2010 International Conference on E-business, Management and Economics
IPEDR vol.3 (2011) © (2011) IACSIT Press, Hong Kong

Linkages between product modularity and integration strategies: a conceptual framework to determine competitive capabilities

M. Sadiq Sohail, Ph. D
Department of Management & Marketing
King Fahd University of Petroleum & Minerals
Dhahran 31261
E-mail: ssohail@kfupm.edu.sa

Obaid Al-Shuridah, Ph. D
Department of Management & Marketing
King Fahd University of Petroleum & Minerals
Dhahran 31261
E-mail: shuridah@kfupm.edu.sa

***Abstract*— Existing streams of literature are integrated to propose a conceptual framework that highlights the effect of product modularity on competitive performance with three integration strategies as potential mediators. The framework aims to provide insights into the influence of product modularity on multiple dimensions of competitive performance.**

Keywords- product modularity, competitive performance, integrations strategy, manufacturing

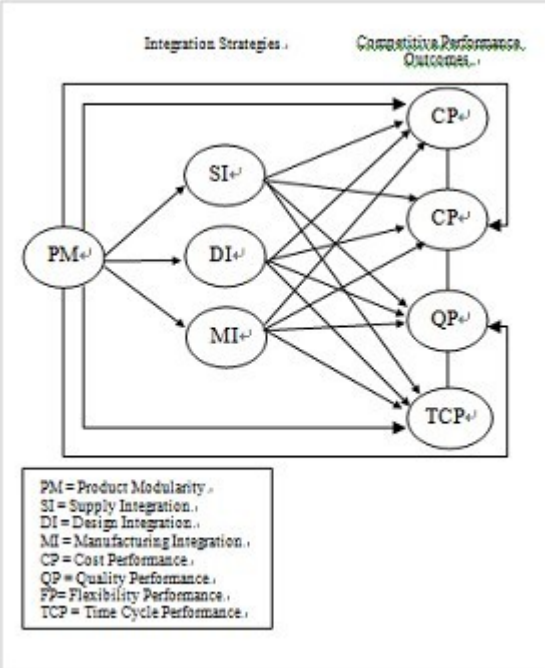
I. INTRODUCTION

Rapid changes in manufacturing technology coupled with an increasing demand of customized products has seen many firms to look at implementing product modularity(PM) strategy as a means of gaining competitive advantage. Since the pioneering work on modular design theory by Ulrich and Tung (1991), a stream of research has emerged on this topic. Much of the literature on PM deals with features of product components and the extent to which modules are independent or separate; the extent to which components are specific; the extent to which modules are transferable or reusable within the production process; and cost saving benefits of PM (Baldwin and Clark, 2000; Schilling, 2000).

Extant literature has considered PM to be an effective approach for mass customization and cycle time reduction (Duray et al., 2000), enabling manufacturers to improve strategic flexibility (Worren et al., 2002; Sanchez, 1995). Numerous studies have reported on the benefits of PM at a firm level (Sanchez and Mahoney, 1996). However, the impact of PM beyond the firm in strategic terms such as external integration and their impact on competitive capabilities have only begun to be explored (Antonio 2009; Howard and Squire, 2007; Gadde and Jellbo, 2002; Worren et al., 2002; Rosenzweig et al., 2003).

Choosing sample from the automotive sector, a more recent examines the relationship between product modularity and competitive performances with supplier integration, design integration, and manufacturing integration as mediators (Jacobs et al, 2007). Given that there are fundamental differences in the industry dynamics, market structures, and customer needs between developed and developing countries of the world, the larger aim of this study is to develop a conceptual framework and after testing the framework further empirically examine the effects of product modularity on competitive performances of the manufacturing sector in a developing and emerging market. In this paper, a conceptual framework is proposed to linkages between PM and the domains of competitive capabilities, that is cost, quality, flexibility and cycle time. The framework also attempts consider the test the mediation effect of integration strategies (supply, design, and manufacturing integrations) between PM construct and each of the competitive performance outcomes (Figure 1).

