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Concurrent Design of Product Modules Structure and Global Supply Chain Configuration

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1. Introduction

In globally distributed supply chains, the classical logistics decisions of facilities location, sourcing and distribution are greatly influenced by political and economic factors. The fierce competition, fluctuations in currency values, intellectual property considerations and international trade agreements, tariffs and laws and government's tax incentives all have a major impact on decisions made by manufactures regarding where to design, produce, assemble and market their products.

The need to satisfy varying customers' demands gave rise to increased flexibility not only in manufacturing systems but also in the product structure through modularity and platform concepts. Mass customization and postponing or moving products differentiation as close as possible to point-of-sale, if applied carefully, can be very beneficial. The protection of intellectual properties and trade-secrets play a role in deciding how a product is broken down into modules, what is contained in each module and where it would be produced.

Variations in the currency exchange rates require careful attention particularly in globally distributed supply chains. Since one of the major criteria for making strategic decisions in supply chain is the overall allocation costs (production, inventory, transportation), they should be calculated considering the in-site currency exchange rate forecasts.

As shown in Figure 1 although the currency exchange variations may be negligible in the short term they become more significant in long term and strategic decisions1[1].

Therefore, it is important to consider those currency trends and exchange rates where suppliers, Manufacturers and markets are located.

Responsiveness and agility are becoming important competitive attributes in addition to quality, variety and price. This leads to employing the concept of 3-dimensional concurrent engineering (3D-CE), as a step beyond design for supply chain and concurrent engineering. This concept was first discussed by Fine (1998) to understand and coordinate the interdependencies among product and process design and supply chain decisions, to maximize the operational and supply chain performance. Since it is the product design that determines which materials, components, and finished products should flow through the

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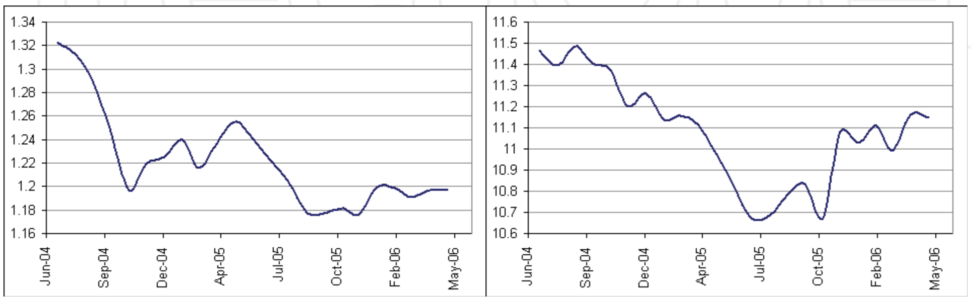
[1] These information are provided from http://www.forecasts.org/exchange-rate/

Source: Supply Chain,Theory and Applications, Book edited by: Vedran Kordic, ISBN 978-3-902613-22-6, pp. 558, February 2008, I-Tech Education and Publishing, Vienna, Austria

supply chain, considering the available supply chain locations, their capacity, costs and their demands while designing a product would help determine the optimum product design and modular structure. Furthermore, by considering different product design alternatives while configuring the supply chain, the optimum locations and capacities of various nodes can be defined.



Canadian Dollar to US Dollar Mexican Peso to US Dollar

Figure 1. Currency Excange Rate (Past Trend , Present Value and Future Projection)

In this paper, a comprehensive decision support model has been developed to concurrently determine the optimal product modularization scenario and the global supply chain configuration in a 3 echelon (suppliers, manufacturing facilities and distribution centers) global supply chain system considering the procurement costs, production, inventory and transportation costs along with the impact of changes in the global market currency exchange rates. The proposed model combines the product design modular configuration problem (including modules make/buy options and the product modular structure alternatives) and the supply chain design configurationproblem (including different locations for suppliers, manufacturers and distribution centers). The application of the decision support model is evaluated using historical data from an automobile wipers system manufacturer.

In section 2 the relevant literature is reviewed. Section 3 describes the developed global supply chain decision making mathematical model and section 4 analyzes the proposed decision making model using data for a generic globally distributed supply chain for an industrial product. Finally in section 5 the conclusions and the future research direction for this line of research are presented.

