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Integrating Product Platform Development with Supply Chain Configuration in a Global Environment

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Abstract
In this research, we have investigated the interaction between product platform development and supply chain configuration in a global environment. A comprehensive decision support model has been developed to simultaneously determine product strategy and supply chain configuration. By Products we refer to the bundle of module option alternatives offered to market segments, and product platform development is a means of looking for the opportunity of sharing module option alternatives among products. A scenario analysis has been performed to gain insights on how platform development is influenced by market conditions and current supply chain configuration. The analysis shows that different supply chain configurations favour different levels of platforming. It also shows that decentralised manufacturing and sourcing configuration does not necessarily support a higher degree of customisation.

1. Introduction

Design sharing among products, such as common platform or component sharing across product lines, has been extensively studied in product development literature, (Ramdas, Fisher, and Ulrich, 2003; Fisher, Ramdas, and Ulrigh, 1999; Gupta and Krishnan, 1999; Krishnan and Gupta, 2001; Krishnan, Singh, and Tirupati, 1998). A new challenge that has emerged in product development research is how to integrate product development with other areas of management. Forza and Rungtusanatham (2002) assert that, despite the undeniable appeal and importance of understanding the complex interdependencies among product design, process design, and supply chain design decisions, very little is known, at present, about how these decisions should be coordinated to maximise operational and supply chain performance.

It is product design that determines which materials, components, and finished products should flow through the supply chain. In order to build the synergy between product development strategy and supply chain management, it is important to understand the implications of linkage between a firm's product market strategy and its supply chain capability and infrastructure. For example, a standardised product strategy that focuses on gaining economies of scales may favour a centralised manufacturing configuration, while a mass customisation strategy may favour a more decentralised supply chain configuration. In this research, we have studied the integration of product platform development with supply chain configuration in a global environment.

Most of the literature examining the implications of product design on supply chain management studied "product-process" choice problems, especially in the context of the benefits of delay of differentiation (Garg and Tang, 1997; Lee, 1996; Lee and Tang, 1997; Swaminathan and Tayur, 1998). In a more recent paper, Novak and Eppinger (2001), empirically explored the link between product architecture and vertical integration decisions. Their analysis suggests that companies that optimise the requirements of their product architecture, as well as the capacity of their supply chain, will outperform the firms that focus only on supply chain structure or product characteristics. Literature on the mathematical modelling approach of product development and supply chain management interface is, on the other hand, almost nonexistent. While Gupta and Krishnan (1999) and Hadjinicola and Kumar (1997) have attempted some analytical modelling, the literature on a model that considers simultaneous optimization of product architecture and supply chain configuration decisions is hard to be found. In fact, no research has been done that looks at the joint decisions related to the selection of modules for product platform identification along with the supply chain decisions related to the selection of global manufacturing sites and suppliers.

In this research, a comprehensive decision support model has been developed to simultaneously determine global product strategy and global supply chain configuration. The proposed model is a combination of the product configuration problem (which includes the module option alternative development problem) and the capacitated network problem with fixed charge on arcs. The formulation of the model is presented in section 2. The proposed model is NP-Hard. Section 2 also shows that successively solving a single module product configuration on capacitated network problems obtains optimal solutions, if the manufacturing configuration could be pre-processed outside of the model. Although the solution procedure adopted in section 2 might be a crude one for the expertises in optimisation, nevertheless, the computation performance of the solution procedure turns out to be satisfactory.

The definition of the platform varies greatly from company to company, and the interpretation of a platform itself has evolved over time. As Ramdas, Fisher and Ulrich (2003) have pointed out:

In the past, car projects (at Ford) within a platform were required to share a core set of "platform components"—often including the chassis and drive train. Today, car projects within a platform are required to share certain aspects of the production process, known as "fixed points"—the method of insertion of a particular component in assembly. In either interpretation of a platform, the product platform echelon facilitates sharing by allowing coordination across concurrent design projects.

There have been two different research approaches in product platform development: active and passive. The first approach is the active platform design approach, in which firms spend significant efforts designing a platform in the early stages of product family development. Product variants are then developed around the platform. In their pioneering work, Krishnan and Gupta (2001) identify the benefits of adopting product platforms as: 1) a potential reduction in development costs through the reuse of design, 2) a lower variable cost effect, since firms tend to invest more time and effort in development of shared systems, and 3) shorter development time in product variants. Under an active platform approach, the commonality across products is deliberately designed into the product family development.

In the second approach, referred to as the passive platform approach, commonalities are identified on the given set of developed products. In a passive platform design, every effort is made to identify commonalities on a certain set of design characteristics, such as product attributes or performance requirements. Gupta and Krishnan (1998) studied the designing assembly sequence in order to maximize the commonality of components and assembly operations among product offerings. They use the term generic subassemblies (GSA) to define subassemblies shared by multiple products with common components and assembly connections. This approach is particularly relevant to component sharing with downward substitution, where a "better than adequate" component version is used on some products, (Ramdas, Fisher, and Ulrich 2003; Fisher, Ramdas, and Ulrich 1999).

We adopt the second approach for this research. The proposed model is an optimization model for physical, modular, discrete, engineered, and manufactured products and the configuration of a global supply chain. Products are the bundle of module option alternatives offered to the market segments. These products are first dissected into major modules, and the development of each major module is then carried out separately from the development of the other major modules. Finally, modules are assembled to form a product through a pre-specified interface. What we mean by product platform development in this research is the process of looking for the opportunity for sharing module option alternatives among the major modules of the product platform.

In section 3, a scenario analysis has been performed to gain insights into the extent to which a platform approach is influenced by market conditions and existing global supply chain structure. Model parameters are generated to resemble the global automobile industry as closely as possible. Solutions of scenarios are then compared to each other in terms of cost performance and platform performance. Section 4 concludes the paper.

2. Model and Computation

Our decision support model takes the following information as its primary inputs; the minimum threshold product feature requirements in each market segment and the associated demand and revenues; the set of modules, their option alternatives, and their associated development costs; the set of market features that can be supported by each of these option alternatives; the set of potential suppliers and their capability/capacity; the set of manufacturing sites and their capability/capacity; and finally, the logistics cost data.

The development of each module might involve several different alternatives. For example, the development of an engine module may involve the development of a 1.1-litre engine, a 1.2-litre engine, a 1.8-litre engine, and so on. Such alternatives are referred to as module option alternatives. It is simply assumed here that each module option alternative is developed without sharing the commonality with other module option alternatives. Therefore, the total module option alternative development cost is simply the sum of each module option alternative development cost. It is also assumed that module option alternatives can be arranged in an order of a certain performance characteristics.

A market segment is defined in this paper as a group of customers in the same region who have a similar set of preferences. The set of preferences is passed from the marketing research team to the product design team in the form of product feature requirements. An engineering team maps the product feature requirement into a specific module option alternative for each major module. In an automotive example, a power feature is mapped onto the engine module and a high-power market feature requirement is mapped onto, say, a 3-litre engine.

It is possible that a certain product feature is mapped onto more than one module. The mile-per-gallon feature of an automobile, for example, may be affected by the size of the engine, the weight of the chassis, and the shape of the body. For such cases, the set of modules (and the set of module option alternatives for threshold requirement) could be considered as a bundle onto which the mile-per-gallon feature is mapped. Therefore, no generality is lost by assuming one-to-one mapping between the product features and modules, as well as between threshold requirements and the module option alternatives.

