2001

Achieving Mass Customization Through Modularity-Based Manufacturing Practices: A Customer-Driven Perspective

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ACHIEVING MASS CUSTOMIZATION THROUGH MODULARITY-BASED MANUFACTURING PRACTICES – A CUSTOMER-DRIVEN PERSPECTIVE

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ABSTRACT

As uncertainty in markets and technology intensifies, organizations are adopting modularity-based manufacturing practices to achieve mass customization and cope with demands for increasingly customized products. Modularity-based manufacturing is the application of unit standardization and substitution principle to product and process design to create modular components and processes that can be configured into a wide range of end products to meet specific customer needs. This study defines customer closeness and modularity-based manufacturing, develops instruments to measure these factors, builds a framework that relates customer closeness, modularity-based manufacturing practices, and mass customization, and tests structural relationships in this framework using LISREL.

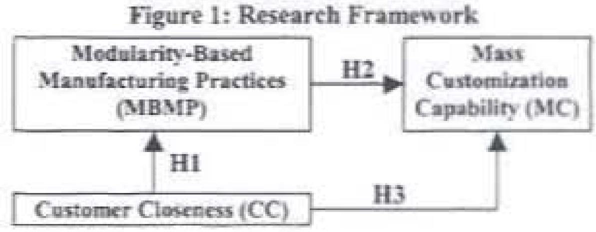
INTRODUCTION

Although the basic principles of modularization have been discussed for decades (Ulrich and Tung, 1991), they are becoming more popular as manufacturers seek increased flexibility. Baldwin and Clark (1997) suggest that modularity is an effective manufacturing strategy that enables firms to cope with rapidly changing customer requirements and increasing technology complexity. Pine (1993) states that "the best method for achieving mass customization – minimizing costs while maximizing individual customization – is by creating modular components that can be configured into a wide variety of end products and services."

Modularity-based manufacturing is the application of unit standardization and substitution principles to product design, production process design, and organizational team design. Given the practical importance of modularity-based manufacturing practices and their impact on firms' mass customization capability, significant amount of empirical research in this area is needed. However, a careful literature review indicates that most research on modularity-based manufacturing practices is descriptive. The few empirical studies focus primarily on product modularity and overlook the implications of modularity on production process design and organizational design. This research defines modularity-based manufacturing practices and proposes a model for investigating the relationships among customer closeness, modularity-based manufacturing practices, and mass customization capability. These hypothesized relationships are examined using structural equation modeling based on large-scale empirical data. To facilitate testing, valid and reliable measurement instruments are developed.

THEORETICAL FRAMEWORK AND RESEARCH HYPOTHESES

Figure 1: Research Framework



The theoretical research framework in Figure 1 suggests that the use of modularity-based manufacturing practices (MBMP) is affected by the firm's degree of customer closeness. Thorough understanding of customer's exact needs should heighten the firm's awareness of the importance of modularity. It should enable manufacturers to utilize modularization principles to create manufacturing systems that respond effectively to individual customer requirements (Kotha, 1996). MBMP, in turn, has a direct impact on mass customization (MC). Empirical evidence suggests that modular designs contribute significantly to cost reduction, production flexibility and product development innovation (Schroer and Ziemek, 1992; Czabala, 1997; Kusunoki, Nonaka and Nagata, 1998). Customer closeness (CC) also has a direct impact on a firm's mass customization capability. In a highly uncertain environment, customers are the final judges of a firm's competitive capability (Doll and Vonderembse, 1991). Thus having a true customer orientation is crucial to manufacturing success (Bowen, Siehl and Schneider, 1989; Murakoshi, 1994).

Customer closeness is defined as the practice of keeping direct and frequent contact with customers, to understand customers' individual needs, and to communicate with customers effectively. In the new post industrial era, firms can no longer profit or even survive without having customers in mind (Doll and Vonderembse, 1991).

