THE IMPACT OF PRODUCT MODULARISATION ON SUPPLY CHAIN RELATIONSHIPS: A FURNITURE INDUSTRY PERSPECTIVE.

P. Dube1, G. Muyengwa2 and K. Battle3

1Department of Industrial Engineering
University of Johannesburg, South Africa
partsond@uj.ac.za

2Department of Industrial Engineering
University of Johannesburg, South Africa
gmuyengwa@uj.ac.za

3Department of Industrial Engineering
University of Johannesburg, South Africa
kbattle@uj.ac.za

ABSTRACT

This paper aims to present research which explores the application of product modularization within a furniture industry supply chain to demonstrate the degree to which supply chain practices are aligned with product architecture in the furniture industry. The paper uses a case study approach to examine the main elements of modular supply network in the furniture industry. The study focused on the key stages of a modular supply chain in order to identify the application of supply chain practices within the context of modular operations. The findings suggest that there is need to increase supply chain integration to ensure that modular products can compete with traditional integral products. The paper provides useful insights into the dynamics of modular supply chain operations, which illustrate the difficulties associated with integrating modular operations and competing with the traditional integral products.
1 INTRODUCTION

Product modularity provides flexibility and responsiveness that enables firms to serve a variety of customer needs. An advantage of modularity in relation to supply chain design is that pursuing product variations has only a limited impact on production and assembly processes. Modular design allows a firm to differentiate its product to a high degree by combining a limited number of standard parts [1]. There has been a considerable body of knowledge investigating the development of product modularisation [2], the impact of buyer-supplier relationships [3]. Modularity has been extensively applied successfully in the electronics and automotive sectors [4] & [5]. This paper seeks to demonstrate the extent to which supply chain practices in the furniture industry are aligned to product modularisation. Using loosely-coupled structures enables firms to achieve greater scope flexibility and scale flexibility. The supply chain must be aligned with product development decisions; it should be designed and managed, so that the products are delivered at the targeted cost, time, and quality [6].

Using modular product design as your new product development strategy decreases time to market, increases the number of product variants, increased flexibility, reduced cost and decreases the number of unique parts in your product architecture [7]. Product modularity offers many advantages to the manufacturing industry which are: reduced labour, reduced waste, reduced inventory, increased quality, improved productivity and enhanced cost and quality performance [8]. Modular supply chain and modular product design allows firms to link together the capabilities of many organizations to support product development [9].

Several barriers exist for the increased use of modular product solutions, which include difficulties associated with complex interfacing between systems, the inability to unfreeze design decisions and higher capital costs.

The local furniture industry has not kept pace with the growth in worldwide furniture trade and has steadily been losing its share of the global furniture manufacturing, having moved from the 34th largest exporter in 2005 to 43rd in 2006 [53]. The escalation of cheap Asian imports, the declining investment in skills development and technological innovation, insignificant research and development funding over the past five years or so has resulted in the declining levels of competitiveness in the industry. This has also contributed to job losses and the reversal from being a net exporter to being a net importer of furniture products. Whilst the largest furniture manufacturers have to some extent managed to hold fort in the face of increasing imports, the biggest casualties have been the small and medium-sized enterprises [53].

It remains doubtful if the local industry will ever effectively compete with the Asian imports [53]. However, it is possible to position the local industry as the producer of high value niche furniture products that are globally competitive based on quality and/or differentiated designs. This requires a concerted effort on the part of the public and private sector to develop programmes that address the challenges that constrain the industry from achieving potential growth levels and significantly raise the levels of competitiveness.

In the following sections the literature relating to modularity and supply chain management will be discussed. This will be followed by research methodology, analysis of case studies and discussion of findings. The implications of the research will be discussed, together with suggestions for future study, in the conclusion.

2 LITERATURE REVIEW

Sections 2.1 and 2.2 hereby review modularization and supply chain management, respectively and relationship between modularization and supply chain management.
2.1 Modularization

Modularity is an approach for managing and developing complex products and processes efficiently by decomposing them into simpler subsystems without compromising the system's integrity [10] & [11]. It is also considered as a new product development strategy in which interfaces shared among components in a given product architecture become specified and standardized to allow for “greater substitutability” of the components across product families [12]. Therefore, Modular product architectures are used as flexible platforms for leveraging a large number of product variations [13] & [14].