Product feature requirements of market segments are interpreted as threshold requirements to allow over-design. A similar approach has been taken by Gupta and Krishnan (2001) and Fisher, Ramdas, and Ulrich (1999). Over-design allows configuring a product that offers higher-ordered module option alternatives than the market segment's threshold requirements. However, over-design does not allow configuring a product with lower-ordered module option alternatives than threshold requirements. We assume that the forecasted demand volume of a market segment is not affected by the actual product configuration. Offering module option alternatives higher than the threshold requirements does not always increase the demand volume of the market segment. An automobile engine with a bigger displacement than the threshold will attract more horsepower-conscious customers. The bigger engine, however, may deliver a less than desirable mile-per-gallon figure to some customers. What is assumed here is that the product configuration does not introduce a significant net change in demand volume. Offering a 2.0 litre engine instead of 1.8 litre engine does not increase the demand volume from 10,000 units to 2 million units, nor vice versa. Therefore, it is possible to identify a single demand figure representing the range of the demand volume by different product configurations. We also assume that all demands of market segments have to be satisfied.

Interfaces among modules of the finished products are specifically defined such that the system integration cost is not altered by product configuration. In other words, perfect modularity is assumed in the proposed model. It is a straightforward extension of the model to formulate imperfect modularity. Therefore, the product configuration is the selection of module option alternatives for market segments from the set of module option alternatives that satisfy the threshold requirements of the market segments.

The product configurations create the flow requirements of specific module option alternatives at demand nodes. The supply chain part of the model finds the supply chain configuration as well as the flow within the supply chain in order to fulfil the flow requirements at demand nodes at the lowest cost. The manufacturing plants receive module option alternatives from suppliers and perform assembly operations to obtain the finished products. The manufacturing plants then distribute the finished products to market segments.

The proposed model is presented below. The definitions of sets and indexes, parameters, and decision variables are presented in Appendix A for ease of reading.

Minimize:

$$\sum_{j\in J}\sum_{k\in K(j)} DC_k * ada_k + \sum_{p\in P} MSC_p * mps_p + \sum_{m\in M}\sum_{p\in P(m)} MUC_{mp} * mps_{mpk} + \sum_{s\in S} SSC_s * sfc_s$$

$$+ \sum_{j\in J}\sum_{s\in S(j)}\sum_{k\in K(j)} STC_{sk} * sft_{sk} + \sum_{j\in J}\sum_{p\in P}\sum_{s\in S(p,j)}\sum_{k\in K(j)}\sum_{q\in Q(k,s)} SUC_{kpsq} * sts_{kpsq} \qquad (1)$$

Subject to:

$$\sum_{k\in K(j)} cpo_{mk} = 1 \qquad j\in J,\ m\in M \qquad (2)$$

$$cpo_{mk} \le ada_k \qquad j\in J,\ m\in M,\ k\in K(j) \qquad (3)$$

$$\sum_{p\in P(m)} mss_{mpk} \ge DV_m * cpo_{mk} \qquad k\in K(j),\ m\in M \qquad (4)$$

$$mss_{mpk} \le MC_p * mps_p \qquad k\in K(j),\ p\in P(m),\ m\in M \qquad (5)$$

$$\sum_{m\in M} mss_{mpk} \le MC_p \qquad p\in P(m) \qquad (6)$$

$$\sum_{m\in M}\sum_{k\in K(j)} mss_{mpk} = \sum_{m\in M}\sum_{k'\in K'(j')} mss_{mpk'} \qquad p\in P(m),\ j,j'\in J \qquad (7)$$

$$\sum_{m \in M} \sum_{k \in K(j)} mss_{mpk} = \sum_{s \in S(p,j)} \sum_{k \in K(j)} \sum_{q \in Q(k,s)} sts_{kpsq} \qquad p \in P,\ j \in J \tag{8}$$

$$sft_{sk} \le sfc_s \qquad k \in K(j),\ s \in S(j) \tag{9}$$

$$sts_{kps} \le SC_s * sft_{sk} \qquad k \in K(j),\ s \in S(p,j), p \in P \tag{10}$$

$$\sum_{p \in P} \sum_{k \in K(j)} \sum_{q \in Q(k,s)} sts_{kpsq} \le SC_s \qquad s \in S(p,j) \tag{11}$$

$$SQ_{skq} * sqc_{skq+1} \le \sum_{p \in P} \sum_{k \in K(j)} \sum_{q \in Q(k,s)} sts_{kpsq} \le SQ_{skq} * sqc_{skq} \qquad p \in P,\ j \in J \tag{12}$$

$$sqc_{skq} \le sqc_{skq'} \qquad \text{For all } q < q' \tag{13}$$

It is implicitly assumed that even if a firm offers a product configuration that includes module option alternatives higher than a market segment's threshold requirements, the market segments are only willing to pay the price for their threshold requirements. Combined with the assumption that all the demands of market segments have to be satisfied, it implies that total revenue is fixed. Therefore, the proposed model is a cost minimisation model rather than a profit maximisation model.

The objective function (1) has six terms. Each term states module option alternative development costs, manufacturing plant setup costs, assembly and transportation costs of finished products, supplier selection costs, setup costs at suppliers, and total unit and shipment costs of module option alternatives, respectively. Constraints (2) state that exactly one module option alternative is to be chosen for each major module to configure a product. Constraints (3) ensure that a module option alternative that has not been developed cannot be chosen for product configuration. Constraints (4) guarantee that all demands of market segments are satisfied. Constraints (5) and (6) express manufacturing plant setup constraints and manufacturing plant capacity constraints, respectively. The proposed model implicitly assumes the full flexibility at the manufacturing plants. Each manufacturing plant can assemble all product models for any of the market segments. This assumption is justifiable in the cases that the assembly requirements of products may not significantly differ across the product models. Constraints (7) state assembly constraints. These constraints uniquely arise in the assembly environment. The flow from manufacturing plants to market segments represents the shipment of finished products consisting of all major modules, whereas the flow from suppliers to manufacturing plants represents the shipment of module option alternatives. The flow requirements of module option alternatives can be viewed as a multi-commodity trans-shipment problem, whereas module option alternatives are the multi-commodities flowing in the system. Finished products require that all the major modules be assembled together. This means that if a certain module has been shipped from a manufacturing plant to a market segment, the rest of the other modules must be shipped with it. Otherwise, the manufacturing plant did not ship a completed product. This implies that the sum of the module option alternatives of a certain module shipped from a manufacturing plant to a market segment should be equal to the sum of the module option alternatives of any other module shipped from the manufacturing plant to the market segment. Constraints (8) are the typical material balance constraints of a network flow. Constraints (9), (10), and (11) are supplier selection constraints, setup for module option alternative production at the suppliers, and the supplier capacity constraints, respectively. The proposed model assumes two stages of setup activities at the suppliers to ship module option alternatives to manufacturing plants. Suppliers must first set up a module production line that is flexible enough to assemble more than one, and possible all, of the module option alternatives. Suppliers then have to invest in tooling for the production of specific module option alternatives. At the first stage, it would cost more if a supplier opts to choose a production line that can process all module option alternatives. The issue will be discussed in the next section for analysis. Finally, constraints (12) and (13) state quantity discount constraints.

Computation

The structure of the proposed model has been referred to as a multi-commodity transhipment problem with assembly constraints and a fixed charge on arcs. It is well known that a capacitated network problem with a fixed charge on arcs is NP-Hard. In this research, we suggest that successively solving the single module product configuration on capacitated network problems is a good solution strategy for the proposed model, if the manufacturing configuration could be pre-processed outside of the model.