2. Literature review

In the 1990's the emphasis on synchronizing supply chain management decisions with product design decisions resulted in another aspect of design for X (DFX) series called design for supply chain management (DFSC) defined as "designing products and processes so that the supply chain related costs and performance can be more effectively managed". Economic packaging, concurrent and parallel processing and postponement strategies (Time and Form) are the three key components of design for supply chain management and commonality, standardization and modularity are some of the important concepts to implement postponement.

In 1995, Nielsen and Holmstrom studied the benefits of taking account of supply chain considerations in the design and process engineering stages in a European car manufacturer offering a large number of options with each model. They argued that designing common components and creating variety at the final assembly stage (postponement) can be a good alternative to pilling inventory of each product variation (high inventory cost) or waiting for the suppliers to deliver the customized product (delay cost). Lee & Sasser (1995) studied the impact of employing principles of design for supply chain for new product development atHewlett Packard (HP) Company, using a standard design for power supply units for HP printers that is applicable in both North America and Europe markets instead of using dedicated power supplies for each market. They developed an analytical model to quantify the complex impacts and benefits of cost drivers like, stock-outs, reconfigurations, manufacturing, logistics and inventory. In another study at HP, Feitzinger & Lee (1997) discussed employing postponement strategy for the assembly of the power supply using a modular design. Garg (1999) studied three product and process modular design alternatives, which differ in their number of supply chain stages and the sequence of some of the processes, for a new line of products to identify the feasible set of product and process designs in terms of their total inventory cost using the Supply Chain Modeling and Analysis Tool (SCMAT).

Many researchers have recently focused on the application and implementation of 3D-CE to maximize operational, supply chain and firm performance. Fixon (2005) argued that the product architecture, when properly defined and articulated, can serve as a coordination mechanism and presented a multi-dimensional framework for a comprehensive assessment of product architecture. Huang et al., (2005) applied an optimization model to study the impact of platform products, with and without commonality, on decisions related to supply chain configuration. They define the scope of supply chain configuration decisions quite broadly to include supplier selection, selection of transportation delivery modes, determination of inventory quantities and stocking points, manufacturing processes to use and production time. Su et al., (2005), applied queuing theory to evaluate time and form postponement structures in a supply chain. Blackhurst at al., (2005), deployed a network-based approach to develop and formalize the Product Chain Decision Model (PCDM), for describing the operation of a supply chain while considering decisions related to product design and manufacturingprocess design and the impact of such decisions on the supply chain. Petersen et al., (2005), discussed the integration of suppliers into the new product development process and their direct implications on manufacturing process design decisions and supply chain configuration decisions. Fine et al., (2005), proposed a quantitative 3-dimensional concurrent engineering (3-DCE) formulation using a weighted goal programming approach to facilitate the assessment of trade-offs among potentially conflicting objectives.

Extensive research can be cited discussing supply chain structures and performance. In 1998, Van Hoek, introduced a framework to analyze the configuration of supply chain in the context of global strategy and showed that implementation of postponed manufacturing not only requires the reconfiguration of the logistic systems but also other operations in the supply chain. Karabakal et al., (2000), studied the American Volkswagen’s vehicle distribution system and presented a combination of simulation and discrete optimization models to analyze the alterative designs in terms of costs and customer service level. Hahn et al., (2000), addressed the supply chain synchronization problem in Hyundai Motor

Company and discussed the mechanism used in order to coordinate production planning and scheduling activities among supply chain members.

Thonemann & Bradely (2002), presented a mathematical model to analyze the effect of product variety on supply-chain performance, measured in terms of expected lead time and cost at the retailers, for a single manufacturer and multiple retailers supply chain. Salvador, Rungtusanatham & Forza (2004) performed an empirical study on European firms in telecommunications, transportation vehicles and food processing equipment industries and explored how the firms supply chain should be configured when different degrees of customization are offered. Tyagi et al., (2004), developed a decision-support systemShi, and to optimize the two echelon global manufacturing supply chain for high performance polymer division in GE plastics company to maximize contribution margin while taking into consideration product demands and prices, plant capacities, production costs, distribution costs and raw material costs. Billington et al. (2004) highlighted the application of HP's new inventory optimization technique to prove supply chain networks design within HP's digital camera and inkjet supplies. In 2005, Nagel et al. proposed a multi objective evaluation method for reconfiguring supply chains based on discrete event simulation. They considered cost-based, environmental and performance-based objectives as their evaluation criteria in their study. Nembhard & Aktan, (2005) developed a supply chain model in which a manufacturing firm can have the flexibility to select different suppliers, plant locations, and market regions and there can be an implementation time lag for the supply chain operations. A real options approach was used to estimate the value of flexibility and determine the optimum strategy to manage it under uncertain currency exchange rates.