II. PROPOSED CONCEPTUAL FRAMEWORK



A. Proposition 1-Potential Linkage Between Product Modularity And Cost

There is broad consensus that PM reduces product cost (Jacobs et al 2007). Costs reductions in modular product design arises due to increasing economies of scale (Ulrich and

Tung, 1991; Pine et al., 1993), inventory cost reduction (Meyer and Mugge, 2001;Weng, 1999), lower repair and development costs (Krikke et al., 2004; Fisher et al., 1999) and reduced set-up times (Tu et al., 2004; Mirchandani and Mishra, 2002). Further, costs are also lowered due to faster assembly of existing modules enabling quick delivery with short lead time (Hargadon and Eisenhardt, 2000; Ernst and Kamrad, 2000).

Another study reports cost benefit arising from engineering and operational efficiencies attributable to modularization (Collier, 1981).Finally, firms can also benefit through a reduction in investment costs (Fisher et al., 1999). Given that PM enables standardized production process, costs associated with tooling, engineering, testing, and support services are all reduced by using standardized components and sub-assemblies (Fisher et al., 1999).

In contrast to the general consensus, one study reports a contrast finding indicating that product modularity does not necessarily lead to cost reductions (Kutner, M., Nachtsheim, C., Neter, J. and Li, W, 2005). This study conclude that PM process actually leads to increase in spare parts costs due to a higher failure rates of modules vis-a` -vis components. However, a limitation of this study is that there is no comparison between the cost of spare parts required by modular products and that for integrated products.

We therefore offer the following research proposition:

Proposition 1: Product modularity will have a positive effect on cost performance.

B. *Proposition 2- Product Modularity and Flexibility*

Flexibility during production process can lead to competitive advantage (Yusuf et al. (2004; Worren et al., 2002). Because of advantages of flexibility, firms try to set up manufacturing systems that are flexible. But a system ability to be flexible and handle variety is ultimately determined by the product architecture (Ulrich, 1995).

Product modularity has an impact on flexibility in a variety of ways. Firstly, production mix flexibility is increased with the use of product modularity (Lorenzi and Lello, 2001). This means that set-up times that the number of set-ups required for modular products are reduced and this also leads to a corresponding decrease in switching time (Worren et al., 2002). Secondly, PM also increases the flexibility of work-in-process inventory (Lee and Tang, 2007). A major advantage of this is the ability to store modules in a variety of geographic regions and then assemble them as and when orders are placed. This arrangement offers a wide variety of end products with very responsive delivery times (Worren et al. 2002)

Further, modular product architecture provides room for design flexibility. In this manner, firms can attempt product improvements, modification, or even innovation by using a relatively small number of independent modules in different permutations. Thus, firms with modular architecture can either launch new products or widen the product ranges by exchanging a few product modules. (Ro, Y.K., Liker, J.K. and Fixson, S.K. (2007),). Modular products have higher independence among its individual modules, which isolates frequently changing modules from the core design. This scales down the frequency of communication across different module designs and the rate of change of the core design. A modular product design tolerates a higher risk of design changes, allows for late product changes that lead to better design solutions, and avoids the need for entire product changes. This improves the design and manufacturing flexibility for market change (Ro, Y.K., Liker, J.K. and Fixson, S.K. (2007),

Recent studies have found that PM is directly correlated with some manufacturing capabilities such as flexibility and customer service (Vickery et al 2003), Modular product design standardizes the interfaces between components that allow a variety of components to be substituted into a product system. Thus, firms can flexibly assemble components to develop new products with greater variety (Ro, Y.K., Liker, J.K. and Fixson, S.K. (2007). Hence, we propose

Proposition 2: Product modularity will have a positive effect on flexibility performance.

