Product architecture design: the role for supply chain configuration

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Abstract

Decisions made at product concept design stage later impact on the alignment of supply chain configuration with the products' physical architecture. This research uses six case studies and ten products, in the consumer appliances, medical devices, automotive and aerospace sectors to understand how concurrent engineering, feedback, and feed-forward anticipatory control, affect this alignment.

Keywords: Modularity, Supply, Product

INTRODUCTION

Organisations are experiencing increasing technology and supply chain disruption. New Product Design (NPD) thinking has emerged as a key enabler to managing global Supply Chain Configuration (SCC). Companies are searching outside their industry for supply chain technologies and innovation, participating in innovation networks (Podolny, 2001), and connecting knowledge across product design and supply chain communities. Using the grounded theory approach, Noble and Kumar (2010) highlight that many consumers and product designers adopt a value-based view of design with design thinking encompassing both value creation (NPD) and value delivery (SCC). While there are currently no deterministic approaches to choosing an optimal product architecture, the process can be guided. In most cases the choice will not be between a modular or integral architecture, but rather it will be focused on which functional elements should be treated in a modular way and which should be treated in an integral way. Despite the significance of SCC innovation we have yet to see a common framework for mirroring Product Modularity (PM) and SCC. Empirical studies demonstrating the effect of PM on NPD performance are scarce (Danese and Filippini, 2010). Companies are slow to share information on SCC innovation, as a result this limits the ability of commercial NPD teams to understand the contribution that SCC can make to value delivery. Lau et al. (2010) argue it is difficult for customers to directly appreciate PM, but they may value the benefits, such as delivery, flexibility, customer service, product variety, and mass customization. They argue that the benefits of PM should be translated into firm capabilities and subsequently improved firm performance. Khan (2009) states that taking a holistic view, rather than focusing on individual supply chain functions, is essential to NPD as supply chains are becoming increasing longer and further away from the market place. As highlighted in a previous systematic literature review, through research and practice, increased alignment of PD and SCC leads to better product performance, Droge et al. (2004).

This empirical study seeks to understand how alignment between Product Architecture (PA) and SCC can be achieved through five case studies incorporating ten products, which are the main Units of Analysis (UoA), each of which is a new to market product and its associated SCC. The research question addressed by this research is: "*How do concurrent product design and control systems affect the alignment between PM and SCC?*" Mechanisms, that are deduced to encourage alignment include concurrent engineering (CE), feedback control (FC) and feedforward anticipatory control (FAC) are studied at the conceptual stage of NPD. These new to market products include breakthrough and platform projects (Wheelright and Clark, 1992).

Four industry sectors were selected for this empirical research; medical devices, domestic appliances, automotive and aerospace. The aerospace and automotive sectors have conducted the most research in product modularity. The medical devices and home appliances sectors were selected due to the high rates of new product introduction, in these sectors, together with the researcher's access to leading companies in this fields.

LITERATURE REVIEW

Feitzinger and Lee (1997) state that it is not only necessary to integrate products and processes, but also the configuration of the entire supply network. The intent to align PM and SCC is one thing, the processes and systems to accomplish this are another. Both PM and SCC are aligned along a modular-integral continuum, as illustrated in figure 1. A systematic literature review determined a viable theoretical base for empirical research is management control systems. The theoretical foundation of the empirical research is in the use of CE, feedback control and FAC. The FAC framework uses double-loop learning (Argyris 1976, 1977; Senge and Fulmer, 1993), where goals and targets can be challenged or questioned. NPD (Henderson and Clark, 1990) and SCC (Helou and Caddy, 2006) are considered as systems.

A governance control system that employs CE, feedback (ex-post) and feed forward (ex-ante) information, the type of system depicted in cybernetics, systems and control theory (Francisco et al., 2012) and in General Systems Theory (Von Bertalanffy, 1950). This conceptual framework is presented in figure 1. It is proposed that Concurrent Engineering (CE), feedback and feed forward anticipatory control (FAC) improve the alignment between PA and SCC. SCC and PD alignment is a multi-dimensional concept, which can be represented by practices, patterns, and attitudes; with the alignment of SCC and PD contributing to improved PD success and the alignment increased though CE, feedback planning and control and FAC.