Forecasting currency exchange rates has always been considered by many researchers to reduce the uncertainties and risk of decision making in different areas. Weigend et al., (1991), Prasolov & WeI, (2000), Nasution & Agah, (2000), Chandhok & Terry, (1986), Rast, (2000) and Paramunetilleke & Wong, (2002), are some of the studies on the development of different methods to forecast the currency exchange rates and their performance.

Little work has been done on the development of decision support models for concurrent supply chain and product module structure design considering the global issues in supply chain design. Our proposed decision support model is unique in the sense that it supports concurrent design of product module structure and supply chain configuration while considering the currency exchange rate variations in a global supply chain environment.

3. Global supply chain model

An optimization-based decision support model, which determines the best way to split production and procurement of a product modules for a global supply chain system is proposed. It selects the optimal set of product module structure and the corresponding supply chain configuration taking into consideration the currency exchange rate in each period at each location while minimizing the overall system cost. Figure 2 shows the generic supply chain and the points of currency exchange rate considerations.

The decision support model is formulated using mathematical programming where the decision variables are, NM_{pnmsit} , as the number of module i purchased in period t from supplier s to produce product n under scenario m at plant p. X_{pnmt} as the number of units of Scenario m of product family n produced at Plant p in period t. I_{pnt} , as the inventory of product family n in Plant p at the end of period t. $TU_{pkt,}$ the number of transportation units used to ship products from Plant *p* to distribution center *k* in period *t*. O_{pt} , total overtime scheduled at Plant *p in period t*. $W_{pt,}$,total regular labor-hours available for Plant *p* in period. Y_{pnkt} as the Units of product family n shipped from Plant p distribution center k in period t. ITpnkt , in-transit inventory of product family n from Plant p, to distribution center k at the end of period t and Inkt , inventory of product family n at distribution center k at the end of period t.

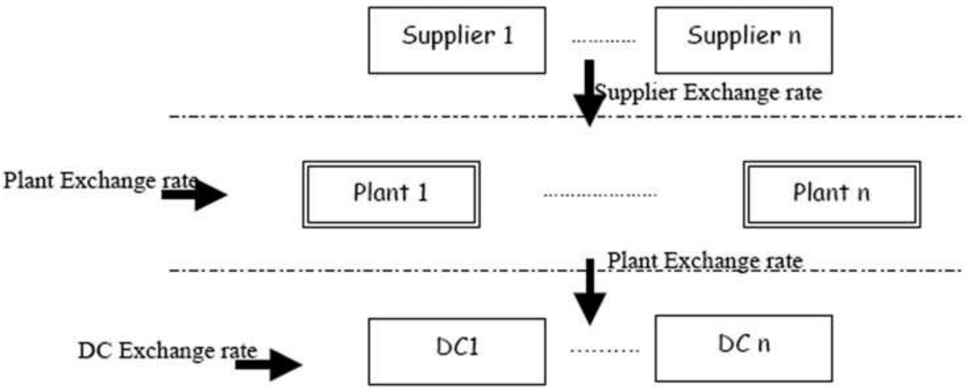


Figure 2. Generic supply chain with exchange rate considerations points

The objective is to minimize the overall following supply chain cost over the planning horizon:
Procurement cost:

$$\sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{m=1}^{M} CM_{pnmsi} NM_{pnmsit} EX_{st} \tag{1}$$

Where:
CM_{pnmsi} : Cost of purchasing module *i* from supplier *s* to produce product *n* at plant *p* (includes transportation cost)
EX_{st} : Currency exchange rate at supplier *s* in period *t*
Production cost:

$$\sum_{p=1}^{P}\sum_{t=1}^{T} L_p EX_{pt} W_{pt} \tag{2}$$

Where:
L_p: Fixed cost per regular labor hour at plant *p*
EX_{pt} : Currency exchange rate at plant *p* in period *t*
Total overtime cost:

$$\sum_{p=1}^{P}\sum_{t=1}^{T} L^{`}_{p} EX_{pt} O_{pt} \tag{3}$$

Where:
$L^{`}_{p}$: Cost of one labor hour on overtime at plant *p*

Total transportation cost (from plant to DC):

$$\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{t=1}^{T} TC_{pk}\, EX_{pt}\, TU_{pkt} \tag{4}$$