Modular design can be viewed as the process of producing discrete functional units that are connected together to provide a variety of product functions. Modular design emphasizes the minimization of interactions between components in order to design and produce those components independently. Each component, designed for modularity, is supposed to support one or more functions. When components are structured together to form a product, they will support a larger or general function [15].

Modularity is an example of architectural innovation that enables greater flexibility for mass customization but “without changing its components” [16]. Modularization enables mass customization not only by providing a means for the repetitive production of components [17]. One of the great advantages of modularization is the ability to assemble repetitive units in controlled conditions. Modular product architectures require physical independence and functional independence. Simply splitting up a product for later assembly is not necessarily termed a modular approach; there need to be a certain level of flexibility in the way that parts are recombined. Modularization requires standardized interfaces to provide embedded coordination that greatly reduces the need for overt exercise of managerial authority to achieve coordination of the product development process [18] & [19] states that a modular product or subassembly has “a one-to-one mapping from functional elements in the function structure to the physical components of the product” and that all interfaces between the components of different modules are decoupled. Modularized product architecture can be disintegrated into loosely coupled components offering high possibility to outsource design to suppliers.

Three rules that define Product architecture are [20]: (1) Architecture, which specifies what modules will be part of the system and what their functions will be. (2) Interfaces, describe in detail how they will fit together, connect, and communicate. (3) Standards, for testing a module’s conformity to the design rules and for measuring one module's performance to another. Two types of macro types of modular product architecture are function-based and manufacturing-based [21]. Function-based is partitioning a product into discrete scalable, reusable modules consisting of isolated, self-contained functional elements. Manufacturing-based modularity is the application of unit standardization or substitution principles to create modular components and processes that can be configured into a wide range of end products to meet specific customer needs.

Besides reduction in cost (due to lesser customization, and less learning time), and flexibility in design, modularity offers other benefits such as augmentation (adding new solution by merely plugging in a new module), and exclusion. Examples of modular systems are automotive industry [22], computers and high rise buildings. Earlier examples include looms, railroad signalling systems, telephone exchanges, pipe organs and electric power distribution systems. Computers use modularity to overcome changing customer demands and to make the manufacturing process more adaptive to change (see modular programming) Modular design is an attempt to combine the advantages of standardization (high volume normally equals low manufacturing costs) with those of customization. A downside to modularity (and this depends on the extent of modularity) is that modular systems are not optimized for performance. This is usually due to the cost of putting up interfaces between modules.
2.2 Supply Chain

In order to grow timber, inputs such as seeds, chemicals, equipment and water are needed. When the timber has reached a mature age (from 12 to 25 years depending on the type of timber) it is sent to sawmills, where machinery and other inputs are used for production. The sawn timber is then delivered to the furniture manufacturers. The manufacturers in turn obtain inputs from other industries such as plastic, metal, textiles, machinery and paint. In addition to this, the furniture manufacturers also source inputs such as machinery as well as inputs from the service sector in the form of design and branding expertise. The finished product leaves the manufacturers, generally through a buyer, into either the domestic or foreign wholesale or retail sector, before it reaches the consumer.

The changing nature of the industry, often represented by large-scale retailers has led to an increasingly common practice of retailers buying straight from manufacturers in a cost saving-initiative. The last step of the value chain is then the consumer who will, in time, either recycle or dispose the furniture.

Value-transfer theory states that in order to concentrate on its core business, a manufacturer will transfer non-core value-adding activities to its supplier also, the supplier reorganizes its own business to accommodate the increased production and management responsibilities and then passes down some value-adding activities to its own suppliers [23]. Value-added activities are shifted from a single organization to the overall modular supply chain as the key modules are outsourced to technically competent module suppliers in modular product design [24].

Product modularization cuts down too much variety in development by simplifying design activities, improving coordination and information sharing across production, sales and engineering [25]. Modular design improves competitive performance, facilitates supplier, manufacturing and design integration by simplifying communication and information sharing and building trust among supply chain partners [26]. Supplier proximity changes due to

Source: Adapted from Kaplinsky et al, [53]
different types of modular product design. Reference Ulrich *et al.* [27] argue that, under holistic customer requirements, when components are designed for a specific product, internal and external integration is required. The decisions about modular design have a substantial influence on the supply chain environment.