C. *Proposition 3-Product Modularity and Quality*

A great deal of research has focussed on application of quality concepts to production processes, but the application of quality measures to improve manufacturing methods is limited to the imposition of design specifications by manufacturers (Jacobs et al, 2005). Researchers have estimated that design accounts for 50 percent of the quality of a product (example, Child et al, 1991). Studies' focusing on specific usage of modular design and its associated standardization has concluded that these practices have led to increases in product quality (Suzik, 1999). Further exploring these relationships, Fisher (2009) concluded that the increase in quality brought about by standardization was attributable to learning curve effects and design improvements. The learning curve effect that resulted from increased production volumes of similar components or subassemblies.

PM improves product quality as it requires companies to specify the module interfaces early (Hargadon and Eisenhardt, 2000), which in turn helps to detect quality problems early and improve the reliability of each module (Mikkola and Gassmann, 2003; Primo and Amundson, 2002; Ulrich and Tung, 1991). Feitzinger and Lee (1997) concluded that quality is improved in PM because problems if any can be isolated to specific modules facilitating targeted corrective action.

Another dimension on effect of quality to PM focuses from a customer's perspective. The total effect of quality is enhanced as customers' perception of quality is enhanced by having a clear corporate image of a firm offering standardized product (Onkvisit and Shaw, 1989). Hence, we propose

Proposition 3: Product modularity will have a positive effect on quality improvements.

D. *Proposition 4-Product Modularity and Cycle Time*

PM leads to reducing cycle time (Sherman et al, 2000; Lorenzi and Lello, 2001). As PM enables manufacture of modules in parallel and assembles them based on order requirements, cycle time is reduced (Novak and Eppinger, 2001; van Hoek and Weken, 1998). Improved component

availability also reduces cycle time (Jacobs et al , 2005). Lee and Tang (2007) report that system service levels improve with modular architectures and contribute to cycle time reduction. Modular product design is considered to be an effective approach for mass customization and cycle time reduction (Ro et al 2007).

We therefore offer the following research proposition:
Proposition 4: Product modularity will have a positive effect on reducing order cycle time.

E. Proposition 5- Role of supplier integration as a potential mediator between PM and competitive performance

The concept of integrating suppliers has received attention since the initial surge in exploring Japanese manufacturing practices (Parker et al, 2008). Early studies focused on finding the competitive advantage that Japanese manufacturers enjoyed over their U.S. and European counterparts (Clark 1989; Clark and Fujimoto 1991; Womack, Jones and Roos 1991).

Jacobs et al (2005) identify three facets of supplier integration from the perspective of the buying organization, supplier development; just in time purchasing; and supplier partnering. Antonio et al (2010) specifically identify three organizational processes that integrate supply chain with PM, namely, information sharing, product co-development and organizational co-ordination). Past studies indicate that PM has a positive influence on supplier integration a sit builds a cooperative relationship by increasing the level of trust through the improved forecasts brought about by product modularity (Petersen et al, 2005).. Supplier integration is also enhanced by reducing communication barrier through the creation of a common language (Lorenzi and Lello, 2007; Galvin and Morkel, 2007).

Studies have also indicated that supplier integration has a positive effect on firm performance (Antonio et al 2007; Carr and Pearson, 1999); cost, quality, and cycle time, (Landeros and Monczka, 1989); increase in innovation and a decrease in cost and cycle time (Lewis, 1995).

We therefore offer the following research proposition:

Proposition 5: Product modularity will have a positive effect on

(a) Supplier integration; and
(b) cost, quality, flexibility, and cycle time through supplier integration.

F. Proposition 6- Role of design integration as a potential mediators between PM and competitive performance

Modularity defines components that are designed independently but still function as an integrated whole (Baldwin and Clark, 1997). Designing for PM attempts to achieve high levels of simplification and standardization in product modularity. Methods used to solve the same modularization problems have different results, clearly indicating the impact of the extent of design integration (Holtta and Salonen, 2003).