Where:
TC_{pk} : Fixed cost of transporting one consignment from plant *p* to distribution center *k*
Cost of carrying inventory at plants:

$$\sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{t=1}^{T} h_{pn}\, EX_{pt}\, I_{pnt} \tag{5}$$

Where:
h_{pn} : Inventory carrying cost of product family *n* at plant *p* held for one period
Cost of carrying in-transit inventory:

$$\sum_{p=1}^{P}\sum_{n=1}^{N}\ \sum_{k=1}^{K}\ \sum_{t=1}^{T} Th_{pn}\, EX_{pt}\, IT_{pnkt} \tag{6}$$

Where:
Th_{pn} : In-transit inventory cost for a unit of product family *n*, produced at plant *p* held for one period
Cost of carrying inventory at distribution centers:

$$\sum_{n}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T} h_{nk}\, EX_{kt}\, I_{nkt} \tag{7}$$

Where:
h_{nk} : The corresponding inventory carrying cost
EXkt : Currency exchange rate at distribution center *k* in period *t*
Subject to the following labor, capacity and transportation constraints:
Resource adjustment:

$$\sum_{n=1}^{N}\sum_{m=1}^{M} a_{pnm} X_{pnmt} = W_{pt} + O_{pt} \quad (\forall\, p\ \ 1 \ldots P,\ t\ \ 1 \ldots T) \tag{8}$$

Total required labor hour in anytime period is assumed to be equal to the available regular labor hours plus the overtime labor hours.
Shipment balance at plant p:

$$\sum_{k=1}^{K} Y_{pnkt} \le I_{pn(t-1)} + \sum_{m=1}^{M} X_{pnmt} \quad (\forall\, p=1 \ldots P,\ n=1 \ldots N,\ t=1 \ldots T) \tag{9}$$

The amount of product family *n* produced at Plant *p* that is shipped to the distribution center *k* in period *t* cannot exceed last period's inventory level plus that period's production.
Plant warehouse capacity:

$$\sum_{n=1}^{N} S_n I_{pnt} \le IC_p \quad (\forall\, p=1 \ldots P,\ t=1 \ldots T) \tag{10}$$

Space required by the net inventory at Plant p in any time period should not exceed the availablestorage space.
Distribution center warehouse capacity:

$$\sum_{n=1}^{N} S_n I_{nkt} \leq IC'_k \quad (\forall\ k=1 \ldots K,\ t=1 \ldots T) \tag{11}$$

The space required by the net inventory at each distribution center in any time period *t* shouldnot exceed the available storage space.

Inventory balance at plant p:

$$I_{pnt} = I_{pn(t-1)} + \sum_{m=1}^{M} X_{pnmt} - \sum_{k=1}^{K} Y_{pnkt}\ ,\ (\forall p\ \ 1 \ldots P,\ n\ \ 1 \ldots N,\ t\ \ 1 \ldots T) \tag{12}$$

In any period, the inventory of product family *n* at Plant *p* is equal to the last period's inventory plus the production level of the product, minus the total shipments of product family *n* to all distribution centers in the same period.

In-transit inventory balance:

$$IT_{pnkt} = IT_{pnk(t-1)} + Y_{pnkt} - Y_{pnk(t-LT_{pk})} \quad ,(\ \forall p\ \ 1 \ldots P,\ n\ \ 1 \ldots N,\ k\ \ 1 \ldots K,\ t\ \ 1 \ldots T) \tag{13}$$

In any time period, the in-transit inventory of product family *n* produced at manufacturing facility *p* being shipped to distribution center *k* is equal to the last period's in-transit inventory plus the shipments sent from manufacturing facility *p* in that period minus the received shipments at distribution center *k* in the same period.

Inventory balance at distribution center k:

$$I_{nkt} = \sum_{p=1}^{P} Y_{pnk(t-LT_{pk})} + I_{nk(t-1)} - D_{nkt} \qquad (\forall,\ n=1 \ldots N,\ k=1 \ldots K,\ t=1 \ldots T) \tag{14}$$

In any time period, the inventory of product family *n* at distribution center *k* is equal to the last period's inventory plus total received shipments in that period minus the demand in the same period.