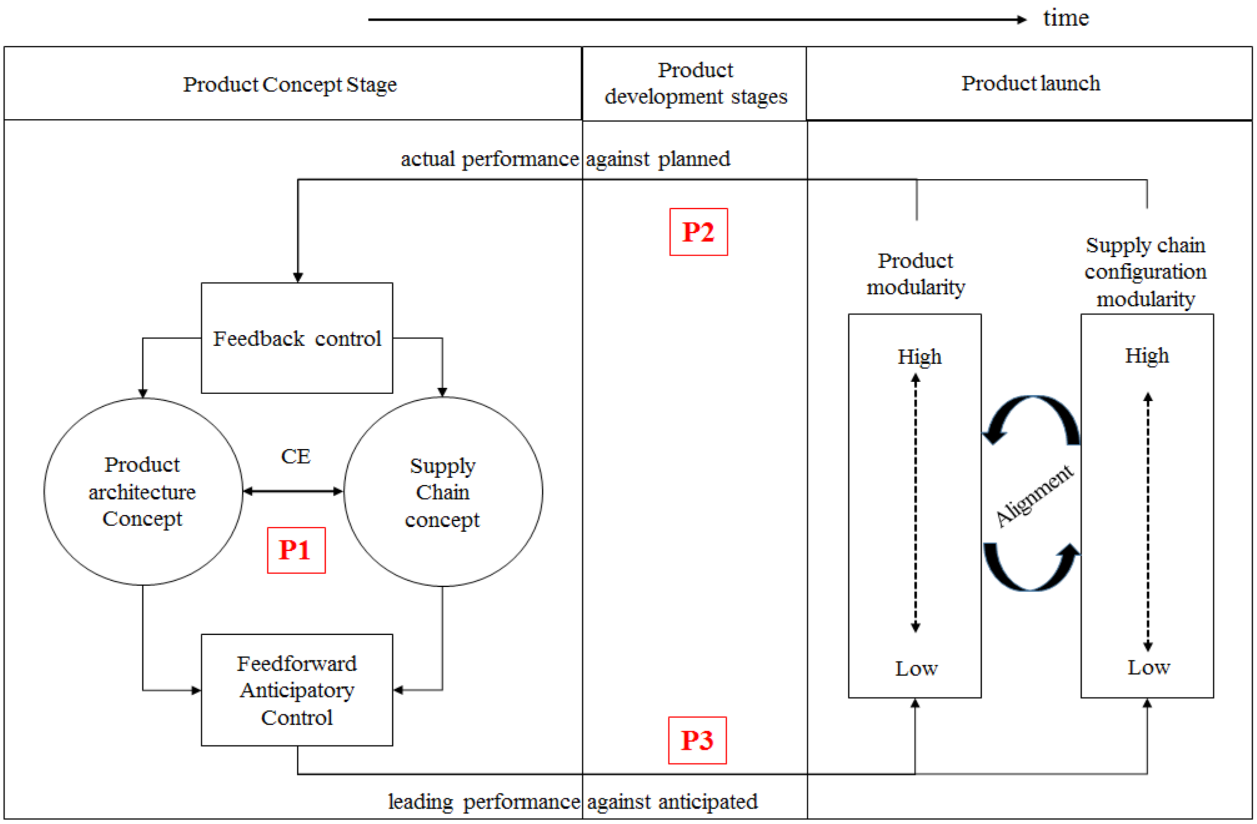

Figure 1 - Conceptual research framework

The case studies were designed to investigate three propositions, illustrated in figure 1. P1, P2 and P3 refer to these propositions:

a) **Proposition 1 -** Concurrent Engineering (CE) between New Product Design (NPD) and Supply Chain Configuration (SCC) leads to improved alignment between Product Modularity (PM) and Supply Chain Configuration (SCC).

b) **Proposition 2 -** The alignment between Product Modularity (PM) and Supply Chain Configuration (SCC) is enhanced by systems feed-back control (FC).

c) **Proposition 3 -** The alignment between Product Modularity (PM) and Supply Chain Configuration (SCC) is enhanced by feedforward anticipatory control (FAC)

