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Supply chain configuration modeling under the influence of product family architecture

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Abstract: Supply chain partners strive hard for operational business excellence, enhanced integrated value chain and sustainable competitive advantage under mass-customization/globalization challenges. In this paper new notions, GBOP (generic bill-of-product: set of product family variants), GBOP/GSCS (generic supply chain structure) interface and GBOP architectural constraints have been introduced to empower supply chain with flexibility to rapidly reconfigure under business environmental dynamism and ability to quickly respond to the varying customer needs with economies of scope. Further a mathematical model is proposed to investigate the influence of GBOP architecture on supply chain configuration, relationship between GBOP and GSCS architectures, optimal redefinition of GBOP/GSCS and decisions related to opening or closing of market segments under cost min. / profit max. objectives.

Keywords: supply chain configuration, supply chain modeling, mass customization, product variety, MIP

1. INTRODUCTION

Increasingly varying customer needs have urged suppliers to offer more product variety for segmented markets in efficient and effective manner. Such efforts can increase sales but adds complexity in terms of resource utilization and responsiveness; potentially increasing total supply chain costs. Mass customization supported with GBOM (generic bill-of-material), has proved reduction in supply chain cost under globalization and competitiveness to some extent but research area where interface between GBOP and GSCS architectures could have strong influence on the supply chain network remains unexplored till date; hence the challenge to fulfill customers varying nature of demand with right product at right place & quantity is still a question difficult to answer. Major supply chain network costs are logistics costs, strongly influenced by increasing oil prices and product variety. There have been much work on platform based modular product and process design strategies to optimize product offerings but product BOM have been rarely incorporated with in supply chain configuration to demonstrate cost reduction, however advantages bundled with early sales benefits and economies of scope could be achieved on the inclusion of GBOP (an extended GBOM of product families) in the supply chain configuration through GBOP architectural constraints and GBOP/GSCS interface integration in a mathematical model. It also provides a mechanism to create a balance between the degree of product variety (optimal diversity) that can be offered through GBOP redefinition and GSCS reconfiguration.

Tseng and Jiao (1996) states that mass customization depends on time-to-market (quick responsiveness), economy of scale (volume production efficiency) and variety (customization) but it is contrary to the product diversity to be offered hence diversity optimization to GBOP shall play very important role to still benefit from the mass customization advantages and fulfill all market segments. Product diversity optimization from functional requirements to GBOP can be best explained in the three steps proposed as shown in Fig. 1 and same has been used as hypothesis for the model in this paper; however principal objective to fulfill customer's demands with delight remains the same:

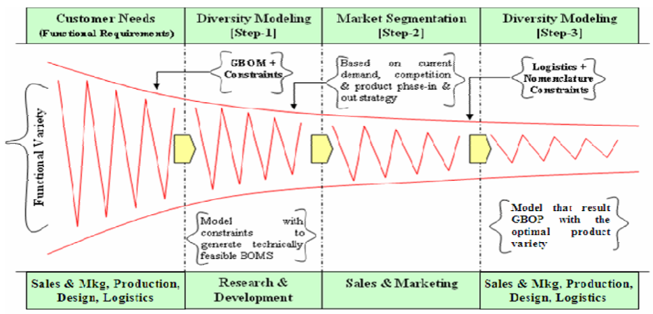

Fig. 1. Diversity optimization process in steps

Step-1: Functional requirements mapped on customer needs are modeled using unified compact representation i.e. GBOM (generic bill of material) to generates all possible, technically feasible product variants under design & process constraints to reduce functional variety to technical product variety.

Step-2: Sales & Marketing based on the GBOM received from step-1 performs market segmentation (regrouping customer demands into similar service level market segments to be served with one product variant) and formulate a product phase-in/out business strategy resulting in product variants agreed to be offered to satisfy customer demands which is less then the technical product variety.

Step-3: Output from step-2 (reduced variety agreed to be offered to customers) are modeled with an extended GBOM architecture i.e. GBOP and fed to the model proposed in this paper to determine an optimal GBOP and associated GSCS configuration under logistics and architecture constraints.

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Objective of the mathematical model proposed in this paper is to find answers to the questions: (*i*) GBOP architecture influence supply chain configuration or vice-versa?; (*ii*) GBOP redefinition influence reconfiguration of optimally configured GSCS or vice-versa?; (*iii*) What is the influence of opening or closing the logical/geographical market segment with the possible replacement of superior product variant?; (*iv*) Which objective criteria (cost min./profit max.) serves best under the influence of GBOP architectural constraints and GBOP/GSCS interface?