Number of transportation consignments:

$$\frac{\sum_{n=1}^{N} V_n Y_{pnkt}}{FTL} \leq TU_{pkt} \quad (\forall\ p=1 \ldots P,\ k=1 \ldots K,\ t=1 \ldots T) \tag{15}$$

In any time period, the number of consignments shipped from Plant *p* to distribution center *k* should be greater than or equal to the total volume required by the products shipped, divided by the volume capacity of the transportation consignment.

In addition, a decentralized safety stock policy is employed since the new market trends make customer satisfaction the main objective of each service activity. Hence, those inventory policies that keep inventories closer to the customers are most preferred in order to increase the customer satisfaction and service level.

Decentralized safety stock (at distribution centers):

$$I_{nkt} \geq \lambda D_{nk(t+1)} + \left(z_{\alpha} \sigma_{nk} \sqrt{MLT_{pn} + TLT_{pk}} \right) \quad (\forall p=1 \ldots P,\ n=1 \ldots N,\ k=1 \ldots K,\ t=1 \ldots T) \tag{16}$$

In any time period, the inventory at a distribution center *k* should be at least equal to a pre-specified percentage (λ) of the next period's demand plus the safety stock. Also the balance between the production level and the number of components purchased are controlled by:

$$X_{pnmt} = \sum_{s=1}^{S} (NM_{pnmsit}) / BOM_{pnmi} \qquad (\forall p=1 \ldots P,\ n=1 \ldots N,\ m=1 \ldots M,\ t=1 \ldots T,\ i=1 \ldots I) \tag{17}$$

At any period *t* the production level of product family *n* at plant *p* is equal to the total number of module *i* purchased from all the suppliers divided by number of module *i* required to produce one unit of product n at plant *p*.

It should be noted that the cost of lost sales and backorders are not considered in the above model. Also it is assumed that the manufacturing lead-time for different scenarios does not change. The increase in the required labor hour for different scenarios justifies this assumption.

4. Case study

An example of an automobile wiper system is used for illustrating the application of the proposed decision support model. The planning horizon is 4 periods and the supply chain consists of 7 suppliers, 5 plants and 6 distribution centers that are globally distributed as shown in Table 1.

Plants location	**Distribution centre locations**
North America 1	North America 1
North America 2	North America 2
North America 3	Asia 1
Asia	Europe
Europe	Asia 2
-	Asia 3

Table 1. Locations of Plants and Distribution centers

Automobile Wipers, whether located on the windshield, rear window, or headlights, are used to clear rain, sleet, snow, and dirt. A typical wiper system consists of four main modules; rubber blades, metal arms, electric motor (to move the arms and blades) and the linkages to move the blades as shown in Figure 3.

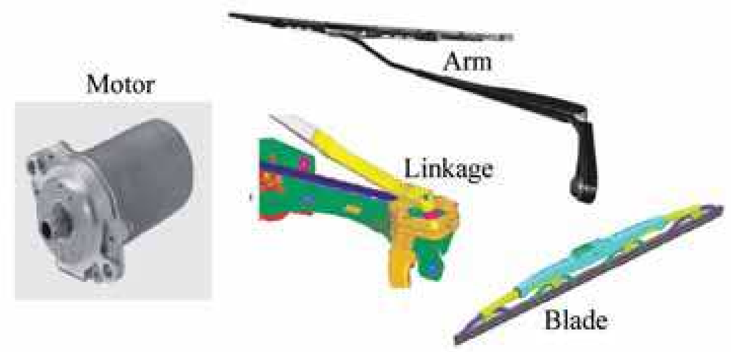


Figure 3. Wiper system Components

4.1 Product modular structure

It is assumed that the motor may be purchased either as an assembled motor module or its components may be purchased separately and the final assembly and

fabrication of the motor is performed at the manufacturing facility. The motor consists of the following major components:
Board, Case and plugs. Table 2 shows the components and their available supplier locations.

Supplier`s location	Supplied components
North America 1	Motor, Board
Asia 1	Motor, Board
Europe 1	Motor, Board
North America 2	Arms, Blades, Case, Plugs
Asia 2	Arms, Blades, Case, Plugs, Linkages
Europe 2	Arms, Blades, Linkages
North America 2	Case, Plugs, Linkages

Table 2. Components and their Suppliers

There are two different scenarios of product modules structure to be considered according to the above motor acquisition alternatives as shown in Figure 4.