RESEARCH METHODOLOGY

This research focuses on a contemporary business phenomenon, with the aim of understanding of behavioural events. Further the research question, "*How do concurrent product design and control systems affect the alignment between PM and SCC?*" is an explanatory question. For these reasons the case study method was selected (Yin, 2014), allowing the phenomena to be studied within its real life context thus enhancing the relevance of the study findings. Interpretative Phenomenological Analysis (IPA) was used to draw on five cases studies, involving ten interviews with expert respondents, offering multiple perspectives on shared experience between product and supply chain designers. Anywhere between three and fifteen participants is acceptable for a group IPA study (Reid et al., 2005). The concepts featured in this research are mapped onto Pettigrew's (1990) 'Meta level' analytical framework these measures constitute the 'outcome variables' as illustrated in figure 2. These outcomes are mainly qualitative measures. The CE, FB and FAC mechanisms are measured during the conceptual stage of NPD, whereas both PM and SCC are measured after product launch.

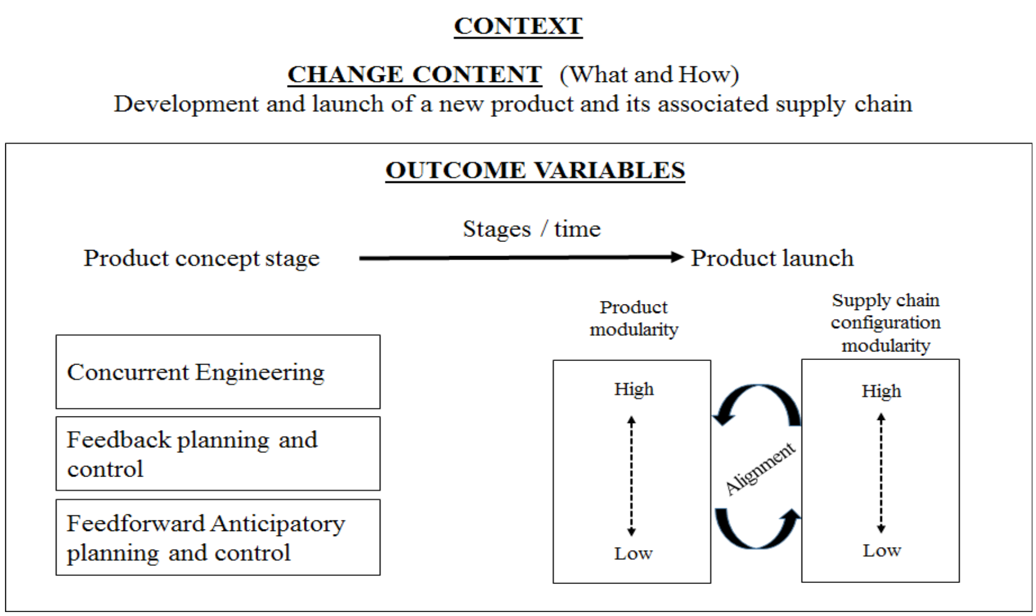

Figure 2 - Meta level case study framework (Adapted from Pettigrew, 1990)

Operationalising modularity is challenging since it is a relative property. The concept is ambiguously understood at a detailed level. Products can generally be decomposed at different levels; modules, building blocks, subsystems, components and subcomponents. "*Modularity can be a characteristic of each or only some of these levels,*" (Brusoni et al. 2001).

CASE SELECTION

Eisenhardt (1989) defines sectors as populations, and maintains that '*the concept of a population is crucial, because the population defines the set of entities from which the research sample is drawn. Also selection of an appropriate population controls extraneous variation and helps to define the limits for generalizing the findings'*. All companies operate global supply bases, and supply in to global market. Pettigrew (1990) states that with the limited number of studies which can usually be completed, it makes sense to choose cases such as extreme situations and polar types. Yin (2014) recommends that each case be carefully selected so that it either predicts similar results (literal replication) or produces contrasting results but for predictable reasons (theoretical replication). In the medical device case study a product exhibiting high level of modularity and a contrasting product exhibiting a low level of modularity (integral level) were selected. In the consumer appliance case a modular and a highly integral product were selected. In both the aerospace cases a modular product was selected at the higher assembly level, whilst an integral architecture products were selected at the lower BOM levels. In the automotive sector modular products were selected at the top level assembly, and more integral products at the lower level assembly.

