An Integrated Framework Matching Product Architecture with Supply Chain Design Policies

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Presentation Outline

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Motivation

Interactions between product strategy, product development, supply chain and final product.

Product Strategy:
- Product Modularity
- Product Platforms
- Component Commonality
- Number of Components
- Product Variety
- Standardization
- Product platform
- Etc.

Final Product Characteristics:
- Price
- Quality
- Maintainability/Serviceability
- Reliability
- Upgradeability
- Etc.

Product Development Decision:
- Location of development facilities
- Number/size of development team
- Development process
- Type of architecture
- Engineering analysis
- Number of modules
- Etc.

Supply Chain Network Decisions:
- Location of supply chain facilities
- Selection of suppliers
- Risk pooling
- Delivery schedules
- Inventory
- Lead time
- Etc.
Motivation: Costs/Opportunities for improvements

Cost of poor product quality/decisions
Opportunity for improvement

More opportunities and less cost

Less opportunities and more cost
Motivation Cont.

- Makers of complex systems, such as automobile makers, are outsourcing more product development and manufacturing to suppliers (Baldwin and Clark, 1997; Clark, 1989; Clark and Fujimoto, 1991).
- Increased dependency of manufacturers on suppliers.
- To cope with modularization, many firms are going into strategic partnership and alliances with other firms.
Motivation Cont.

- Annual growth rate in the number of alliances form is about 25%. Yet, 60 – 70% of these alliances fail in the first year (Harrigan 1988; Savona, 1992; Bruner and Spekman, 1998; Duysters et al., 1998).
- Supply chain structure is not only influenced by the cost and quality of the components, but also by the product architecture and compatibility of the suppliers in the supply chain network.
- However, there is no literature available to help us understand the relationship between product architecture and the supplier-manufacturer relationship in the supplier chain.
Problem Statement

Develop an integrated multi-objective model using fuzzy logic and optimization methods that is capable of addressing the concerns of product architecture and supply chain early in the conceptual stage of product development.
Research Questions

1. How to use the vague and imprecise knowledge and information available on the suppliers during conceptual stage of product development to help design the structure of the supply chain network.

2. What is the effect of product architecture, supplier compatibility on the structure of the supply chain?

3. What are the differences between optimal supply chain configurations between different product architectures?
Product Architecture

- Product Architecture: - Relates how functions of a product are allocated to its constituent components – Ulrich, 1995.
- Integral (or closed) and Modular (or open)
- Integral architecture: one-to-many or many-to-one mapping between functional elements and physical components (Otto and Wood, 2001).
- Modular architecture: one-to-one mapping between functional elements and physical components (Otto and Wood, 2001). This allows components to be produced separately or loosely coupled and used interchangeably in different configurations without compromising of system integrity.
Product Architecture Types

Components:
- upper half
- lower half
- nose piece
- cargo hanging straps
- spring slot covers
- wheels

Functional Elements:
- protect cargo from weather
- connect to vehicle
- minimize air drag
- support cargo loads
- suspend trailer structure
- transfer loads to road

Example of Integral Product

Product Architecture Types

**Components**
- box
- hitch
- fairing
- bed
- springs
- wheels

**Functional Elements**
- protect cargo from weather
- connect to vehicle
- minimize air drag
- support cargo loads
- suspend trailer structure
- transfer loads to road

Example of Modular Product

Advantages of Modularization

1. Shorten new product development lead time.
2. Introduce multiple product models quickly at reduced costs.
3. Introduce many successive versions of the same product line with increased performance levels.
Impacts of Modularization on Supply Chain Relationships

Many firms are coping with the challenges and opportunities offered by modularization through:

- Outsourcing of product development and manufacturing activities to suppliers.
- Reducing the number of suppliers.
- Suppliers are gaining more bargaining power.
- The relationships between OEM and suppliers are becoming more interdependent.
- OEM and suppliers are going into strategic partnerships and alliances.
- Annual growth rate in the number of alliances formed is about 25%. Yet, 60 – 70% of these alliances fail in the first year (Harrigan 1988; Savona, 1992; Bruner and Spekman, 1998; Duysters et al., 1998).
Gaps in the Literature

1. Most focus on either product architecture or supply chain.
2. Qualitative or simple rule of thumbs methods for determining the relationship between product architectures and supply chain policies for the few ones that focus on both.
3. Simplistic (single) optimization objectives e.g. cost, tolerance, etc.
Proposed Framework

**Step 1: Product Information Acquisition**
- Identify design objectives for evaluating modular architecture and suppliers.
- Identify modularity and supply chain requirements
- Identification of metrics to evaluate design objectives.
- Analysis of imprecise information using fuzzy logic

**Step 2: Formulation and solution of optimization model:**
- Formulate multi-objective optimization model.
- Solve the optimization model using GA to select optimal modules and suppliers considering product and supply chain objectives

**Step 3: Post-optimality analysis:**
- Study the impact of product architecture on supply chain network.
- Formulate scenarios for product strategy.
Supply Chain Network

Supply Chain: - all parties (suppliers, manufacturers, distributors and retailers) involve directly or indirectly, in fulfilling a customer needs – Chopra and Meindl 2001.