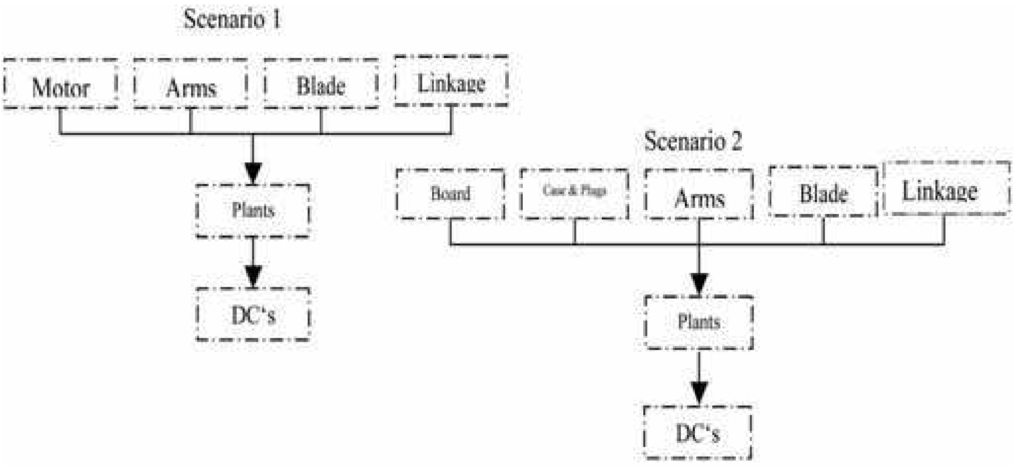


Figure 4. Available product design scenarios

The Lingo (Lindo Systems Inc., 2005) optimization tool is used as the solver for the above ILP decision support model to find the optimal set of supply chain configuration and product module structure scenario for this specific example,. The optimal solution selected the product modular structure scenario #2 and the supply chain network configuration shown in Figure 5 with a total cost of $ 34,607,460.

In this example, purchasing the motor components from the proper supplier and performing the assembly at the manufacturing facility is more cost effective than buying the assembled motor module. Although the market is stronger (higher demand) in North America, because of the lower costs in Europe and Asia, the model tends to choose locations in those areas for suppliers and manufacturing facilities.

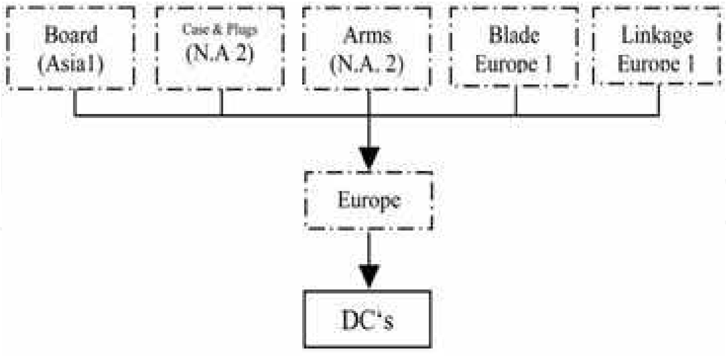


Figure 5. optimal set of product structure scenario and supply chain configuration

4.2 Model applications

4.2.1 Currency considerations

One of the unique applications of this model is analyzing the impact of variations in the currency exchange rate on the configuration of the supply chain. This is useful specially while designing the initial configuration of the supply chain network since this model not only gives the optimum supply chain configuration but it can also be used to analyze the impact of currency variation at each node of the network on the optimum supply chain configurations. For this purpose it is assumed that as a result of economical and industrial evolution the currency value for supplier North America 2 becomes 6% stronger. Figure 6 shows the optimal supply chain configuration under this scenario. As shown in Figure 6 this change in the exchange rate, results in a new optimal solution in which supplier North America 2 is no longer optimal for "Case & Plugs" and "Arms", instead the model suggests that in this case it is optimal to outsource supplying these components from Asia 2.