DATA COLLECTION

Case studies were developed based on multiple data sources, informal meetings, semi-structured interviews secondary data, published reports, and research papers. Data collection commenced with three preliminary interviews, with supply chain and design experts from two companies, see table 1. The interviewees were selected based on their practitioner experience, in product design and supply chain configuration. In all instances I commenced with one respondent, and requested a second interviewee, on the basis of gaining the alternate perspective. All experts are key decision makers, within their companies. Four criteria are used to judge the quality of the case study research, namely: construct validity, internal validity, external validity and reliability (Yin, 2014). Table 2 outlines the measures taken to address each of the quality criterion.

RESEARCH RESULTS

Table 3 includes the synthesis of the results for the case studies, and will be used to support the analysis presented here. Early SCC involvement in CE appears to lead to higher levels of alignment, as illustrated with the automotive and aerospace cases, see table 3. In the cases of the tier one automotive and aerospace suppliers, there is in-depth customer involvement in CE. In the cases of the medical device and domestic appliances, the primary focus is on supplier ability assessment. Feedback control seems to have a positive influence on alignment, for platform products, in particular for product in the automotive and aerospace sectors. They exhibit greater than sixty per cent component commonality, between products. The domestic appliance case indicates the least emphasis on feedback control. The COO statement that "*we could be making* *more use of warranty returns data"* represents an inclination towards the development of a robust use of this data. PM and SCC can be characterised by varying levels of modularity. A 2x2 matrix was developed, to represent the alignment of these two constructs, see figure 3. The UoA are positioned in this matrix, based on the levels of PM and SCC modularity, outlined in table 3.

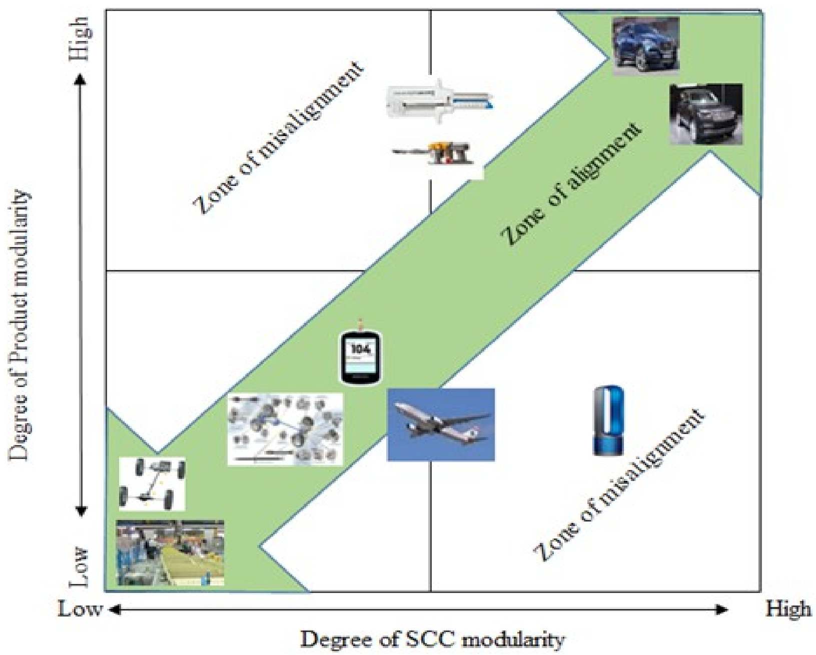

Figure 3 - PM-SCC alignment

RESULTS RELATING TO RESEARCH PROPOSITIONS

PROPOSITION ONE

All UoA with exception of the surgical cartridge are platform products. This product has been on the market for twenty years. The air purifier, cordless dryer, and surgical cartridge all have low levels of SCC involvement, and show low levels of alignment, supporting the proposition that CE involvement improves the alignment between Product Modularity (PM) and Supply Chain Configuration (SCC). Ulku and Schmidt (2011) mention that matching low levels of modularity in PM and SCC is not observed in practice, is challenged by this research, which illustrates close alignment at the sub-assembly levels, in automotive and aerospace.