In the proposed model, relaxing the product configuration variables to continuous variables does not guarantee the integer solutions. Let *Z(j)* be the reduced problem of the proposed model in which *Z(j)* includes only product configuration variables of module $j \in J$, supplier arcs of module $j \in J$, and manufacturing arcs of the proposed model. Then, *Z(j)* is a single module product configuration problem on capacitated arcs, where module $j \in J$ itself is the finished product. Problem *Z(j)* has the same arc costs with the proposed model on supplier arcs, but $(1/|J|)$ of arc costs of the proposed model on manufacturing arcs since manufacturing arcs of the proposed model are shared with other modules.

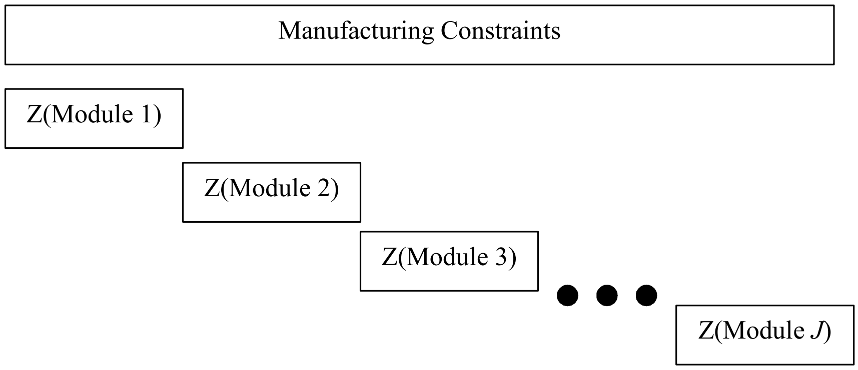
<u>Theorem 2.1.</u>

Let $X[Z(j)]$ be the set of solution vectors of problem *Z(j)* for all modules $j \in J$. Then, $X[Z(j)]$ establishes the lower bound of the proposed model.

<u>Proof:</u>

$X[Z(j)]$ might not be a feasible solution for the proposed model, since any of problem *Z(j)* enforces the assembly constraints. Therefore, $X[Z(j)]$ establishes only the lower bound of the proposed model. ■

In fact, problem *Z(j)* is a sub-problem of the proposed model, and sub-problems *Z(j)* for all modules $j \in J$ are linked to each other by sharing manufacturing constraints, such as assembly constraints. The following figure illustrates the problem structure of the proposed model.



Suppose manufacturing configurations can be pre-processed outside of the proposed model. In other words, which manufacturing plants serve particular market segments have been already been decided. In modelling terms, it is equivalent to stating that the manufacturing configuration is determined only by the shipping cost of the finished products and manufacturing setup cost, but not by shipping cost of the module option alternatives from suppliers. Let *Z(pm)* be a special case of the proposed model, where *pm* is the pre-processed manufacturing configuration.

Theorem 2.2.

Let $X[Z''(j)]$ be the set of solution vectors of problem $Z''(j)$ for all modules $j \in J$, where $Z''(j)$ is the reduced problem of *Z(pm)* such that $Z''(j)$ includes only product configuration variables of module $j \in J$, supplier arcs of module $j \in J$, and manufacturing arcs of problem *Z(pm)*. Also, $Z''(j)$ has the same arc costs with *Z(pm)* on supplier arcs but $(1/|J|)$

of arc costs of *Z(pm)* on manufacturing arcs. Then, $X[Z''(j)]$ is the optimal solution of *Z(pm)*.

<u>Proof:</u>

By theorem 2.1, $X[Z''(j)]$ establishes the lower bound of *Z(pm).* Since flow on manufacturing arcs of $Z''(j)$ should coincide with *pm*, $X[Z''(j)]$ is a feasible solution of *Z(pm)*. Since $X[Z''(j)]$ is a feasible solution of *Z(pm)* at the lower bound, $X[Z''(j)]$ is an optimal solution of *Z(pm).* ■

It is straightforward that $X[Z''(j)]$ is a feasible solution to the proposed model. Therefore, $X[Z''(j)]$ establishes the upper bound of the proposed model. It should be noted that the complexity of problem $Z''(j)$ is still NP-hard, since $Z''(j)$ is a capacitated network design problem with fixed charges on supplier arcs. Therefore, the performance of the solution algorithm for the capacitated network design problem would have a significant impact on the total computation time of problem $Z''(j)$.

In the literature review section of their recent article, Holmberg and Yuan (2000) found that the uncapacitated version of the fixed charge network design problem has been quite well studied in several research reports. However, very few references could be found in the literature for capacitated network design. Problem $Z''(j)$ is different from the typical fixed charge network design problem in the sense that $Z''(j)$ assumes two stages of fixed charge activities on supplier arcs: 1) process improvement for module $j \in J$ and 2) tooling for module option alternative $k \in K(j)$. To the best of our knowledge, very few, if any, references could be found in the literature for a multistage fixed charge network design problem. The positive side to the computation aspect for problem $Z''(j)$ comes from industry practice. The primary concern of the proposed model for this study is platform-able modules. In the era of integrated suppliers, firms typically have only a handful of suppliers for the source of such major modules. Consequently, the size of the fixed charge network design problem of $Z''(j)$ is typically small enough to be solved in acceptable computation time without the help of a specially designed solution algorithm.

A total of 1,152 test problems are solved in a block of 96 test problems. All of the computations have been performed on a Gateway Solo VE 9300 XL with 126 MB of RAM, equipped with a Pentium III 733 MHz processor. The code is written in Microsoft Visual C++ 6.0 connected to CPLEX 6.6. Most of the blocks of 96 test problems were solved in a few hours. The longest computation time for a block of 96 test problems was about 20 hours. The actual code is kept in the authors' personal file and is available from the authors upon request.

3. Analysis

In this section, a scenario analysis has been performed to gain insights into the extent to which a platform approach is influenced by market conditions and the existing global supply chain structure. The proposed model is a comprehensive optimisation model that includes market conditions, development costs, supplier capabilities, and logistic costs. A full factorial design, therefore, generates a prohibitively large number of scenarios to be analysed. In this research, scenarios are generated from factors representing the level of market segmentations and global supply chain structure. The main factors of the analysis are the geographic configurations of the supply chain, supplier plant capability, worldwide demand volume, and number of global market segments.

Geographic Configuration of Supply Chain

The main purpose of this research is to investigate the interaction between product strategy and supply chain configuration. Does a decentralized manufacturing and sourcing configuration really support a higher degree of customization? On the other hand, does a centralized supply chain configuration really lead to a higher degree of platforming? The interaction between product strategy and supply chain configuration is going to be investigated through five different geographic configurations of supply chain.

Local Manufacturing and Local Sourcing (LL): LL configuration refers to the supply chain configuration in which a large number of manufacturing plants with small capacities are scattered across the regions, and the manufacturing plants serve only the market segments located in the same region. Similarly, there are a large number of suppliers with small capacities scattered across the regions, with suppliers supplying only to manufacturing plants located in the same region. Here, in the LL configuration, each region has one manufacturing plant and two suppliers for each major module.

Central Manufacturing and Central Sourcing (CC): CC configuration refers to the supply chain configuration in which a small number of manufacturing plants with large capacities serve all the market segments of all the regions. Similarly, a small number of suppliers with large capacities supply to all the manufacturing plants of all regions. Here, in CC configuration, there is only one large manufacturing plant and eight suppliers in total (two suppliers for each module).