Research on PM an d design integration address a variety of concerns that include assembly line design (He and Kusiak, 1998); decomposition of manufacturing systems (Kusiak, 1990; Kim *et al.*, 1993); modular work cell design (Chen *et al.*, 1999) product platform and family design (Erens and Verhlust, 1997; Gonzalez-Zugasti *et al.*, 2000; Muffatto and Roveda, 2000; Sanderson and Uzumeri, 1995) and assembly line design (He and Kusiak, 1998);

Apart from the affect of product modularity on key elements of design integration, an affect of design integration has been found to affect competitive performance (Jacobs et al, 2005). Design integration resulted was also reported to reduced product cost (Sharma, 2004) . Another study based on a case analysis found that design integration constructs enables faster production thereby giving more time to market products (Mabert et al, 1992). Reduction in production cost, improved reliability of product leading to better financial performance of firm was reported as benefits through design integration (Parker, 1997).

Thus, there is support in the literature that modularity and design integration are related and affect competitive performance. We therefore offer the following research proposition:

Proposition 5: Product modularity will have a positive effect on

(a) Design integration; and
(b) Cost, quality, flexibility, and cycle time through design integration.

G. Proposition 6- Role of manufacturing integration as a potential mediators between PM and competitive performance

Given the global competitiveness, successful product development can only be achieved if the firm effectively integrates internal functions including manufacturing (Kahn, 2001; Sherman et al., 2000),

A number of studies have shown that manufacturing integration has a positive impact on performance. Sohal et al. (2001) report that manufacturing integration techniques resulted in overall improvements for the study firm, aside from other contributory factors. In a different setting and employing a different methodology, a case study of a manufacturing firm concluded that, integration techniques were found to reduce costs (Collett and Spicer, 1995). Another work, based on a simulation study comparing cellular manufacturing and job shop layouts concluded that the cellular approach decreased WIP and cycle time (Shafer and Charnes, 1993).

Thus, we propose:

Proposition 7: Product modularity will have a positive effect on

(a) Manufacturing integration; and
(b) Cost, quality, flexibility, and cycle time through manufacturing integration.

III. RESEARCH IMPLICATIONS

The proposed framework establishes a starting point for empirical investigation of the mediation effect of integration

strategies and competitive performance outcomes on PM. This paper develops a framework and is part of a larger study which seeks to empirically examine the proposed relationships. Empirical verification could focus on one or more links at a time. Furthermore, extensive longitudinal study could test the framework over periods of time. Measurement scales are available in the literature for all the constructs in this framework, which could be adapted to suit settings in developing nations. Sample for an empirical study could be drawn from similar organizations within an industry or across manufacturing industry. The model could be tested as a whole or in parts by employing appropriate statistical procedures to verify the validity of the proposed framework.

IV. ACKNOWLEDGMENTS

This study was funded by the King Fahd University of Petroleum and Minerals, Saudi Arabia under the KFUPM Internal Grants program (Project # IN090009). Authors thank KFUPM for the financial as well as other facilities support for this research.

REFERENCES

[1] Baldwin, C.Y. and Clark, K.B., "Managing in an age of modularity", Harvard Business Review, Vol. 75 No. 5, 1997. pp. 84-94.

[2] Carr, A.S. and Pearson, J.N., "Strategically managed buyer-supplier relationships and performance outcomes", Journal of Operations Management, Vol. 17 No. 5, 1999. pp. 497-519.

[3] Carr, A.S. and Pearson, J.N., "Strategically managed buyer-supplier relationships and performance outcomes", Journal of Operations Management, Vol. 17 No. 5, 1999. pp. 497-519.

[4] Clark, K. and Fujimoto, T., Product Development Performance – Strategy, Organization, and Management in the World Auto Industry, Harvard Business School Press, Boston, MA. 1991.

[5] Clark, K., Chew, W.B. and Fujimoto, T., "Product development in the world auto industry", Brookings Papers on Economic Activity, Vol. 3, 1987. pp. 729-81.