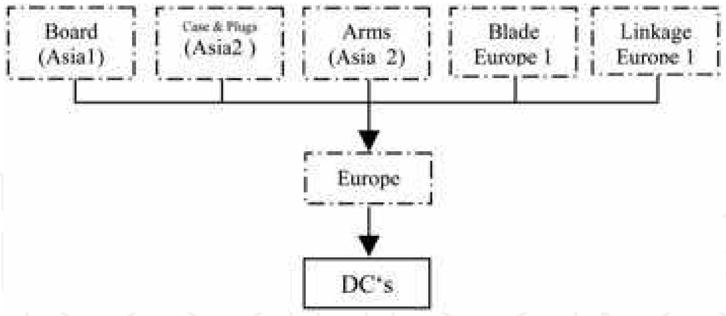


Figure 6. Optimal set of product structure scenario and supply chain configuration under changes in the currency exchange rate

Also the presented model can be applied to determine the optimal initial configuration of global supply chains. In another words, since the currency exchange rates are considered in the decision making process in this model using the present, optimistic and pessimistic currency exchange rate forecasts, one could decide about the best supply chain design in view of the possible trends in the exchange rates and determine the critical locations through the supply chain. Table 3 shows the extent of variations in the currency exchange rate under which the present solution would remain optimum.

Supplier`s location	Variation range
Board	5
Case/Plugs	6
Arms	6
Blades	2.5
Linkage	3
Plant location	3.5

Table 3. Currency Exchange Rate Variation Range for the Present Optimal Solution.

4.2.2 Demand shifts

Another application of the developed model is concerned with one of the recent issues in the global supply chain decision making. The question is how the increase in Asian market demand and the recent shift in market trends- from North America ranking first to Asian markets beingthe highest ranked market- will affect the decision making in global supply chains?

New demand data (with Asia ranking first, North America second and Europe third) was used for the example under consideration to explore its effect. The change in the market demand affected did not affect the optimal product structure design but did change the optimal supply chain network configuration as shown in Figure 7. It should be noted that this result is data dependent and can not be generalized. However, the developed model can be used to evaluate any scenario given its specific set of data and constraints.

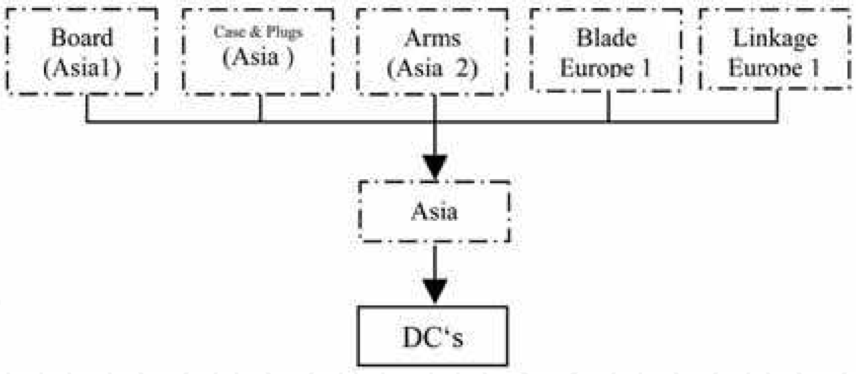


Figure 7. optimal set of product structure scenario and supply chain configuration under changes in the market demand

4.2.3 Postponement strategies in product design and supply chain configurations

Postponement is one of the strategies for managing supply chain integration along with mass customization and modularization. While the goal of mass customization is to produce customized goods at low costs, postponement focuses on delaying such customization and implementing it as close to the customers as possible. The extent of customization and postponement of products is rooted in modularization of product structure designs (Mikkola & Larsen, 2004).In the broadest terms, postponement is a strategy whereby some of the activities in the supply chain are not performed until customer orders are received. According to Lee (1998) postponement is about delaying the timing of crucial processes in which end products assume their specific functionalities, features and identities. It was originally proposed as an approach to reduce the risk and uncertainty costs tied to the differentiation of goods. The logic behind postponement is that, the delay leads to the availability of more information, thus improving the quality of decision making, and also avoids building up inventories of finished goods in anticipation of future orders.

Postponement is categorized as Form and Time postponement. Form postponement is closely related to modularization and calls for a fundamental change of the product architecture by using designs that standardize some of the components (hence changing the form of the product architecture) or process steps. It involves delaying the differentiation of the products until later stages of the supply chain. Time Postponement involves delaying the differentiation of the products until later stages of the supply chain.

The proposed model was used to analyze the impact of employing postponement strategy on the configuration and performance of supply chain. A new product modular design structure scenario, that implements form postponement by delaying the differentiation of the products until later production stages, was introduced. For this analysis an additional term that represents the differentiation cost, due to the work done at distribution centers, was added to the model.