Central Manufacturing and Global Sourcing (CG): CG configuration refers to the supply chain configuration in which a small number of manufacturing plants with large capacities serve all the market segments of all regions. However, a large number of suppliers with small capacities are scattered across all the regions, and suppliers can supply to any manufacturing plants in any of the regions. Here, in the CG configuration, there is only one large manufacturing plant similar to the CC configuration. However, suppliers are scattered across regions, such that each region has two suppliers for each major module, similar to the LL configuration.

Local Manufacturing and Global Sourcing (LG): LG configuration refers to the supply chain configuration in which a large number of manufacturing plants with small capacities are scattered across all the regions, and manufacturing plants serve only the market segments located in the same region. Also, there are a large number of suppliers with small capacities across all of the regions, but suppliers can supply to any manufacturing plants in any of the regions. Here, in the LG configuration, the numbers of manufacturing plants and suppliers are the same as the LL configuration.

Global Manufacturing and Global Sourcing (GG): GG configuration refers to the supply chain configuration in which a large number of manufacturing plants with small capacities are scattered across all of the regions, and manufacturing plants can serve any market segments in any of the regions. Similarly, there are a large number of suppliers with small capacities across all of the regions, and suppliers can supply to any manufacturing plants in any of the regions. Here, in the GG configuration, the numbers of manufacturing plants and suppliers are again the same as the LL configuration.

Supplier Plant Capability

In reality, every supplier plant has a different level of capability. The definition of capability itself varies significantly in the research literature. In this research, the supplier plant capability refers to the set of module option alternatives a supplier's plant can supply. For example, suppose there are four alternatives of engine modules — a 1.0-liter engine, a 1.4-liter engine, a 1.6-liter engine, and a 2.0-liter engine; some engine plants may be able to provide all of the engine alternatives, whereas other engine plants may be able to supply only a partial set of engine alternatives. Scenario analysis is going to investigate the impact of the level of suppler plant capability on platforming and supply chain performance. Suppose suppliers generally have a low level of capability. Does this lead to the selection of a higher number of supplier plants? If so, how does this affect the degree of platforming?

Here, two levels of supplier capability are chosen to generate scenarios.

High Capability: Any supplier can supply all of the module option alternatives.

Low Capability: In a low level of supplier capability, suppliers can supply either the lower half of module option alternatives or the higher half of module option alternatives.

The supplier setup cost is assumed to be proportional to the supplier plant capability, which implies that the setup cost for supplier plants with high capability is twice the setup cost for suppliers with low capability.

Worldwide Demand Volume

A high rate of technological change, the trend toward a greater degree of product variety, and progressively shortening product life cycles typically lead to a lower worldwide demand volume for any given product model. Therefore, the cost pressure of satisfying diverse needs of customers might be more severe when the lifetime demand volume is low. In reality, lifetime demand volume varies from product model to product model. Although it exceeded its wildest dream, BMW had expected that only about 100,000 units of its new Mini would eventually leave BMW's new factory in Oxford, England ("BBC News," May 22, 2001). Saturn has produced more than 2.4 million units since the company's introduction (company web site, June, 2001). More popular models than these, such as the Ford Focus, however, are expecting a much higher lifetime demand volume.

Here, four levels of worldwide demand volume are chosen to generate scenarios: A half million units of lifetime demand volume worldwide; 1 million units of lifetime demand volume worldwide; 2 million units of lifetime demand volume worldwide; 3 million units of lifetime demand volume worldwide.

Number of Global Market Segments

It is assumed that world markets consist of three regional markets. A statistic shows that more than 90 percent of the worldwide demand volume of vehicles is attributed to these three regional markets, namely Europe, Asia, and North America (*MVMA Motor Vehicle Facts and Figures*, 1984). With a given lifetime worldwide demand volume, a higher number of global market segments naturally indicates a higher level of market fragmentation. The preliminary numerical experiment showed that an extremely low number of global market segments would not show any interesting results, whereas too high a number of global market segments would only increase the computational burden.

Here, three levels of the number of global market segments are chosen to generate scenarios. For simplicity, it is assumed that each region has the same number of market segments: 24 market segments (8 market segments per region); 48 market segments (16 market segments per region); and 72 market segments (24 market segments per region).

Other Factors and Parameters

It could be argued that the number of module option alternatives in threshold requirements may indicate the level of market fragmentation. Threshold requirements for less fragmented market segments could be stated with a lower number of module option alternatives, whereas the threshold requirements for more fragmented market segments may require that a higher number of module option alternatives be stated. The actual computations showed that an extremely low number of module option alternatives, such as 2, 3, or 4 per module, would not provide an interesting insight. On the other hand, too high a number of module option alternatives, such as more than 10 per module, would increase the computational burden without contributing very much in the way of additional insights. Here, only the computation results from scenarios of 8 module option alternatives per module are reported. For simplicity, it is assumed that each module has the same number of module option alternatives. It is also assumed that platforms consist of four major modules.

Relying on Industry Publications of the automobile industry, every possible effort is made to generate model parameters to resemble the global automobile industry as closely as possible. Despite the effort, there have been difficulties in estimating module option alternative development costs and quantity discount price-break points. To test whether the results are really affected by different levels of module option alternative development costs and quantity discount price-break points, the whole set of scenarios were re-run with three different levels of module option alternative development cost and four different levels of quantity discount price break points. The results show that the general nature of solutions remains unchanged for all levels of module option development costs and quantity discount break-points. Along with the computation code mentioned in section 2, the set of parameters used in scenario analysis are available from the authors upon request.

Performance Measures

The cost benefit of platforming, more precisely the reduction in total module option alternative development costs, could be a measure for the degree of platforming. It might be better, however, to have a more direct measure for platforming. Three such measures are introduced here — the number of product configurations, weighted distances of product configurations from thresholds, and the Platformability Index.

Number of Product Configurations: A product configuration refers to a specific combination of module option alternatives that forms a complete product. The total number of possible product configurations can be obtained by multiplying the number of module option alternatives of each module. If overdesign is not allowed (equivalently, platforming is not allowed), the number of product configurations actually offered to market segments would be equal to the number of market segments, assuming each market segment has its own unique product feature requirement. (The number of potential product configurations is generally far greater than the number of market segments. For example, 4,096 different product configurations can be generated from 8 module option alternatives per module and four major modules. In reality, no company serves that many market segments simultaneously.) As the level of platforming increases, however, the total number of product configurations actually offered to market segments is likely to fall. It could be argued, therefore, that a low number of product configurations offered to market segments would imply a high level of platforming, and vice versa.

Weighted Distances of Product Configurations from Thresholds: It could be argued that the diversity of market segments could be best served if the product feature requirements are taken for the product specification of the market segments rather than for threshold requirements. The implication is that the closer the product configurations are to the threshold requirements, the better-served are the diverse needs of market segments. Suppose the order in which module option alternatives are arranged by a certain performance characteristic can be used as the basis of a scale, then the difference in the order between the module option alternatives actually offered to market segments and threshold module option alternatives of the market segments, could measure the degree of overdesign. The higher the degree of overall overdesign, the less the diversity of market segments served. Here, distance refers to the difference between the module option alternatives actually offered to market segments and threshold module option alternatives of the market segments. Other things being equal, product configurations with low overall distances serve the diverse needs of market segments better than the ones with high overall distances.