A modularized product has a set of independent modules, which allows standardization [28]. Standardized modules can be better outsourced to suppliers [29], using a loosely integrated approach [30]. Iterative communication and coordination among suppliers and manufacturers in the development process can be reduced when the supplier can focus on its predefined specifications without being too concerned about other modifications [31].

Modular product design may reduce the need for extensive internal integration [32] & [33]. The development of modular systems can lead to vertical and horizontal disintegration [34].

In order to ensure the conformance of different product components the supply chain must be integrated as closely as possible for ease of communication and coordination. Extensive integration should help the suppliers to develop innovative new products through collaboration [35]. Reference Diez [36] says close supply chain design improves information sharing, especially tacit knowledge sharing, e.g. physical co-location and face-to-face communication. The tacit knowledge then promotes innovation that leads to a competitive advantage [37]. Modular design can lead to more supply chain collaboration as it increases the supplier’s need for relationship-specific investments and for agreement on the design of common modules [38].

### 3. RESEARCH METHODOLOGY

Shaw [39] and Gill *et al.* [40] warn the use of hypo-deductive approaches to understanding small firms which can restrict the generation of knowledge. Advantages of qualitative research tend to be behavioural stressing qualitative differentiation and innovation [41]. Therefore, it calls for an approach that allows the researcher to “get close” to participants, penetrate their internal logic and interpret their subjective understanding of reality [42]. Thus, we consider that our research enquiry on The impact of Product Modularisation on Supply Chain relationships is of interpretive kind. The present study focuses on theory development which is mainly of exploratory kind and aims at identifying the factors that appear to influence the supply chain focusing on product modularisation. The selection of qualitative case study research is based on the reasons such as:

- there is little formal theory describing supply chain complexities in the context of small medium enterprises [43]; and
- the issue needs to be explored in its most natural and social context to learn about possible unforeseen variables influencing the phenomenon [44].

A multiple case study approach is adopted to increase external validity [45]. We chose to visit each company thrice. For all companies, a number of quantitative and qualitative data were collected: business specific characteristics (volume, turnover, lead time, position in supply chain), issues related to various business functions (production, marketing, manufacturing), perception and vision of CEO/GM. The first visit consisted of an introduction, a plant visit and a semi-structured interview based on the researcher’s questions. The second visit helped to interact with various departmental heads in more detail and uncover some of the more issues affecting the premise of present research. In the final visit, gaps and missing data were filled. Moreover, the key informants reviewed the tables with quantitative data, and the researchers’ interpretations, increasing triangulation [45] and construct validity [46]. Most interviewees (20 in number) were CEO/owner or other departmental heads with a clear view and knowledge of operations, products and buyers. The varying motives, differing control structures and owner-led planning process of small to medium enterprises organization requires triangulation utilizing multiple sources and means.
In order to limit the effects of subjective biases and improve the validity and reliability of study, approaches like questionnaire, interview schedules, observations and study of organization’s archrivals were adopted. In addition, all the interviews were recorded and transcribed, thus allowing further detailed analysis.

The interview schedule has included questions on various sections such as marketing/sales, purchasing, manufacturing, and production planning and control. The interview questionnaire has collected responses on a Likert scale of 1-5 related to the profile of company, basic supply chain issues, buyer-supplier relationship, and enablers/barriers to SCM implementation. However, the purpose of using interview questionnaire was just to ensure the consistency of qualitative data and not to use for any further statistical analysis. We attempted to capture the notion of SCM from operations point of view. For the purpose, departments like manufacturing, production planning, marketing, and purchasing were studied in detail. In order to avoid a too narrow collection of data and understand the effect of overall environment of organization, we also asked for variables related to overall business approach/orientation, operations strategy, products, markets, business strategies and relationships with their major suppliers and buyers. In line with Voss et al. [45], we will first describe our sample and then do cross case comparison followed by the analysis. Pseudonym (for example, Company V, Company X . . .) has been used to protect the anonymity of the case organizations involved in this study.