2. LITERATURE REVIEW

Let us review some basic issues regarding mass customization (product family, modularity/commonality, product diversity, product family architecture), supply chain configuration models and solution algorithms adopted for the SCCP (supply chain configuration problem).

Meyer and Lehnerd (1997) described product family as a set of similar products derived from a common platform, having specific features to address the specific market segment needs. Every member in a product family is called a product variant and is subjected to address a specific group of end users in market segment, covered by the product family. Ulrich (1995) has defined product diversity as a set of product variants that could be offered to a market segment and product variety as functional and technical varieties. Functional variety is carried out by the sales and marketing department and is a product diversity described based on the grouping of similar functional requirements however the same is further processed with technical variety enforcing design and manufacturing constraints that reduces this product variety to a number of legal product variants.

Tseng and Jiao (1996) discussed the product family architecture as a generic model based on commonality and can generate families of products having a common base, differentiation enabler and configuration mechanism. Common base represents the components/modules that have a commonality in all the product family variants where as a differentiable module creates a difference between product variants and mechanism provides the rules to generate legal variants. Thomas and Griffin (1995) in invited review provided classification of all supply chain network models till date like production/inventory, distribution/inventory etc. which serve as the basis to understand and grab the two stage, single product and single period network models.

Until last decade product design and supply chains were being treated separately but Vidal and Goetschalckx (1998) proposed future research guidelines to incorporate not only the domain for diversity modeling but also the inclusion of BOM in global supply chain configuration models. Special focus of the article is on the MILP (mixed integer linear program) problem formulation under SCCP (supply chain configuration) classified at strategic, tactical and operational levels to provide a clear understanding of future research trends and applicability of the methods/techniques used to solve each type of problem. Blackhurst et al. (2005) formalized PCDM (product chain decision model) using network based approach and established that product and process decisions influence the supply chain structure decisions. Fixson (2005) in this special review has very precisely investigated the product architectural (functions, components and interfaces) assessment to link the product, process and supply chain design decisions.

Special issue on coordinating product process and supply chain design (Rungtusanathama and Forza (2005)) comprises articles related to concurrent product-process-supply chain design but does not incorporate the GBOM architecture to create a sense and respond mechanism in supply chain modeling. Huang et al. (2005) in their article used the example from Graves and Willems (2001) based on GBOM with two product variants and established that supply chain design for two product variants separately is more costly then establishing and managing a common supply chain based on the risk pooling of inventories etc, however GBOM architectural constraints have not been incorporated in the proposed model. Lamothe et al. (2006) has worked on the concurrent design of market segmentation based on modularity to define a product family and optimizing supply chain cost based on the product variants. Authors have also proposed a methodology for market segmentation (based on modularity) for product family and its supply chain design to reduce operating costs and global supply chain design model.

Based on the above literature review it is quite evident that the problem domain under discussion pertains to the research area that has not yet been fully explored. Only Lamothe et al. (2006) and Huang et al. (2005) have worked in the domain of strategic global supply chain design with the incorporation of GBOM constraints, however MILP model proposed in this paper incorporates the GBOP/GSCS interface, GBOP architectural constraints and investigates the influence/links of/between GBOP architecture on/and supply chain configuration decisions for the flexibility to rapidly reconfigure under business environmental dynamism i.e. optimal GBOP redefinition and GSCS configurations.

3. PROBLEM DESCRIPTION

Model proposed undertake a multi stage and multi period global supply chain with multiple product demand portfolios (i), production facilities (t), distribution centers (u) and geographically located market segments (v). Market segments are further divided into logical market segments (v') based on the service level ranging from basic to highest level corresponding to one product variant (possible multiple architectures). However each higher service level product variant can fulfill the customer requirements of lower service level with customer delight as represented with OR nodes in the generic model representation Fig. 2.

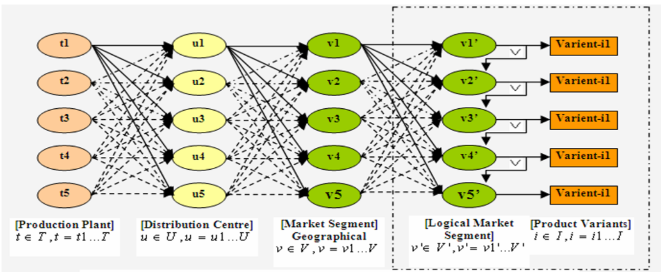

Fig. 2. Generic supply chain configuration model