PROPOSITION TWO

The effectiveness of FC is linked to product life-cycle, platform design, the systems deployed to feedback product and SCC performance data, and the level of predictive data analytics employed. PM and SCC modularity need to be 'designed-in', at the concept stage (Cohen &

Fine 2000), where organisational design and task allocation are considered. Koen (2005) argues that Stage-Gate® might have a negative impact on the efficiency of platform projects. Companies using the Technology Readiness Levels (TRL) methodology, at product concept stage, for example the medical device company, tend to have a higher level of PM-SCC alignment than those using the Stage-Gate® process, for example the domestic appliance co.

PROPOSITION THREE

The effectiveness of FAC is linked to rate of technology change, degree of newness of product, the systems deployed to provide double-loop learning, and the level of prescriptive data analytics employed. For products that show the lowest levels of alignment, the surgical staple, cordless vacuum cleaner, air purifier and aircraft these companies expressed the highest level of interest in FAC. These companies FAC declared intended actions would move these UoA closer to the zone of alignment, as illustrated in figure 3. FAC has a specific role in minimising the difference between planned and actual performance and to improve the alignment of PM - SCC. During the interviews it became apparent that new product introduction rate (NPIR) was not the most critical PD performance metric, associated with companies who seek to align PM and SCC. The delivery of a reliable, cost-efficient, quality product is more important than achieving the precise NPIR. Where time was devoted to implemented FAC, there is evidence of closer alignment, and where FAC was not conducted alignment is poor.

CONCLUSIONS

The study established a process for presenting the alignment of modularity based practices, patterns, and attitudes within new product design and supply chain configuration. Regulated industries such as automotive, aerospace and medical devices appear to align their modular based PM-SCC processes more closely. Companies appear to be increasingly focusing on alignment, for platform and breakthrough products. On the downside, high levels of PM-SCC alignment could lead to inefficient NPD for radical product designs. OEMs should seek to be continuously involved in the design of key component technologies. Managers should realize that PM-SCC integration is not a simple project-level decision. It is a decision that spans across multiple projects, and across an entire organisation.

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Table 1 - Interviews reference data

Phase	Company	Turnover (US Dollars) 2014	Number of employees 2015	Role(s)	Unit of Analysis	Number of interviews	Total duration (in minutes)
Preliminary	Toy Manufacturer	$4.182B	12,582	Global Operations Manager	Plastic Toys	1	40
	Global Contact Manufacturing	$26.147B	150,000	VP Design Product Design	Blood Glucose Meter	1	36
				Snr Director Product Design	Industrial controller	1	35
Case companies	Medical Devices	$74.331B	126,500	Principle Global Engineer	Surgical cartridge	2	120
				Senior Process design Engineer	Blood Glucose Meter	1	95
	Domestic appliances	$2.005B	4,545	COO and Board member	Air Purifier	2	135
				Director Global Manufacturing	Cordless vacuum cleaner	2	145
	Automotive	$28,169B	27,953	Purchasing Director	Sports utility vehicle	1	120
				Director products, programs and operations	Crossover utility vehicle	2	95
	Automotive driveline products	$10.832B	55,000	Director Group business improvement	Driveline solutions	1	105
				Group Director - Supply chain excellence	Drive shaft	1	65
	Aerospace	$66.311B	55,000	Director Group business improvement	A350 trailing wing	1	35
				Snr. Aerospace maintenance consultant engineer	A330 aircraft	2	210