![Figure 1](image1.png)

**Figure 1.** Number modules supplied and number of modular products

![Figure 2](image2.png)

**Figure 2.** Size of the technical department
A lounge settee is an innovative consumer product that adopted modular design to increase product variety for company V. In the context of supplier integration (SI), the preliminary product design was created in-house, product modules were co-developed with the key module supplier. The module supplier was involved early in new product development (NPD) by designing a recliner mechanism to create an innovative settee(s). This module was critical to the overall quality and comfort of the settee. The module could be mixed and matched with other components without sacrificing the quality of the settee. The manager said that since the product module was innovative, extensive communication with the key module supplier was very important, they could assess and modify their manufacturing processes through frequent face-to-face meetings with the case company’s engineers. Suppliers were closely involved in the whole NPD process including new product idea generation, business/technical feasibility assessment, product/process conceptual development, prototype building and full-scale production. The knowledge sharing between the case company and these suppliers had helped ensure that the suppliers’ production processes were suitable to manufacture the innovative recliner module. Company V and its supplier shares inventory information weekly with the suppliers. With respect to customer integration CI, company V only shared forecast inventory information with its retailers. Company share information concerning product performance with the retailers, and failure mode effect analysis is conducted to improve the quality of the product. The company conducted market research, such as customer surveys, to identify customers’ needs. Thus, CI is appropriate in improving the quality of the settee. The supply chain network for company X is illustrated in Figure 5.
An office desk is an innovative product for Company W. The product was modularized to enable mixing modules with minimum architectural modifications. Modules are designed internally leading to faster product customization as requested by the customers. Company W developed and manufactured the desks in-house. Company W modularized the product and commonized some of the components in order to use standard parts. The standard parts were purchased on the open market and the modules were made in-house. In this way, the company could not only control architectural and modular knowledge and production capability but also gain greater sourcing flexibility and low-cost opportunities. However, the company did share quarterly inventory levels and yearly forecast order information with the supplier to ensure on-time delivery. Company W relied on the input from the customers to co-design and refine new product structure. When customers were directly involved in the design the company could ensure the customized functions fitted the customer's requirements. The technical department size had five workers one engineer and his assistance. The supply chain network for company X is illustrated in Figure 6.

Company X

Kitchen fitting is a conventional single product development project for a customer who makes decisions about the product architecture and material use. As required by the customer, the case company adopted a cut to fit modular product design and manufactured all the product modules in-house. The company depended on informal and trusted relationships with the suppliers to get modules like granite stones for kitchen cabinet tops. Forecast inventory level or other production information is shared with the suppliers to ensure on-time delivery. The functional modular product did not require close supplier integration; however production information was shared for supply chain efficiency. For customer integration, the customer was involved in the project because the both the customer and the case company understand the product’s design. In the II context, as the project was relatively simple and the project team was small, the case company only assigned one engineering manager as a coordinator to manage the development project with five internal staff, each of whom was assigned to develop a specific component or module. As most of the development activities were routine, formal integration mechanisms, as the project manager argued, would lead to higher development costs and extra planning time.
Thus, tight formal internal integration mechanisms were not adopted in this case. The supply chain network for company X is illustrated in Figure 7.

![Figure 7](image7)

**Company Y**

Reception furniture is a single innovative product for Company Y. The reception furniture has many product designs depended on special requests from the customers, customers are concerned about physical dimensions and appearance, functional requirements and production cost. Company Y purchased modules from suppliers like sheet metal design and glass material design. The company integrated suppliers and customers in the new product design. This supplier co-development practice helped the development team select appropriate materials for the product. Throughout the development process technical know-how was continuously shared. To ensure on-time delivery, forecast orders and other production information was shared with other suppliers. To develop the reception furniture, the development team worked closely with the suppliers and customers through frequent face-to-face communication and communicated with the international customers via internet-based information systems. Project management was adopted to integrate multiple internal functional units in this project. The supply chain network for company Y is similar to the one for company V (Figure 5).

**Company Z**

The main products for company Z are tables and chairs and there are integral products, no modules are used to create these products. The company only shared the forecast inventory and order information with the supplier to gain supply chain efficiency. The customer coordinated closely with the project team through frequent sharing of technological and marketing knowledge. The product and resulted in a good relationship with the customer. The case company had no formal integration mechanisms to coordinate the technical members because the team only had four members and the products are very simple structure with very few components. Supply chain network for company Z is shown in Figure 8.