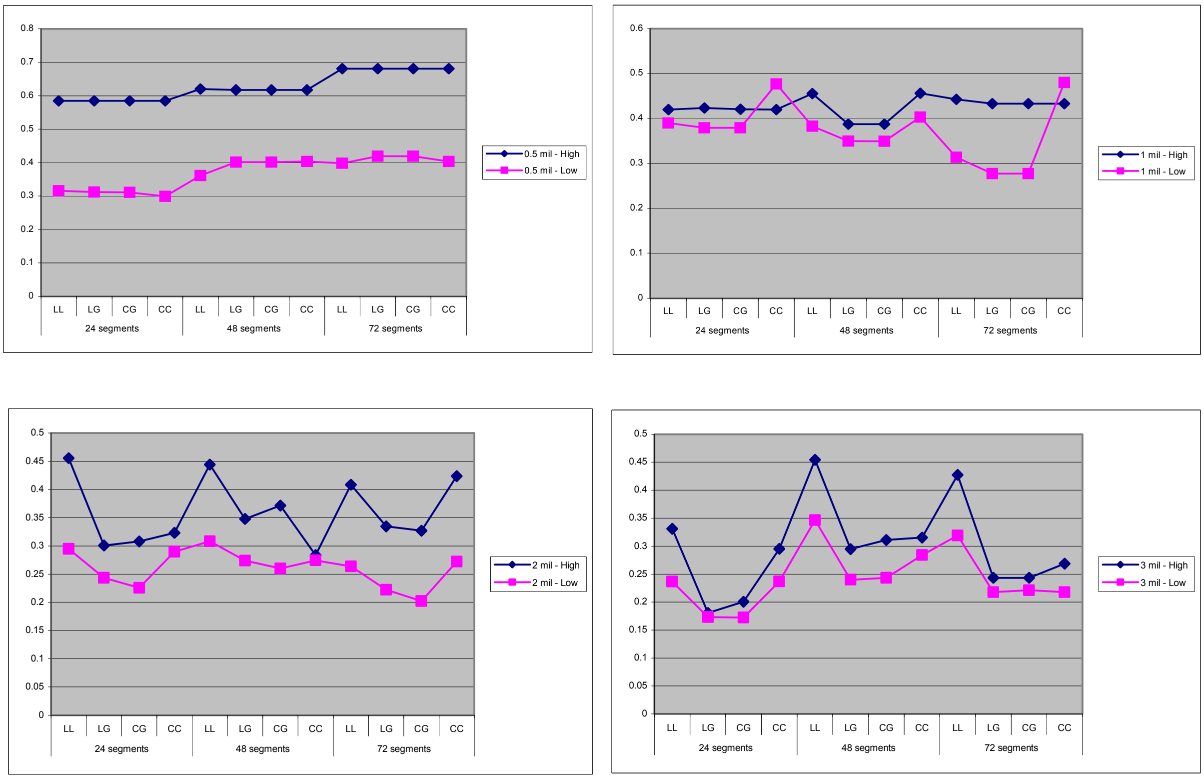
The measurement developed in this research is the weighted average distance of market segments. A distance in a module of a higher value might be more easily perceived by customers than a distance in a module of a lower value. A distance offered to market segments with high demand volume should be weighted more than a distance offered to market segments with low demand volume. Hence, the distance is weighted by the relative value of modules and the demand volume of market segments. A numerical example of the measuring distance is presented in Appendix B. It is implicitly assumed in the computation that the order in which module option alternatives are arranged is equally spaced in distance scale. In other words, any module option alternative and the module option alternative of one level higher in the order are exactly one unit distance apart. In reality, this may not be the case. For instance, distance might be exponentially weighted as the difference increases. It is a straightforward task, however, to incorporate such cases into the above computation. Instead of simply subtracting the order of the threshold requirement from the order of the module option alternative actually offered to market segments, one might apply a proper weight scheme to the subtraction.

Platformability Index: Another form of platformability measure could be derived from the weighted distance measure. In the example in Appendix B, the product configuration {3, 4} is the highest one among threshold requirements. The weighted distance of 1.56 is, therefore, indeed the maximum possible weighted average distance of the given threshold requirements in the example. On the other hand if each market segment had been offered the product configuration exactly the same as its threshold requirement, the weighted distance would have been zero. The weighted distances of any other production configurations will fall between zero and the maximum possible weighted average distance of the given threshold requirements. With this observation in mind, the following index might provide a useful insight:

Platformability Index = (Actual weighted average distance) / (Maximum weighted distance)

The actual weighted average distance refers to the weighted average distance computed from the product configurations actually offered to the market segments. Maximum weighted distance is obtained assuming that the highest product configuration among threshold requirements would be offered to all market segments. The index will have a value between zero and one. The index will be zero if each market segment is offered the product configuration at its threshold requirements. No platforming opportunity has been exploited through overdesign. On the other hand, the index will have a value of one if each market segment is offered the product configuration formed by using the highest level of option alternatives demanded as threshold by the marketplace for all the modules. In general, the closer to zero the index, the lesser the platforming through overdesign; and the closer to one the index, the greater the platforming through overdesign.

The index has one distinct advantage over weighted average distance as a platformability measure, and that is that the value of maximum weighted distance depends on specific numerical incidences of the scenario. In other words, the value of maximum weighted distance varies scenario by scenario. For example, the weighted distance of 1.56 when maximum weighted distance is 1.56, may not represent the same level of platforming by the weighted distance of 1.56 when maximum weighted distance is, say 3. Such a problem could be easily overcome by using the index. The index could have been named the "overdesign" index, since it measures the level of overdesign relative to the given maximum overdesign opportunity. The index possesses the characteristic, however, that a lower value of the index indicates a lower level of platforming, while a higher value of the index indicates a higher level of platforming. It is reasonable to argue that a "platformability" index is an appropriate name for the index. Nevertheless, the interpretation of the platformability index is rather similar to the weighted average distance. It measures the relative loss of product diversity to the maximum possible loss of product diversity (represented by maximum weighted distance) by overdesign. Therefore, the platformability index will not be reported as an independent platformability measure. Instead, the index is reported as a complementary measure for the weighted average distance.

