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Modularity as a Source of Comprehensive Innovation:

Its Concurrent Roles in Improving Agility and Reducing Lead Time

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Abstract

Quantum leap, or paradigm shift, is occurring in product design field where modularity to be a key feature in developing product architectures. Modularity is necessary in building robust product platform (Meyer, et.al., 1997). Modular architecture enables to use chunks to implement one or a few functional elements in their entirety, and to build well-defined interactions among chunks to the primary functions of the product (Ulrich, et.al., 2000). The concurrent effect of modular architecture in improving agility and reducing lead time are able to be quantitatively proved using hypothetical data.

Keywords : *Modularity, comprehensive innovation, agility, lead time.*

1. Introduction

Presently, global environment faces paradigm shift from domestic to *global economy*. Transformation underlying the emergence of global economy concerns with technology of manufacturing that previously emphasis on large-scale, mass-production, and assembly-line techniques has shifted to more flexible technology to manufacture in high-volume, flexible, nimble, and customized production manner. Today, manufacturers are necessitated to adopt flexible technology to cope with product variety issues in the dynamic marketplace.

The ability of Japanese automakers to accommodate and to respond demand fluctuations in marketplace has been pinpointed as an essential factor in their ongoing success. By offering a wide variety of products, Japanese automakers have been able to cover all segments of the automotive market. Unfortunately, the Japan automotive industry success faces fact of sharply decreases in production of passenger cars for domestic and foreign markets in 2001, as illustrate in **Figure 1**

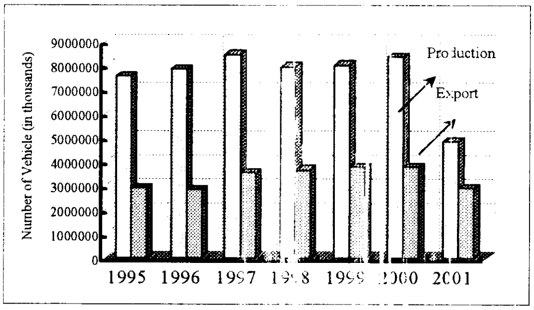

Figure 1. Japan Production of Passenger Cars.
Source : JAMA Inc., 2001

In this circumstance, to consistently cope with fast-changing customer requirements for product variety, automakers urged to increase efficiency through implementation of *modularity* in product development and Manufacturing process. Modular architecture allows automakers to develop robust product platform to offer a wider variety of products by combining modules for several models, whereas each of which is a variation of a single *platform* (Meyer, et.al., 1997; Lung et.al., 1999).

Modularity is a source of comprehensive innovation in product development process, whereas the key innovations were to permit a more flexible organization of assembly. Technological innovations were incorporated into both product, as *build-in technology*, and manufacturing process, as *technology know-how*. Today, Japan automakers are attempting to develop modular approach for the production of passenger cars through platform strategy. According to the approach, four of Japan's automakers, encompassing Toyota Motor Corp., Honda Motor Co., Mitsubishi Motor Corp., Mazda Motor Corp., and 19 parts manufacturers intend to join Covisint that allows automakers to purchase parts and materials on a global basis (JAMA Inc., March 2001).

Introducing product variety incorporates a dynamic aspect in terms of the rate of manufacturing agility and the lead time necessary to design and launch new models. This paper is dedicated to describe concurrent effect of modularity in improving agility and reducing lead time quantitatively. We organize this paper as follow, Section 2, explains analytical framework, Section 3, development of mathematical model, and Section 4, simulation of the model. Finally, in Section 5, We present concluding remarks, and propose future works in techno- economics research.

2. Analytical Framework

Generally speaking, modular architecture enables to increase 'commonalization', whereas sharing of major components and other parts between different automotive models has formed the basis of economies of scope (M.C. Belis-Bergouignan, et.al., 1999). In automotive industry, the increasing standardization of components has paved the road of *economies of scope* for their use in manufacturing of different finished products, particularly, in the use of a common platform to make distinct models.