Table 2 - Quality criteria

Construct validity	1	Multiple sources of evidence were used (Eisenhardt; Yin, 2014).
	2	Key informants were in top management positions, COO, Global Operations Manager, Principle Engineer, VP Product Design, Purchasing Director, Snr Consultant Engineer, Snr Process design engineer, Director Global manufacturing, Snr Director product design, Group Director - Supply chain excellence - with full responsibility for product and supply chain design processes.
	3	Construct operationalization was supported by a literature review.
Internal validity	1	Assured through pattern matching (Yin, 2014).
	2	Two units of analysis selected or each case study.
	3	Where possible units of analysis selected from both extremes - high and low modularity levels.
	4	In the case of automotive and aerospace a key Tier One supplier was also included in the case studies.
External validity	1	Achieved through analytic generalization and replication logic (Yin, 2014).
	2	Case studies are taken from five industry sectors, medical devices, domestic appliances, automotive, automotive driveline solutions and aerospace.
	3	Two of the industry sectors are highly involved in modular-based practices automotive and aerospace - this was determined from a systematic literature review.
Reliability	1	Reliability is achieved through transparency of the process (Yin, 2014).
	2	The case study protocol defines the way the data were collected.
	3	In the data collection phase a case study database has been developed.
	4	Draft cases studies prepared and validate by each case company.

Table 3 - Cross case analysis

	Surgical cartridge	Blood Glucose meter	Air purifier	Cordless vacuum cleaner	Sports utility vehicle	Crossover utility vehicle	Auto driveline	Auto drive-shaft	A350 trailing wing	A330 aircraft
Product modularity (PM)	Components in the staple are loosely coupled	Components are tightly coupled with exception of test strip, and battery	Tight component coupling	Tight component coupling, product, there are user options	Strong slot and bus modularity cross car line	Strong slot and bus modularity, approx 60% parts commonality	Bus modularity, with low level of modularity on drive-train	Low level of modularity with exception of protective cover	Tight component coupling	Tight component coupling, with bus modularity for avionics, and other upgradeable options
Level of PM	High	Medium-low	Medium-low	Medium	High	High	Medium-low	Medium-low	Low	Medium-low
Supply chain configuration (SCC)	Global Supply chain, with single final assembly plant, in Mexico	Global Supply chain, with single final assembly plants for meters and strips	There is limited configuration to order (late-customisation) . PSA used as final integrator	There is configuration to order. PSA is used as final integrator	Build to customer Order. Tier one suppliers deliver tested modules	Build to customer Order. Tier one suppliers deliver tested modules	Limited use of build to order, procurement time drives SCC process	Low number of suppliers, continuous build process, products assembled to order	Single process, in single location. Product is built to order, and delivered to single plant	Multiple global assembly sites, with increasing roles for Tier one integrators. Product built to order
Level of SCC modularity	Medium	Medium-low	Medium-high	Medium-high	High	High	Medium-low	Medium-low	Low	Medium
PM aligned or not?	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Concurrent Engineering (CE)	Late SCC involvement, product is not designed for cost, not a platform design	Late SCC involvement, product is not designed for cost, not a platform design	Late SCC involvement. There is strong supplier ability assessment	Late SCC involvement. There is strong supplier ability assessment	Early SCC involvement, large number of single sourced parts	Early SCC involvement, large number of single sourced parts	Early SCC involvement, strong customer involvement, use of knowledge brokers	Early SCC involvement, strong customer involvement, use of knowledge brokers	Early SCC involvement, process development preceeds product development	Early SCC involvement, strong supplier involvement.
Feedback control (FC)	User's (Practitioners) require more SKU flexibility	User's require more product functionality	Strong platform-design, more use could be made of warranty data	Strong platform-design, with SKU management at product level	Strong use of warranty data, and supplier performance evaluation	Strong use of warranty data, and supplier performance evaluation	In-depth failure analysis, strong focus on NPIR achievement	In-depth failure analysis, strong focus on NPIR achievement	Strong use of virtual (electronic) design, integration and zero means testing	Strong platform-design, with focus on both product and SCC performance metrics
Feedforward anticipatory control (FAC)	Proposal being developed to re-design the product, for user customisation	Plan to introduce Wi-fi enabled, non-invasive and other product technologies	Strong focus on the achievement at launch of the product marketing claim	Strong focus on achieving product marketing claim, and modular process devel.	Strong focus on NPIR achievement and modular process development	Strong focus on NPIR achievement and modular process development	Performance measures developed to pro-actively measure SCC performance	Strong focus on application engineering, and modular process development	Strong focus on materials and process capability development	Strong focus on materials and process capability development. Geo-politics play key role in SCC design