Example of Typical Supply Chain Network

Procurement Nodes

Intermediate Nodes

End Node

Customers
Optimization Model

Objectives:
1. Minimize: Total Supply Chain Cost (Inventory and Production Costs)
2. Maximize: Partnership between suppliers

Decision Variables

\[ S_{i}^{out} = \text{Output service time guarantee by node } i \text{ to its downstream node(s).} \]

\[ y_{iO_i} = 1 \text{ if option } O_i \text{ is selected at node } i, \ 0 \text{ otherwise} \]
Optimization Model

Subject to the following constraints:

1. Processing time of the selected option at each node.
2. Production cost of the selected option at each node.
3. Inventory coverage time is non negative at each node.
4. Supplier partnership factor between selected suppliers at two adjacent nodes.
5. Only one supplier is selected at each node (single sourcing).
6. Service times, number of options, and compatibility factors are non-negative at each node.
7. A supplier is either selected or not.
The Optimization Model

Definition of Parameters

\( \mu_i \) = Mean of demand at node i.
\( O_i \) = Option selected at node i.
\( \beta_{ij} \) = Partnership index of node i and node j
\( \beta_{O_iO_j} \) = Partnership index of option selected in node i and the option selected in node j
\( T_{iO_i} \) = Processing lead time for each alternative option \( O_i \) at node i.
\( T_i \) = Processing lead time at node i.
\( C_{iO_i} \) = Production cost for each alternative option at node i
\( c_i \) = Production cost at node i.
\( S_{i}^{in} \) = Input service time for stage i. ( \( S_{i}^{in} = \max\{S_{j}^{out}\} \), for \( j \in \text{input nodes to node } i \).
\( S(i) \) = Set of suppliers available for selection at node i.
\( C_i \) = Cumulative cost of finished item at node i.
\( W_i \) = Cumulative cost of item being processed at node i.
\( AOH_i \) = Average on-hand inventory level at node i.
\( WIP_i \) = Working inventory level at node i.
\( H \) = Manufacturer’s time interval of interest.
Optimization Model

Minimize \( \sum_{i \in N} \left[ h_i ((C_i \times AOH_i) + (W_i \times WIP_i)) + (H \times c_i \times \mu_i) \right] \) & Maximize \( \sum_{i,j \in A} \beta_{ij} \)

Subject to:

1. \( \left\{ \sum_{O_i \in S(i)} T_{iO_i} y_{iO_i} \right\} - T_i = 0, \) for \( i \in N \)  
   (Processing time at each node)

2. \( \left\{ \sum_{O_i \in S(i)} C_{iO_i} y_{iO_i} \right\} - c_i = 0, \) for \( i \in N \)  
   (Production cost at each node)

3. \( S_i^{\text{in}} + T_i - S_i^{\text{ou}} \geq 0. \) for \( i \in N \)  
   (Inventory coverage time is non-negative)

4. \( \left\{ \sum_{O_i \in S(i)} \sum_{O_j \in S(j)} y_{iO_i} \beta_{O_iO_j} y_{jO_j} \right\} - \beta_{ij} \) for all \( (i, j) \in A \)  
   (partnership index between two adjacent suppliers)

5. \( \sum_{O_i \in S(i)} y_{iO_i} = 1 \) for \( i \in N \)  
   (Only one supplier is selected at each node)

6. \( S_i^{\text{ou}}, O_i, \beta_{ij} \geq 0 \) for \( i \in N \)  
   (Non-negativity)

7. \( y_{iO_i} \) is binary for \( i \in N \) and \( O_i \)  
   (A supplier is either selected or not at each node)
Goal Programming

Let,

\[ \lambda_{TSCC} = \text{Optimal cost value when Total Supply Chain Cost is the only objective of the optimization model.} \]

(Target value for cost).

\[ \lambda_P = \text{Optimal Partnership value when Partnership is the only objective of the optimization model (Target value for Partnership).} \]

\[ \Delta = \text{Deviation of each objective from its target value} \]
Goal Programming Cont.

Minimize \{ \Delta \}

Subject to:

1. \[ \sum_{i \in N} \left[ h_i \left( (C_i \times AOH_i) + (W_i \times WIP_i) \right) + (H \times c_i \times \mu_i) \right] - \Delta \leq \lambda_{TSCC} \] (TSCC Goal)

2. \[ \left\{ \sum_{i,j \in A} \beta_{ij} \right\} + \Delta \geq \lambda_p \] (Partnership Goal)

3. \[ \left\{ \sum_{O_i \in S(i)} T_{io_i} y_{io_i} \right\} - T_i = 0, \] for \( i \in N \)

4. \[ \left\{ \sum_{O_i \in S(i)} C_{io_i} y_{io_i} \right\} - c_i = 0, \] for \( i \in N \)

5. \( S_{i}^{in} + T_i - S_{i}^{out} \geq 0. \) for \( i \in N \)

6. \[ \left\{ \sum_{O_i \in S(i)} \sum_{O_j \in S(j)} y_{io_i} \beta_{oio_j} y_{jo_j} \right\} - \beta_{ij} \] for all \( (i, j) \in A \)

7. \[ \sum_{O_i \in S(i)} y_{io_i} = 1 \] for \( i \in N \)

8. \( S_{i}^{out}, O_i, \beta_{ij} \geq 0 \) for \( i \in N \)

9. \( y_{io_i} \) is binary for \( i \in N \) and \( O_i \)
Research Contributions

1. Develop a multi-objective model using fuzzy logic and optimization methods that is capable of addressing some of the concerns of product architecture and supply chain early in the conceptual stage of the product development.

2. Illustrate the modeling framework through various automotive subsystems at Ford Motor Company and Visteon Corporation.
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Questions