[6] Collett, S. and Spicer, R.J., "Improving productivity through cellular manufacturing", Production & Inventory Management Journal, Vol. 36 No. 1, 1995. pp. 71-6.

[7] Collett, S. and Spicer, R.J., "Improving productivity through cellular manufacturing", Production & Inventory Management Journal, Vol. 36 No. 1, 1995. pp. 71-6.

[8] Duray, R., "Mass customization origins: mass or custom manufacturing?", International Journal of Operations & Production Management, Vol. 22 No. 3, 2002. pp. 314-28.

[9] Ernst, D., "Limits to modularity: reflections on recent Industry and Innovation, Vol. 12 No. 3, 2005. pp. 303-35.

[10] Ernst, R. and Kamrad, B. (2000), "Evaluation of supply chain structures through modularization and postponement", European Journal of Operational Research, Vol. 124, pp. 495-510.

[11] Feitzinger, E. and Lee, H.L., "Mass customization at Hewlett-Packard: the power of postponement", Harvard Business Review, January-February, 1997. pp. 116-21.

[12] Fisher, M.L., "What is the right supply chain for your product? A simple framework can help you figure out the answer", Harvard Business Review, March-April 1997. pp. 105-17.

[13] Gadde, L-E. and Jellbo, O., "System sourcing – opportunities and problems", European Journal of Purchasing & Supply Management, Vol. 8, 2002. pp. 43-51.

[14] Galvin, P. and Morkel, A., "The effect of product modularity on industry structure: the case of the world bicycle industry", Industry and Innovation, Vol. 8 No. 1, 2001. pp. 31-47.

[15] Hargadon, A.B. and Eisenhardt, K.M. (2000), "Speed and quality in new product development", in Cole, R.E. and Scot, W.R. (Eds), The Quality Movement Organization Theory, Sage, London, pp. 331-46.

[16] Kahn, K.B., "Market orientation, interdepartmental integration, product development performance", Journal of Product Innovation Management, Vol. 18, 2001. pp. 314-23.

[17] Kotler, P., A Framework for Marketing Management, 2nd ed., Prentice-Hall, Englewood Cliffs, NJ. 2003.

[18] Krikke, H., Blanc, I.I. and van de Velde, S., "Product modularity and the design of closed-loop supply chains", California Management Review, Vol. 46 No. 2, 2004. pp. 23-39.

[19] Landeros, R. and Monczka, R.M., "Cooperative buyer/seller relationships and a firm's competitive posture", Journal of Purchasing and Materials Management, Vol. 25 No. 3, 1989. pp. 9-18.

[20] Lee, H.L. and Tang, C.S., "Modelling the costs and benefits of delayed product differentiation", Management Science, Vol. 43 No. 1, 1997. pp. 40-53.

[21] Lewis, J.D., "Business world: Western companies improve upon the Japanese 'keiretsu'", Wall Street Journal, December 12, 1995. p. A21.

[22] Lorenzi, S. and Lello, A.D., "Product modularity theory and practice: the benefits and difficulties in implementation within a company", International Journal of Automotive Technology and Management, Vol. 1 No. 4, 2001. pp. 425-48.

[23] Lorenzi, S. and Lello, A.D., "Product modularity theory and practice: the benefits and difficulties in implementation within a company", International Journal of Automotive Technology and Management, Vol. 1 No. 4, 2001. pp. 425-48.

[24] Meyer, M.H. and Mugge, P.C., "Make platform innovation drive enterprise growth", Research-Technology Management, Vol. 44 No. 1, 2001. pp. 25-39.

[25] Mikkola, J.H. and Gassmann, O., "Managing modularity of product architecture: toward an integrated theory", IEEE Transactions on Engineering Management, Vol. 50 No. 2, 2003. pp. 204-18.