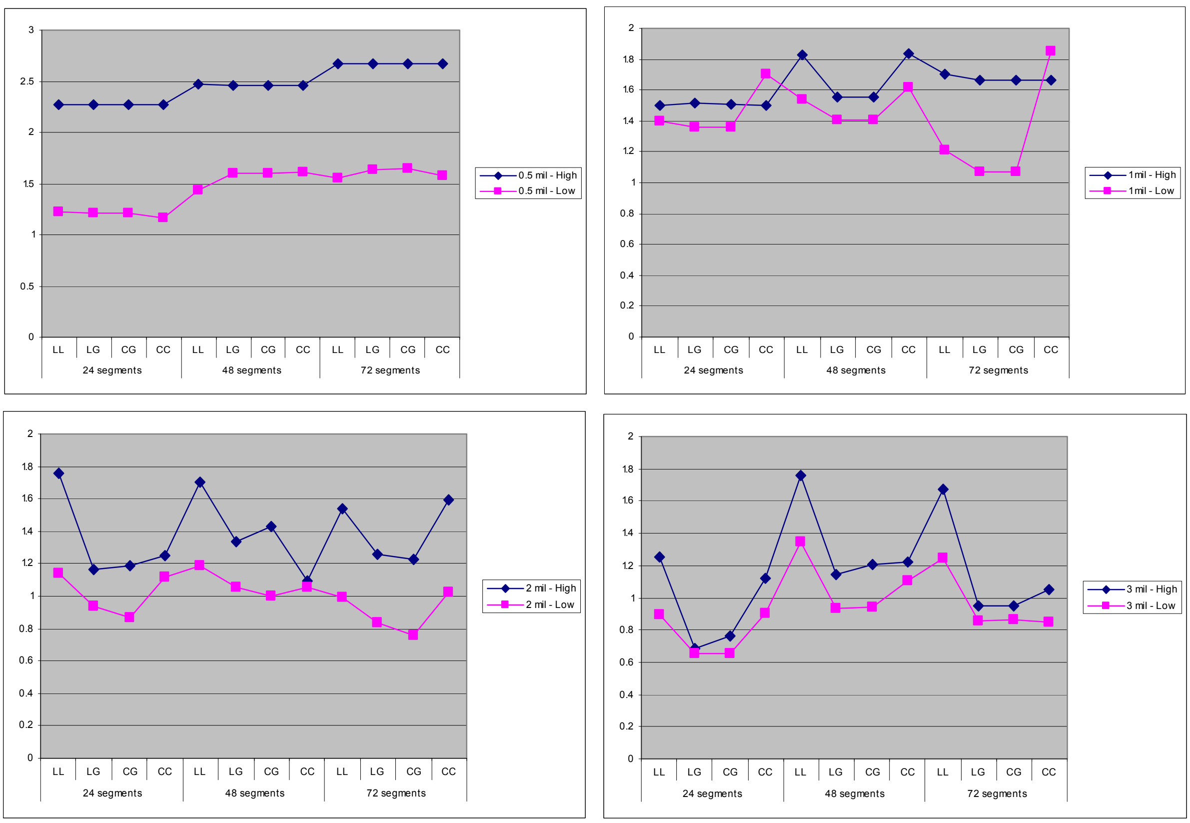


Graph 1: Platform Index

Performance Analysis on Supply Chain Configurations

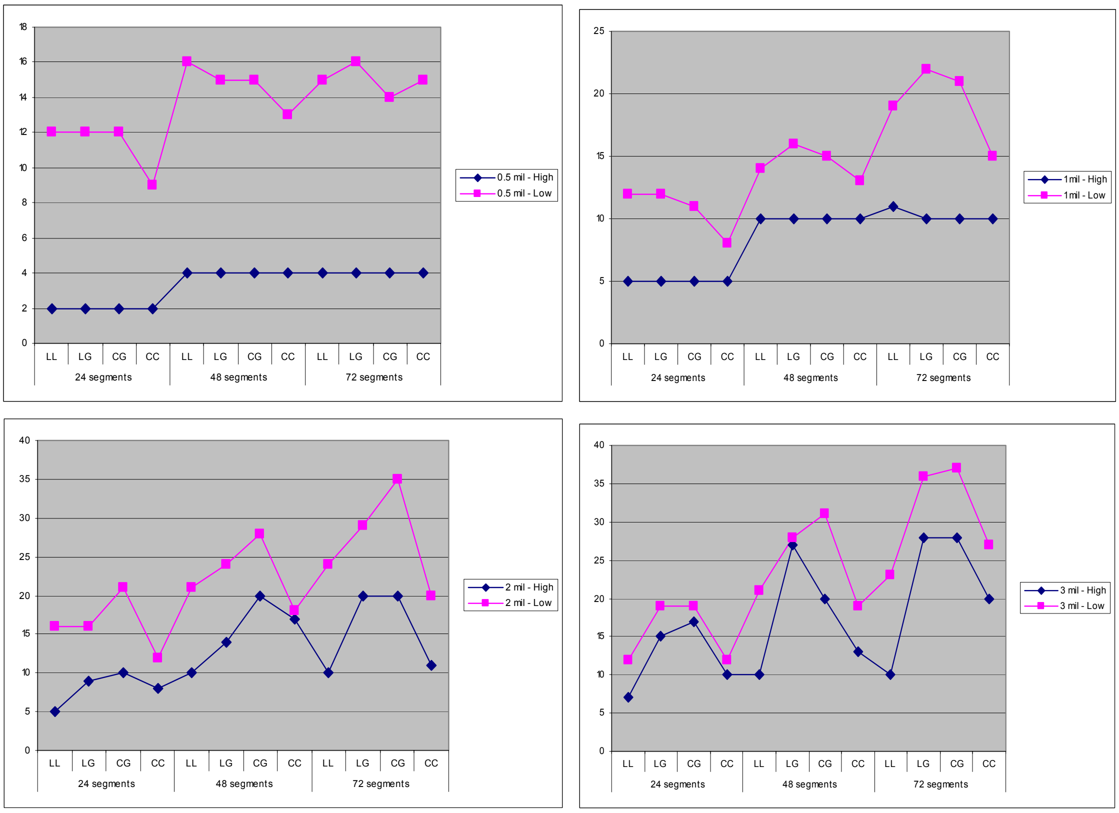
<u>Platforming vs. Supply Chain Configurations:</u> Graph 1, Graph 2, and Graph 3 illustrate Platform Index, Weighted Configuration Distances, and Number of Product Configuration to Supply Chain Configurations, respectively. Although it doesn't show well

in the cases with 0.5 million worldwide demand volume, a pattern emerges as the worldwide volume increases to 1 million, 2 million, and 3 million units. LL and CC strategies consistently show higher levels of platforming than LG and CG strategies for all market segmentation levels. It was expected that the CC strategy would have a high level of platforming since economies of scale could be maximised with central sourcing. We hadn't expected that the LL strategy would have a high level of platforming. Suppliers could have much higher volumes in the Global Sourcing configuration than in the Local Sourcing configuration. The cost savings from quantity discount are, therefore, bound to be higher in the Global Sourcing configuration than in the Local Sourcing configuration, which leads us to



Graph 2: Weighted Configuration Distances

expect that the degree of platforming would be higher in the Global Sourcing configuration than in the Local Sourcing configuration. However, the observation indicates otherwise. The higher volume for suppliers in the Global Sourcing configuration enables suppliers to obtain quantity discount without a high degree of platforming. On the other hand, suppliers in the Local Sourcing configuration have to pursue a higher degree of platforming to obtain quantity discounts due to the relatively lower volume available for them. As a result, the Local Manufacturing-Local Sourcing (LL) configuration shows a higher degree of platforming than the Local Manufacturing-Global Sourcing (LG) and Central Manufacturing-Global Sourcing (CG) configurations in the presence of quantity discount. It is also observed that the difference of the degree of platforming between in the LL configuration and in the Global Sourcing configuration (LG or CG) increases with an increase in worldwide demand volume.