Cost of differentiation at

$$DC\colon \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T} D_{nkt} EX_{kt} DF_{nkt} \qquad (18)$$

DF_{nkt} : Cost of differentiation for one unit of product n at distribution center k at period t

This differentiation cost stands for the final assembly and fabrication of the products that has been postponed from manufacturing plant to distribution centers to increase the responsiveness and customization level of the system. Some data adjustments were required for demand, production cost at and demand forecast errors to show employment of postponement strategy.

Figure 6. Safety stock level with /without postponement strategy

In this example, purchasing the motor components from the proper supplier and performing the assembly at the manufacturing facility is more cost effective than buying the assembled motor module. Although the market is stronger (higher demand) in North America, because of the lower costs in Europe and Asia, the model tends to choose locations in those areas for suppliers and manufacturing facilities.

In this example, the choice of employing postponement strategy did not affect the optimal supply chain configuration but it affected the total cost of the supply chain as explained above.

4.2.4 Other applications of the model

Another application of this decision support model would be analyzing the impact of introducing a new product modular structure on the optimal configuration of the supply chain network. The output data of the model can also be used to determine the effect of variation in the exchange rates, or suppliers' costs on the optimum supply chain configuration and product modular design scenarios. This information would help the managers in making better decisions considering all the possible options.

5. Discussion and conclusions

Present competitive global market with ever increasing demand for high quality customized product, calls for a more agile response from the organization and its partners in the supply chain along with an optimized and globally integrated configuration for the supply network. The idea in the past was that marketing success was based upon strong brands and innovative technologies. Instead today the winning combination is strong brands and innovative technologies supported by an integrated supply chain capable of responding more quickly to volatile market demand and changing conditions. Manufacturing enterprises need to focus their effort on achieving greater agility and responsiveness planning, predicting and reacting quickly to the market changes by selecting the proper supply chain configuration and appropriate product modular design structure while considering the globalization factors such as monetary valuations trends.

The proposed decision support model captures some of the critical aspects of supply chain and product design architecture to concurrently determine the optimal modular product structure and the global supply chain configuration in a 3 echelon (suppliers, manufacturing facilities and distribution centers) global supply chain system considering the procurement costs, production, inventory and transportation costs along with the impact of changes in the global market currency exchange rates. The proposed model is a combination of the product design configuration problem (including the modular options and the product design strategy alternatives) and the supply chain design configuration problem (including different locations for suppliers, manufacturers and distribution centers). The use of the developed decision support model has been illustrated using an example of automobile wipers system.

In this model, estimates of currency exchange rates were used as input parameters. There are methods to calculate and forecast the currency exchange rates (Yang & Burns, 2005). Using these methods to calculate and make short and long term forecastscan provide more dynamic estimates.

Product demand and production and transportation lead-time are also assumed to be fixed numbers in this model but considering the stochastic nature of these factors, including their probability distributions would improve the quality of the decision made using the proposed model. Introducing different product design strategies like platform design or strategies influenced by Intellectual Property considerations, considering other supply chain node locations, or including additional supply chain performance indexes like, suppliers' quality and lead-time, responsiveness, customer service level and environmental factors in the objective function of the decision support model would be worthwhile exploring.

Countries and governments compete in attracting international investments and jobs by offering attractive packages of leverage contribution schemes, international trade agreements and tax incentives. Any decisions regarding locating manufacturing facilities for products and their modules and selecting suppliers must factor in all these considerations, in the context of location- specific monetary values along with the site-specific exchange rates, while trying to minimize total cost of the global supply chain and maximize profit.

6. Acknowledgement

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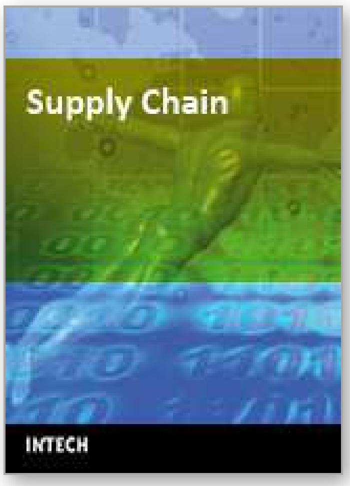

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Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization. An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money. From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle. The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

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