![Figure 8](image8)
4. KEY FINDINGS AND DISCUSSION

Figure 1, 2, 3, 4 shows the relationships between PM and SCI in all the cases. In the case discussion, SCI consists of three dimensions: suppliers integration, Customer integration and internal integration. In each dimension the cases were divided into tightly coordinated or loosely coordinated. According to the degree of PM, the cases were divided into modular design or integrated design. This classification was agreed by the interviewees in all the case companies.

Many authors argue that modular design is aligned with a loosely coordinated supply chain, whereas integrated design is associated with a tightly coordinated supply chain (Fine et al., 2005[47]; Sanchez, 1995[48]). From case information discussed above PM is related to a loosely coordinated supply chain. This is based on empirical evidence that the product modules were standardized (Company X), the team size was small (Company V, W). However, this study found some exceptional cases in which a tightly coordinated supply chain was adopted. This was because a new module was developed (Company X and Y) and technological knowledge was captured from the customer (Company Y). Company Y and X has a highly integrated supply chain, figure 3 shows that the number of meetings downstream and upstream is very high.

In Figure 4, the delivery lead times for company X and Y are low indicating that product modularity increases the supply chain efficiency leading to high flexibility.

Integrated design was associated with a tightly coordinated supply chain. This association was due to the nature of integrated design (Company Y and X). However, this study found an exceptional case in which a loosely coordinated supply chain was adopted. This was because the product modules were standardized (Company V) and the team was small (Company V).

By comparing the five cases, product design complexity is affecting the relationship between PM and SCI.

**Complexity and Product design**

This study suggests that the relationship between PM and SCI is strongly affected by the complexity of the product architecture. For supplier integration, in the reception furniture (Company Y), the case company co-developed the new module with the module supplier, who was involved early in product design, business meetings and design workshops. The other modular products like lounge settee (Company V) and office desks (Company W), were much less coordinated with their suppliers because the supplied materials were of a conventional type available in the open marketplace. For innovative product architecture, like the reception furniture (Company Y) required the supplier and customer to co-develop its new product. Company Z was a contrasting case that did not coordinate suppliers as the raw material was standardized and the product architecture was integral.

Our case comparison indicates that modular design may be related to a loosely coordinated supply chain, whereas complex product architecture is associated with a tightly coordinated supply chain. The interrelated relationships among PM, SCI in this study found that if product modules or components are innovative, it is important to work closely with the key suppliers or customers regardless of whether modular or integrated design is adopted. This result is consistent with the view that product innovation requires information sharing and product co-development in the supply chain [49]. When complex product design is adopted, integration with critical component suppliers may not be avoidable. This finding suggests that the alternative of module commonization can lead to a loose supply chain for modular design.

Although literature suggests a loosely coordinated supply chain for modular product development [50], our empirical findings show that, for innovative product development (Company X and Y), SCI is indispensable. This finding is consistent with empirical studies.
which found that integrating supply chain partners and internal functional units is crucial in solving technical problems and specifying the interfaces of new product modules [51].

This study extends the extant literature in that it uses product innovation as a key factor to explain why modular product design needs SCI.

5. CONCLUSION

By studying five companies in the furniture industry, this study provides further explanations of the impact of PM on SCI. According to the findings, the authors have verified that there is a direct relationship between PM and some dimensions of SCI [52]. A highly modularized product will result in increased supply chain integration, tightly coordinated supply chain. Further research should focus on information management, product innovation or value-transfer activity across a supply chain.

It should be acknowledged that the present study is subjected to some limitations. Perhaps, the most serious limitation of this study was its narrow focus on South African manufacturing companies and hence without supporting replication of studies like this, our results should be considered tentative and should be generalized with care. Further, research should endeavor to test the inductions and process model offered by this research based on a large survey and cross-industry study. The purpose of this research is to raise select concerns in supply chain integration and product modularity in chosen South African companies and not to opt for statistical generalization.

Further research could be aimed at empirically testing the findings of this research. Interesting in this respect is also to explore the possible link between supply chain structure, SME’s position and product modularity. This link is important because mutuality between supply chain partners and hence motivation to invest depends upon the structure of the supply chain.

6. REFERENCES


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