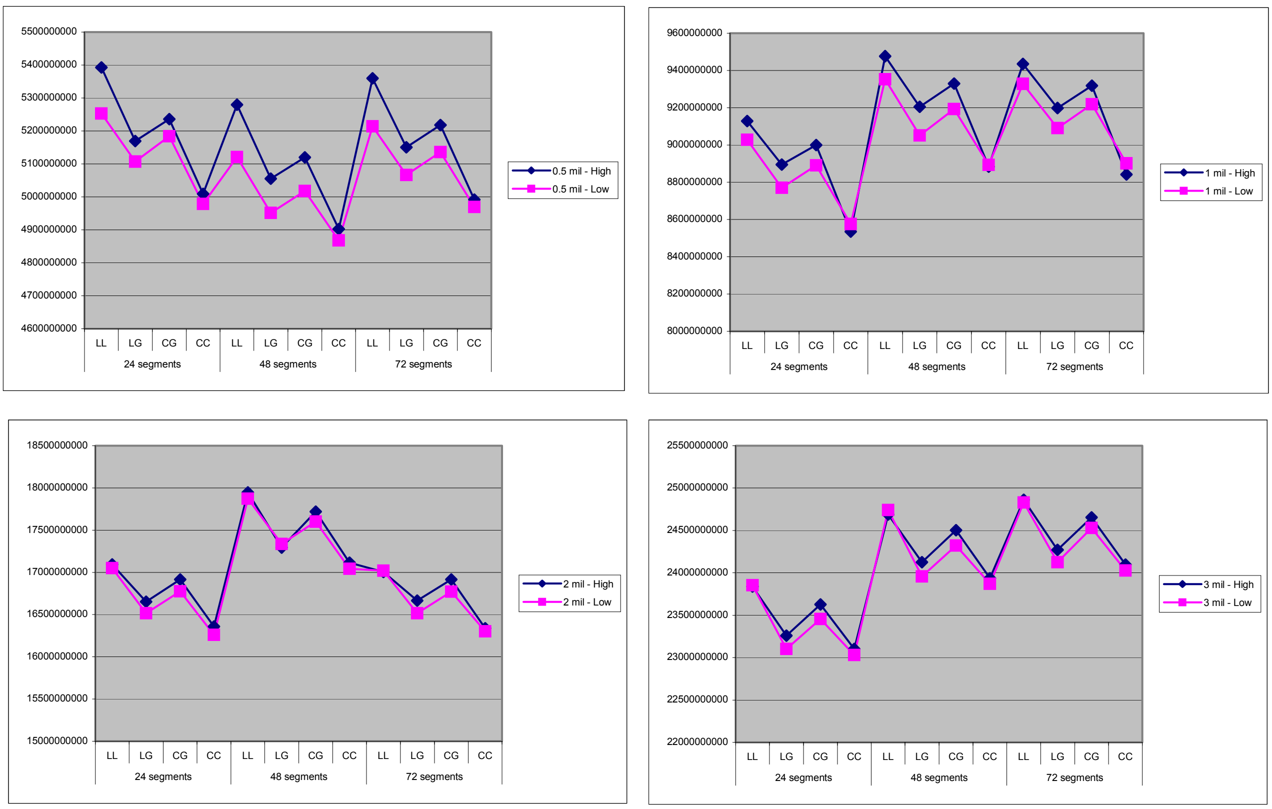
Graph 3: Number of Product Configurations

The LL strategy can be approached in the context of local content rule. With ever growing economic blocks, the local content requirement has become of practical interest, especially in the North American and European markets. Under the net cost method of the NAFTA agreement, at least 50 percent (60 percent for automobiles) of the net cost of any good must represent NAFTA labour and/or NAFTA originating components in order for that good to qualify for NAFTA's preferential treatment. The most up-to-date information for local content rule can be found on the DoC NAFTA database (1999). Research works on local content rule are quite rare. Munson and Rosenblatt (1997) developed a mathematical model incorporating local content rule in global sourcing decisions. In the presence of a local content rule, firms are encouraged (or forced) to choose local suppliers. Consequently, firms would choose a supply chain configuration close to the LL configuration. The implication of imposing a local content rule is that it could reduce the diversity of products and increase the level of platforming.

Total Cost vs. Supply Chain Configuration: Total Cost of each supply chain configuration is illustrated in Graph 4. The LL configuration strategy is the most restricted option compared to other configuration strategies. Consequently, with a given market segmentation level, the LL configuration strategy is consistently the most expensive option. The CC configuration strategy proves to be the most economic option due to the maximum level of economies of scale. Between the LG and CG configuration strategies, the CG strategy turns out to be the more costly option than the LG strategy due to increased shipment costs from the manufacturing plant to the market segments in different regions. Inbound logistics also cost more under the CG than under LG strategy. Although the CC strategy shows the lowest total cost in all cases within the experiment set, the gap between the CC and LG strategies is getting narrower as worldwide demand volume increases. When worldwide demand volume is low, the potential savings from fixed cost components and quantity discount could outweigh the potential savings in transportation costs from the localised configuration. As worldwide demand volume increases, however, transportation costs would become more critical cost components.

Observations from Other Factors

The Degree of Platforming vs. World Wide Demand Volume: The degree of platforming decreases with an increase in worldwide demand volume. In the presence of quantity discount, the degree of platforming decreases at much slower rates. The vast majority of the total cost is attributed to the total procurement cost of the module option alternatives, and the total procurement cost of the module option alternatives is predominantly determined more by worldwide demand volume than by anything else. As worldwide demand volume increases, the relative burden of fixed cost in development falls, whereas overdesign cost becomes much more significant. When worldwide demand volume is high, the burden of overdesign outweighs the savings from overdesign. Consequently, the degree of overdesign falls as worldwide demand volume rises. In the presence of quantity discount, the burden of overdesign could be lessened through quantity discount as worldwide demand volume increases. In the presence of more favourable quantity discount, such as a greater price cut at lower volumes, the degree of platforming decreases at much slower rates.



Graph 4: Total Costs

The Role of Supplier Capability: The scenarios with suppliers of low capability consistently show lower total costs than the scenarios with suppliers of high capability. It is due to our assumption that the supplier process capability improvement cost has been assumed to be proportional to the supplier capability, and supplier capability is measured by the number of module option alternatives it can supply. It is assumed that a supplier of low capability can supply either the lower half of the module option alternatives or the higher half of module option alternatives. The implication is that the process improvement cost of having one high-capability supplier is equal to the process capability improvement cost of having two low-capability suppliers. The consequence is that the supply chain with low capability suppliers has more flexibility in selecting suppliers, since the capability for lower-end module option alternatives and the capability for higher-end module option alternatives can be bought separately from each other. The supply chain with high-capability suppliers has no such flexibility since the capability for the entire range of module option alternatives comes at once at a higher process capability improvement cost. For example, instead of having one high-capability supplier supplying two manufacturing plants in two different regions, the supply chain might be able to have one lower-end supplier for a manufacturing plant in one region and one higher-end supplier for a manufacturing plant in the other region. The total inbound transaction cost could be reduced by having two low-capability suppliers. Although this observation is an outcome of our assumption, it still could be suggested that blindly pursuing a higher level of supplier capability may not deliver the most desirable results. This observation can be strengthened when the performance of the product configuration is investigated. The degree of platforming increases with an increase in the level of supplier plant capability, ceteris paribus.

If potential suppliers have huge capacity, such that any one of them could effectively satisfy all of the worldwide demand volume single-handedly, supplier capability might not be a significant factor on the degree of platforming. Within the parameters of scenario analysis, however, high-end suppliers alone cannot satisfy worldwide demand volume. Some of the lower-end suppliers have to supply some portion of the module option alternatives. This means developing only a small number of module option alternatives, and offering a highly overdesigned product is not a feasible option when suppliers have a low level of capability. Some of the lower-end module option alternatives have to be developed, as well. The opportunity for overdesign to pursue a high degree of economies of scale is greatly reduced when suppliers have a low level of capability. Therefore, when suppliers have a low level of capability, 1) a greater number of module option alternatives are developed, 2) a greater number of product configurations are offered to the market segments, and 3) a low level of overdesign reduces the weighted distances from the threshold requirements. In the perspective of diversity in product line, less overdesign is not necessarily an undesirable outcome. In fact, one might argue the opposite. A supply chain with low capability suppliers is more supportive in that it can offer diversity in the product line than otherwise.