The concept of modularity is commanding increasing attention by researchers because of its definitive advantage in coping with the increasingly turbulent manufacturing environment. Baldwin and Clark (1997), proponents of modularity, cite the computer industry as the pioneer in promoting modularity. Through the widespread adoption of modular designs, the computer industry has dramatically increased its rate of innovation. They regard modularity as a strategy for organizing complex products and processes efficiently, and they argue that it is modularity, more than any other technology, that makes the rapid developments in computer industry possible. By reviewing, organizing, and summarizing the literature, three categories of common modularity-based manufacturing practices are identified and discussed here.

Product Modularity is the practice of standardizing product modules so that they can be easily re-assemble/re-arranged into different forms, or shared across different product lines. The architecture is created for product modularization when the interfaces between functional components are standardized and specified to allow the substitution of a range of components without requiring changes in the designs of those components (Garud and Kumaraswamy, 1995; Sanchez and Mahoney, 1996).

Process Modularity is a relatively new concept. It is the practice of standardizing production process modules so that they can be easily re-sequenced or new modules can be added in response to changing product requirements. Feitzinger and Lee (1997) suggest that process modularity is based on three basic principles: 1) Process standardization: break down the process into standard sub-processes that produce standard base units and customization sub-processes that further customize the base units; 2) Process re-sequencing: re-sequence the sub-processes so that standard sub-processes occur first while customization sub-processes occur last; 3) Process postponement: postpone the customization sub-processes until a customer order is received or put them into distribution centers to achieve maximum flexibility.

Dynamic Teaming is the practice of easily re-organizing production teams and linking them to necessary resources in response to product and/or process changes. This is the application of modularity principles to organizational design and team-building processes. In order for modular to be successful, a well-coordinated team effort from management and various support functions is required (Duncan, 1999).

Mass customization (MC) is the ability of a firm to quickly produce customized products on a large scale at a cost comparable to non-customized products (Boynton et al., 1993; Kotler, 1989; Pine, 1993). An organization's MC capability is determined by its ability to produce differentiated products with cost effectiveness, volume effectiveness, and responsiveness (Tu, et al., 2001). These components are essential for organizations that pursue MC.

Research Hypotheses

The proper design of product and process modules should be based on a thorough analysis of how each customer may use the product and how those uses may change over time. Murakoshi (1994) described several customer-driven manufacturing systems that connect customer requirements with the firm's product and process design capabilities on a real-time basis. The system can help customers clarify their needs if they do not know exactly what they want. Staying closer to customers is the fundamental guarantee for the modularity strategy to be successful. Therefore, it is hypothesized that:

Hypothesis 1: Firms that are closer to customers will have higher levels of modularity-based manufacturing practices.

Manufacturers adopt modularity to achieve a performance level that is not possible using traditional approaches. The standardized modules can be easily and quickly reconfigured and reused to cut down product development and production costs, reduce time to delivery, minimize potential quality problems, and most importantly, increase flexibility of responding to changing customer requirements. It is therefore hypothesized that:

Hypothesis 2: Firms with higher levels of modularity-based manufacturing practices will have higher levels of mass customization capabilities.

Murakoshi (1994) suggested that a primary benefit of customer-driven manufacturing systems is that inventory losses and product model change losses due to dead stock can be minimized. He further indicated that the sophisticated one-for-one handling customer-driven system may push up manufacturing costs, but the cost increase are far below the value added for the customer, which will produce a strategic competence for the firm in the long run. Therefore, it is hypothesized that:

Hypothesis 3: Firms that are closer to customers will have higher levels of mass customization capabilities.

RESEARCH METHODOLOGY

Item Generation and Pilot Study

Generating items that cover the domain of a construct determines the validity and reliability of an instrument (Churchill, 1979). A comprehensive literature review was completed to define the constructs and identify an initial list of items. Structured interviews with manufacturing executives and academic researchers provided additional insights. The interview results were carefully analyzed and a common pattern of thinking was recognized, which formed the basis for further revision of the research constructs and measurement items. A pilot study was then completed that targeted senior manufacturing managers. The study provided valuable preliminary information about the reliability and validity of the measurement scales. Corrected Item-Total Correlation (CITC) was used to purify the scales (Kerlinger, 1978). Exploratory factor analysis was used to assess the unidimensionality of the scales. This study used the most popular method of evaluating scale reliability, Cronbach alpha (1951). Alpha values over 0.7 were considered acceptable (Nunally, 1978). Based on the pilot study results, the questionnaire was further revised and ready for large-scale data collection phase.

