *structures* of a new product.
Two Basic Types: Integral versus Modular Architecture

(1) Integral Architecture
(2) Modular Architecture

Integral and Modular Architecture

Product Function Hierarchy
Product Structure Hierarchy
Product Function Hierarchy
Product Structure Hierarchy

Legends: F = Product Function as a Whole,  S = Product Structure as a Whole
F1, F2=Sub-functions of the Product,  f1 - f4 = Sub-sub-functions of the Product
S1, S2 = Large Modules,  s1 - s4 = Small Modules
--------------- = connection

* In order to simplify the diagram, the connection between F and S, and the same between F1, F2, S1 and S2 are omitted.

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Basic Classifications of Product-Process Architecture

**Modular architecture**: one-to-one correspondence between functional and structural elements.

**Integral architecture**: many-to-many correspondence between the functional and structural elements.

**Open architecture**: “mix and match” of component designs across firm.

**Closed architecture**: mix and match only within a firm.

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Three Basic Types of Product Architecture

Closed-integral, Closed-modular, Open-modular

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Closed-Integral Architecture (Car)

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Closed-Modular Architecture (Mainframe Computer)

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Open-Modular Architecture (PC)

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Closed-Integral Architecture (unit-body)
Closed-Modular Architecture (Body-on-Frame, or Truck-type)
Quasi-Open-Modular Architecture? (Chinese local makers)
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5 Hypothesis: Capability-Architecture Fit at National Level

A group of firms in the same country or region, facing similar environmental constraints, national-regional institutions, demand patterns or other forces specific to a particular geographical area may develop similar types of organizational capabilities.

Products with the architecture which fits this organizational capability tend to demonstrate competitive advantage (if not profitability).

History matters
Ratio of Export and Integral Architecture Index  Scatter chart(1)

(Regression Equation Number 1 assembly products 52sample)

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Ratio of Export and Integral Architecture Index Scatter chart (2)
(Regression Equation Number 4 Raw Materials products 43sample)

C. Oshika and Fujimoto, MMRC, University of Tokyo
Axiomatic Design and Design Process

\[
\begin{align*}
\begin{bmatrix} FR_1^* \\ FR_2^* \end{bmatrix} &= \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} \\
\end{align*}
\]

\[
\begin{align*}
FR_1^* &= a_{11} \cdot DP_1 + a_{12} \cdot DP_2 \quad (1) \\
FR_2^* &= a_{21} \cdot DP_1 + a_{22} \cdot DP_2 \quad (2)
\end{align*}
\]
Integral Architecture

\[
A = \begin{bmatrix}
a_{11} & 0 & \cdots & 0 \\
0 & a_{22} & \ddots & \\
\vdots & \ddots & \ddots & \\
0 & \cdots & 0 & a_{mm}
\end{bmatrix}
\]

C. Okuma and Fujimoto, MMRC, University of Tokyo
2-Stage Design Process Model

\[
\begin{align*}
DP_1^0 (\hat{a}_{11} \sim \hat{a}_{12}, FR_1, FR_2) \\
DP_2^0 (\hat{a}_{21} \sim \hat{a}_{22}, FR_1, FR_2)
\end{align*}
\]

\[
\begin{align*}
DP_1^* (a_{11} \sim a_{12}, FR_1, FR_2) \\
DP_2^* (a_{21} \sim a_{22}, FR_1, FR_2)
\end{align*}
\]
Try-And-Error Coordination

Okuma and Fujimoto, MMRC, University of Tokyo
Design-Based Comparative Advantage

(1) Products may be Designed
Where Organizational Capability and Product Architecture Fit

(2) Products may be Produced
Where Products are Designed
(Scale Economy and Product Differentiation) or
Where Organizational Capability and Process Architecture Fit or
Where Products are Sold (Production Located in the Market)

Design Matters When Policy Makers Choose Industries to be Promoted

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Predictions on Architecture-based Comparative Advantage

**Japanese firms -- integration capability**
More competitive in products with **closed-integral architecture**. Based on **integration-based manufacturing capability**

**Chinese firms – mobilization capability**
More competitive in labor-intensive products with **open-modular (or quasi-open) architecture**

**Korean (large) firms – concentration capability**
More competitive in capital-intensive products with **modular architecture** (moving toward **integral**?)

**ASEAN firms – labor-retaining capability??**
More competitive in labor-intensive products with **closed-integral architecture**?

**U.S. firms – conceptualization capability**
More competitive in knowledge-intensive products with **open-modular architecture**

**European firms – expression capability**
More competitive in **closed-integral products** based on brand-design-marketing capability
Architectural Geopolitics: A Prediction in the Pacific Region

Integral Axis

Modular Axis

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Trade Pattern of Steel Products among Korea, China and Japan

<table>
<thead>
<tr>
<th></th>
<th>Korea</th>
<th>China</th>
<th>Japan</th>
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(in Mil. Tons)

C Fujimoto, Oh and Ge, University of Tokyo
Variety of Steel Sheets for the Automotive Applications
## Case 2: Surface Treatment Steel for Automobile’s Outer Panel

<table>
<thead>
<tr>
<th>Process</th>
<th>Function</th>
<th>Surface Appearance</th>
<th>Corrosion Resistance</th>
<th>Dent Resistance</th>
<th>Formability</th>
<th>Weldability</th>
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Integral Architecture Index = **0.48 = 33 □ (9X8)**

*C Ge and Fujimoto, University of Tokyo*
# Case 3  Cold Rolled Steel for Inner Panels of Automobile

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<th>Function Process</th>
<th>Surface Appearance</th>
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Integral Architecture Index = 0.23 = 15 △ (8X8)  

Relatively modular  

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Implications to Japanese Industrial Policies

The post-war Japanese industrial policy tended to be oriented to “full set” industrial development.

But this policy often meant protective industrial policies.

It has become unrealistic to maintain the full-set industrial policy.

The government has to infuse strategic thinking into its industrial policy by discerning strength and weakness of the Japanese firms. Capability-architecture framework may help this initiative.

Industrial policy-makers need to select sectors with good capability-architecture fit, identify best-practice firms in such sectors, establish alignment between the industrial policy and the firms’ best-practice, and stimulate capability-building competition (not only price competition).

That is, shift to “front-runner-oriented industrial policy”