Proliferation of models and variants implies increased complexity in the organization of production. Hence, there would be an 'optimal' level of product variety according to market conditions and available production methods. The 'efficient level of variety' could be identified on the basis of the relationship between the profitability of companies and the breadth of its product ranges.

Figure 2 depicts correlation of platform-model in Japan automotive product between 1990-1993. Herein mentioned that variety of products is a function of platforms and modules, which will be shared in the automotive models and variants. Modules is created using chunks to implement one or a few functional elements in their entirety, which can be assembled interchangeably using a flexible interfaces (Ulrich, et.al., 2000). Referring to Fujimoto's et.al. (1999) previous research, herein we postulate hypotheses,

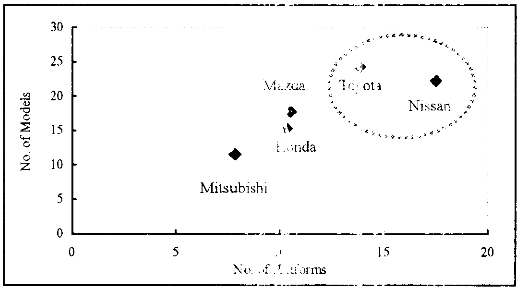

Figure 2. Japan Automotive Platform-Model between 1990-1993.
Source : Jetin, ... 1999.

H_1 : Increasing commonalization result in higher rate of modules interchangeability that leads to increase product agility.

H_2 : Increasing agility leads to reduction of lead time to launch new models.

The hypotheses can be formulated in mathematical model as described in the following section

3. The Development of Model

The issue of product variety has been discussed primarily in the context of what amounts to models and body styles in the automotive industry. Concept of variety has a meaningful interpretation in many settings. An automotive product can have variety if it can be created in a number of discernible different versions of a basically similar item, as illustrated in **Figure 3**.

According to Fujimoto and Raff (1999), automaker should provide a specific range of potential products by developing a number of models (NPRD) in order to fulfill requirements in a particular target market. In this case, the company has to consider the variety of parts kits (NPRT), parts production process, final assembly lines, assemblers, supplier chains, dealers, and dealer channels. Thereby, in this context agility can be pointed out as a relationship relating to one of the several concepts of variety relative to a pair of productive resources.

Suppose the minimum necessary flexibility (hereinafter, minimum flexibility) for each pair of productive resources as the ratio between the two levels of variety, as depicted in **Figure 4**. Therefore, it can be formulated (Fujimoto et.al., 1999),

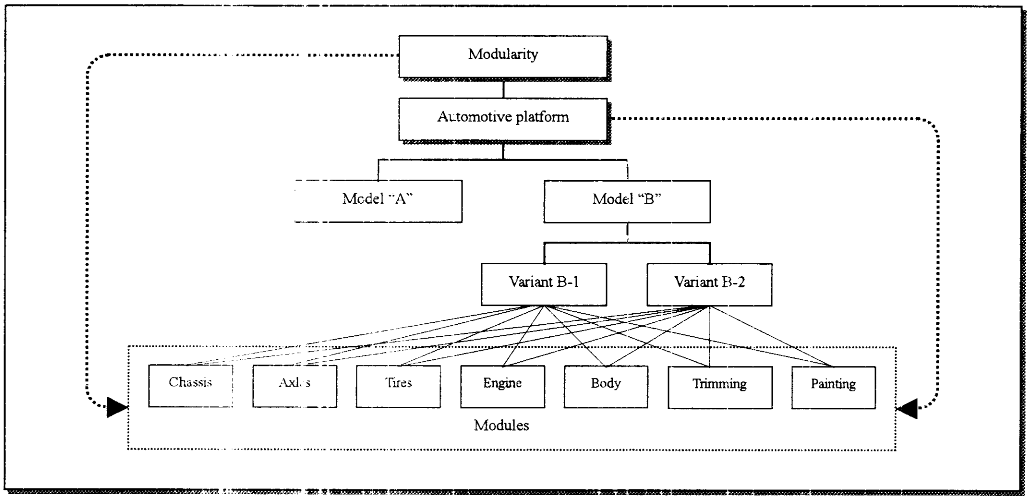

Figure 3. Interchangeability of Modules amongst Automotive Models and Variants.