[26] Mirchandani, P. and Mishra, A.K., "Component commonality: models with product-specific service constraints", Production and Operations Management, Vol. 11 No. 2, 2002. pp. 199-215

[27] Muffatto, M., "Platform strategies in international new product development", International Journal of Operations & Production Management, Vol. 19 Nos 5/6, 1999. pp. 449-59.

[28] Novak, S. and Eppinger, S.D., "Sourcing by design: product complexity and the supply chain", Management Science, Vol. 47 No. 1, 2001. pp. 189-204.

[29] Onkvisit, S. and Shaw, J.J., "Service marketing: image, branding, and competition", Business Horizons, Vol. 32 No. 1, 1989. pp. 13-18.

[30] Onkvisit, S. and Shaw, J.J., "Service marketing: image, branding, and competition", Business Horizons, Vol. 32 No. 1, 1989. pp. 13-18.

[31] Parker, M., "Mission possible: improving design and reducing costs at Boeing Helicopter", IIE Solutions, Vol. 29 No. 12, 1997. pp. 20-4.

[32] Ro, Y.K., Liker, J.K. and Fixson, S.K., "Modularity as a strategy for supply chain coordination: the case of US auto", IEEE Transactions on Engineering Management, Vol. 54 No. 1, 2007. pp. 172-89.

[33] Rosenzweig, E., Roth, A. and Dean, J., "The influence of an integrative strategy on competitive capabilities and business performance: an exploratory study of consumer products manufacturers", Journal of Operations Management, Vol. 21, 2003. pp. 437-56.

[34] Sanderson, S. and Uzumeri, V. (1990), "Strategies for new product development and renewal: design-based incrementalisation", working paper, Rensselaer Polytechnic Institute, Centre for Science and Technology Policy, Troy, NY.

[35] Shafer, S.M. and Charnes, J.M., "Cellular versus functional layouts under a variety of shop operating conditions", Decision Sciences, Vol. 24 No. 3, pp. 665-81. 1993.

[36] Shafer, S.M. and Charnes, J.M. (1993), "Cellular versus functional layouts under a variety of shop operating conditions", Decision Sciences, Vol. 24 No. 3, pp. 665-81.

[37] Sharma, K.J., "Concurrent engineering in practice: a brief review", International Journal of Manufacturing Technology and Management, Vol. 6 Nos 3/4, 2004. pp. 334-44.

[38] Sohal, A.S., Fitzpatrick, P. and Power, D., "A longitudinal study of a flexible manufacturing cell operation", Integrated Manufacturing Systems, Vol. 12 No. 4, 2001. pp. 236-45.
[39] Suzik, H.A., "GM announces modularity project", Quality, Vol. 38 No. 5, 1999. p. 14.
[40] Tu, Q., Vonderembse, M.A., Ragu-Nathan, T.S. and Ragu-Nathan, B., "Measuring modularity-based manufacturing practices and their impact on mass customization capability: a customer-driven perspective", Decision Sciences, Vol. 35 No. 2, 2004. pp. 147-68.
[41] Ulrich, K. (1995), "The role of product architecture in the manufacturing firm", Research Policy, Vol. 24 No. 3, pp. 419-40.
[42] Ulrich, K. and Tung, K., "Fundamentals of product modularity", Proceedings of the 1991 ASME Design Engineering Technical Conferences – Conference on Design/Manufacture Integration, Miami, FL, 1991. pp. DE 73-9.
[43] Ulrich,K.T. and Eppinger, S., Product Design and Development,McGraw-Hill,New York, NY. 1995.
[44] van Hoek, R.I. and Weken, H.A.M., "The impact of modular production on the dynamics of supply chains", International Journal of Logistics Management, Vol. 9 No. 2, 1998. pp. 35-50.
[45] Worren, N., Moore, K. and Cardona, P., "Modularity, strategic flexibility, and firm performance: a study of the home appliance industry", Strategic Management Journal, Vol. 23 No. 12, 2002. pp. 1123-40.