The Degree of Platforming vs. Number of Market Segmentations: The more the market segments, the more the number of different sets of threshold requirements! It is not surprising to see that the different numbers of platform configurations tends to increase as the number of market segments increases. However, Platform Index and Weighted Configuration distances measures do not show trends that can be generalised.

4. Concluding Remarks

In this research, we have investigated the interaction between product platform development and supply chain configuration in a global environment. A comprehensive decision support model has been developed to simultaneously determine product strategy and supply chain configuration. Products are the bundle of module option alternatives offered to market segments, and the product platform development is a means of looking for the opportunity of sharing module option alternatives among products.

Although insights on how platform development is influenced by market conditions and current supply chain configuration are obtained through numerical analysis rather than by the development of a theory, the analysis shows quite interesting results. It shows that different supply chain configurations favour different level of platforming. It also shows that a decentralised manufacturing and sourcing configuration does not necessarily support a higher degree of customisation.

A few topics remain to be studied in future. The analysis of this research focuses on supplier selection in investigating the influence of supply chain configuration on product platform strategy. The configuration of manufacturing plants is implicitly assumed, i.e. it is "pre-determined." It would be interesting to examine whether different manufacturing configurations support different product platform strategies.

The proposed model does not reflect any uncertainty. For instance, there is no guarantee that the product strategy and supply chain configuration suggested by the proposed model will perform well when product demands fluctuate. Examining the performance of product strategy and supply chain configuration to uncertain demands would offer interesting future research.

Appendix A

Sets and Indexes

R: Set of regions, indexed by r.

M: Set of market segments, indexed by m.

$M(r)$: Set of market segments in region $r \in R$; $M(r) \subseteq M$.

J: Set of major modules of product, indexed by j.

$K(j)$: Set of module option alternatives of module $j \in J$, indexed by k.

$K(j,m)$: Set of module option alternatives of module $j \in J$ that satisfy the threshold requirements of market segment $m \in M$; $K(j,m) \subseteq K(j)$.

P: Set of manufacturing plants, indexed by p.

S: Set of suppliers, indexed by s.

$S(j)$: Set of suppliers may supply option module alternatives of module $j \in J$; $S(j) \subseteq S$.

$S(p,j)$: Set of suppliers may supply option module alternatives of module $j \in J$ to plant $p \in P$; $S(p,j) \subseteq S$.

$Q(k,s)$: Set of price-break points (for quantity discount) for module option alternative $k \in K(j)$ by supplier $s \in S$, indexed by q.

Parameters

(For ease of reading, all parameters are defined using capital letters.)

DC_k: Development cost of module option alternative $k \in K(j)$.

DV_m: Demand volume of market segment $m \in M$.

MC_p: Manufacturing capacity at plant $p \in P$.

MSC_p: Manufacturing setup cost at plant $p \in P$.

MUC_{mp}: Unit assembly cost of finished product at plant $p \in P$ to serve market segment $m \in M$. It includes unit transportation cost from plant $p \in P$ to market segment $m \in M$.

SC_s: Capacity of supplier $s \in S$.

SSC_s : Supplier selection cost for supplier $s \in S(j)$.

STC_{sk} : Setup cost for module option alternative $k \in K(j)$ at supplier $s \in S(j)$.

SUC_{kpsq} : Unit cost of option alternative $k \in K(j)$ from supplier $s \in S(j)$ to plant $p \in P$ at price-break $q \in Q(k,s)$. It includes unit cost of option alternative $k \in K(j)$ and unit shipping cost from supplier $s \in S(j)$ to manufacturing plant $p \in P$.

SQ_{ksq} : Allowed quantity of module option alternative $k \in K(j)$ at supplier $s \in S(j)$ at price-break $q \in Q(k,s)$.

Decision Variables

(Note: For ease of reading, all decision variables are defined using lower-case letters.)

ada_k : Binary variable to indicate whether module option alternative $k \in K(j)$ has been developed.

cpo_{mk} : Binary variable to indicate whether product configuration for market segment $m \in M$ includes module option alternative $k \in K(j)$.

mps_p : Binary variable to indicate whether manufacturing plant $p \in P$ has been setup for production.

mss_{mpk} : Continuous variable of the amount of shipment of module option alternative $k \in K(j)$ from manufacturing plant $p \in P$ to market segment $m \in M$.

sfc_s : Binary variable to indicate whether supplier $s \in S(j)$ has been chosen.

sft_{sk} : Binary variable to indicate whether supplier $s \in S(j)$ has been chosen for a supplier of module option alternative $k \in K(j)$.

sqc_{skq} : Binary variable to indicate whether module option alternative $k \in K(j)$ is shipped from supplier $s \in S(j)$ at price-break $q \in Q(k,s)$.

sts_{kpsq}: Continuous variable of the amount of shipment of module option alternative $k \in K(j)$ from supplier $s \in S(p, j)$ to manufacturing plant $p \in P$ at price-break $q \in Q(k, s)$.

Appendix B

Computation Example: Weighted Distances from Threshold

Suppose a product consists of two major modules and each module has four module option alternatives. Each module option alternative is denoted as 1, 2, 3, or 4, such that 1 is the lowest-end module option alternative, 2 is the second-lowest module option alternative, 3 is the second-highest module option alternative, and 4 is the highest-end module option alternative. Module 1 is credited for 40 percent of the total value of the product, and Module 2 is credited for the rest of the value (60 percent). Also, there are four market segments. Market segment 1, segment 2, segment 3, and segment 4 are attributed to 10 percent, 20 percent, 30 percent, and 50 percent of worldwide demand volume, respectively. Finally, all four market segments are offered the same product configuration of {3, 4}, meaning the product is assembled with alternative 3 of Module 1 and alternative 4 of Module 2, where threshold requirements of market segments are given in the following table:

	Module 1	Module 2
Market Segment 1	1	2
Market Segment 2	3	4
Market Segment 3	2	1
Market Segment 4	1	3

Computation

Let i and j be indexes of modules and market segments, respectively. The weighted distances are computed by the following formula:

Weighted Distances from Thresholds =

$$\sum_j \sum_i \text{(distance of module i * weight of module i) * weight of market segment j}$$

where weight of the module refers to the relative value of the module to the total value of the product, and the weight of the market segment refers to the relative demand volume of the market segment to worldwide demand volume. Non-weighted distances are computed in the following table:

Non-weighted distance from threshold:

	Module 1	Module 2
Market Segment 1	3 – 1 =2	4 – 2 = 2
Market Segment 2	3 – 3 = 0	4 – 4 = 0
Market Segment 3	3 – 2 = 1	4 – 1 = 3
Market Segment 4	3 – 1 = 2	4 – 3 = 1

Now from the formula, the weighted distance is:

[(2*0.4) + (2*0.6)] * 0.1 (weighted distance in market segment 1)

+ [(0*0.4) + (0*0.6)] * 0.2 (weighted distance in market segment 2)

+ [(1*0.4) + (3*0.6)] * 0.3 (weighted distance in market segment 3)

+ [(2*0.4) + (1*0.6)] * 0.5 (weighted distance in market segment 4)

= 1.56 (weighted average distance of all market segments)

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