$$[MPF] = NPRD\ /\ NPRT \quad (1)$$

and

$$[MOF] = NPRT\ /\ NPRC \quad (2)$$

then naturally can be derived.

$$[Product\ variety] = [Parts\ variety] \times MPF \quad (3)$$

and

$$[Parts\ variety] = [Process\ variety] \times MOF \quad (4)$$

where,

MPF = minimum parts flexibility
MOF = minimum process flexibility
$NPRD$ = number of models
$NPRT$ = variety of parts kits
$NPRC$ = parts production process lines.

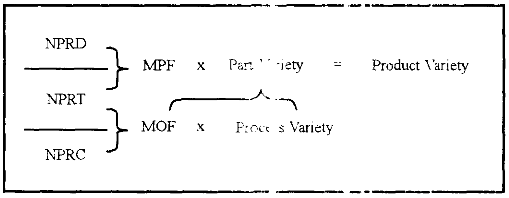

Figure 4. Measurement of Product Variety.

Dynamically automakers continue a capability-building competition, which enhances the firm's ability to handle variety and flexibility. Afterwards, based on equation (3), product agility can be measured.

$$A_P = a.[Product\ variety]^{\alpha}.m^{\beta}{}_{i}.c^{\gamma}{}_{i} \quad (5)$$

where,

A_p = level of product agility
a = constant
α = elasticity of product variety
m = number of modules in platform i, $\alpha \geq 1$
β = elasticity of modules
c = number of common parts in platform i, $\beta \geq 1$
γ = elasticity of common parts

Moreover, in order to avoid the interdependence between the stochastic disturbance term and the endogenous explanatory variable(s), therefore, we develop a recursive model to measure the level of product agility effect towards reduction of lead time. The nature of lead time model is formulated in the following three-equations system, as depicted in **Figure 5**

$$\begin{aligned} L_{1i} &= \delta_{10} + \varepsilon_{11}.Ap_{1i} + \varepsilon_{12}.T_{2i} + u_{1i} \\ L_{2i} &= \delta_{20} + \delta_{21}.L_{1i} + \varepsilon_{21}.Ap_{1i} + \varepsilon_{22}.T_{2i} + u_{2i} \\ L_{3i} &= \delta_{30} + \delta_{31}.L_{1i} + \delta_{32}.L_{2i} + \varepsilon_{31}.Ap_{1i} + \varepsilon_{32}.T_{2i} + u_{3i} \end{aligned} \quad (6)$$

where,

L = lead time to launch new models based platform i
T = technology embodied in platform i.

The disturbance are such that,

$$cov(u_{1i}, u_{2i}) = cov(u_{1i}, u_{3i}) = cov(u_{2i}, u_{3i}) = 0$$

Statistically, this is assumption of ***zero contemporaneous correlation*** that stated the similar disturbances in different equations are uncorrelated.

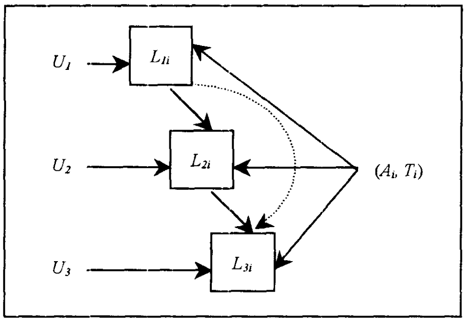

Figure 5. The Recursive Model.

4. Simulation

The convergence by Japan automakers towards greater product variety is a relatively recent phenomenon, and it should not mask the divergences, which had been previously detected in their trajectories. Assessment on the agility can be traced by investigating historical Toyota's data in **Table 1**. Toyota with its 24 models and 13 platforms, continued to experience limited variety.