Large-Scale Data Collection

The final version of the questionnaire was administered through large-scale mailing to 2831 manufacturing managers who were randomly selected from SME's U.S. membership database. There were a total of 320 responses from the mailings, of which 303 were complete and usable. All major types and sizes of manufacturing industries were well represented in the sample. The respondents and non-respondents were compared on the basis of firm size, industry type, and sales volume. No significant differences were found. It was thus concluded that non-respondent bias was not a cause for concern.

LISREL Measurement Modeling Results

In instrument development, the tests of unidimensionality, discriminant validity, and reliability are important for establishing construct validity.

The Customer Closeness (CC) construct was conceptualized as having one dimension and 5 items. Exploratory factor analysis was performed and one single factor emerged with all factor loadings above 0.80, indicating very good unidimensionality and convergent validity of the measurement instrument. An alpha score of 0.91 for the five items of CC construct represents excellent scale reliability. The Modularity-Based Manufacturing Practices (MBMP) construct was initially represented by three dimensions comprising 20 items: Product Modularity (PM) (7 items), Process Modularity (PRM) (6 items), Dynamic Teaming (DT) (7 items). Examination of CITC scores resulted in the elimination of 5 items. The final Cronbach's alphas were 0.83 for PM, 0.82 for PRM, 0.88 for DT. All the resulting 15 MBMP item were then submitted together to a construct-level factor analysis. Three clear factors emerged from the factor analysis and all factor loadings were above 0.60. The items used to measure MC were developed by Tu et al., (2001). Please refer to that paper for instrument details.

LISREL Structural Equation Modeling Results and Hypotheses Testing

To test the relationships among MBMP, MC and CC as illustrated in Figure 1, LISREL structural equation modeling method was used. The results of the structural equation model support Hypothesis 1 with a LISREL path coefficient of 0.58, which is statistically significant at $p<0.01$ ($t = 5.23$). Hypothesis 2 is supported with a path coefficient of 0.31, which is statistically significant at $p<0.01$ ($t = 2.80$). The results also supported Hypothesis 3 with a path coefficient of 0.22, which is statistically significant at $p<0.01$ ($t = 2.31$).

RESEARCH FINDINGS AND IMPLICATIONS

As customers become more demanding, it is essential that management understand how to effectively use modularity principles to design and operate manufacturing systems that can quickly meet specific customer needs. The results show that MBMP has significant positive impact on MC. Thus MBMP can actually help firms to better meet fast changing customer needs at a reasonable cost when traditional tightly coupled system design is incapable of handling uncertainty. Moreover, the study results also confirmed that modularity practices are not limited to product modularity. The new practices of production process modularity and team modularity are both very effective ways of improving performance. The results also show that CC has significant positive impact on MBMP. Good modular products and processes that truly accommodates customers' changing requirements are much more difficult to design and implement. Therefore, firms hoping to reap benefits from modularity strategy must make every effort to get closer with customers. The direct positive impact of CC on MC is also verified by this study. It convincingly shows to manufacturing practitioners that firms focusing more on their customers performs consistently better than others. Thus, getting to know customers better than others should be an important step for firms striving to succeed in the highly competitive global marketplace.

CONCLUSIONS

The above empirical results along with the validated measurement instruments for MBMP and CC should provide both researchers and practitioners with valuable insights to the effective use of MBMP. They can also become a set of useful tools for relevant academic research projects and practical assessment of modularity-based manufacturing management practices. Future research can examine the proposed relationships in a more contingent manner by incorporating some contextual variables.

Full references available upon request.