Table 1 Toyota's Variety of Products

Years	Total Output	No. of Models	No. of Platforms	Model by Platform	Product Variety
1960-64	116.353	2.0	2.0	1.0	2.00
1965-69	617.929	4.2	3.8	1.1	4.18
1970-74	1.565.609	8.2	5.4	1.5	12.30
1975-79	2.017.450	10.4	6.4	1.6	16.64
1980-84	2.369.111	16.2	8.8	1.8	25.60
1985-89	2.751.758	19.2	10.2	1.9	34.56
1990-93	2.827.028	24.3	13.8	1.8	39.74

Assumes $NPRT$ = 2, 4, 6, ... ; and $NPRC$ = 1, 2, 3, ..., that will increase linearly. While, m = 10, 12, ... ; and c = 10, 14, ... that will increase randomly. According to lead time, we assume value of T's will increase respectively in the following values : 5, 6, 8, 11, 15, 20, 26. **Table 2** describes the simulation result.

The system elements of variety and agility are complimentary. The agility of product and of system as a whole depends upon how much variety is being produced and where it is being produced and also on the location and amounts of investments in flexibility.

Table 2 Simulation Result Using the Three-equations System

Years	m_t	c_t	A_t	T_t	L_t
1960-64	10	10	0.05000	5	76.4020
1965-69	12	14	0.01520	6	89.6449
1970-74	13	16	0.00772	8	116.9430
1975-79	15	17	0.00292	11	157.9743
1980-84	17	20	0.00230	15	212.7580
1985-89	20	22	0.00030	20	281.2220
1990-93	21	25	0.00008	26	363.4071

Relationship between level of product agility (A_i) towards lead time (L_i) resulted from simulation using the three-equations system describes that higher level of agility leads to shorter lead time to launch new models, as described in **Figure 6**.

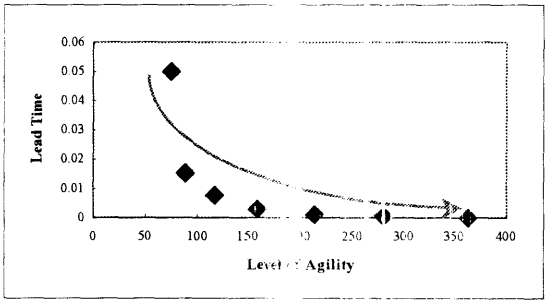

Figure 6. Impact of Product Agility towards Lead Time.

Herein, implicitly we state that technology has no significant effect towards reduction of lead time under particular circumstances when level of agility very low.

5. Concluding Remarks

This paper attempt to investigate concurrent roles of modularity in improving agility and reducing lead time. We find the evidence and prove it quantitatively using a recursive model encompasses level of agility and technology as exogenous variables, meanwhile, we take into account lead time as an endogenous variable, which will influence value of lead time in the next point of time.

Herein we point out findings based on the simulation result using the recursive model. They are,

(i) Referring to equation (1) to (5), there is evidence that rate of product agility is directly influenced by number of modules and common parts that are designed in a platform. Therefore, the first hypothesis (H_1) is accepted.

(ii) Higher level of product agility has significant impact towards reduction of lead time. Therefore, the second hypothesis (H_2) can be accepted.

Moreover, we mention that interactions between level of agility and technology towards lead time could not be proved empirically, because of the evidence shows that technology has no effect towards reduction of lead time, particular when level of agility very low.

According to Japan automotive industry, herein we highlight that important success factor in the global competition is its pursuit of modularity and parts commonality, which enable automakers to maintain certain level of product variety to respond to the demand variety, while restricting its part variety for scale economy.

In the future, in accordance with Covisint that is formed by four of Japan's top automakers, particular works has to be done to investigate number of automakers that prefer to concentrate on the advantages, which they could potentially derive from changes in their sourcing relationships, developing a new organization, called *modular assembly*. In this organization the productive chain is hierarchies into a root and branch type organization, and each level is organized in a similar fashion, in that the different tasks, which must be accomplished at that particular stage of the chain are delegated to the various companies, which are to be involved at that moment in time, encompassing the assemblers, the first tier supplier, the second tier subcontractors, and so forth. This new modular organization potentially become core competitive advantage to win competition from the U.S. and Europe automakers in global dynamic environment.

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