

**Creating Dynamic Capabilities:
The Role of Modular Product and Process Architectures**

A thesis submitted in partial fulfilment of the requirements for the degree of
Doctor of Philosophy

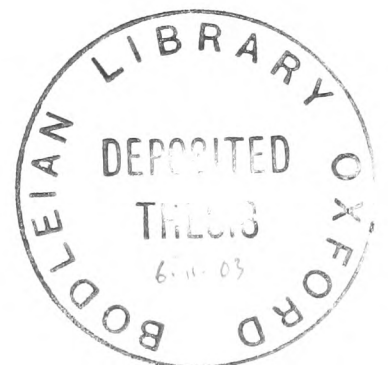
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THESIS ABSTRACT

This research examines how companies adapt to more unpredictable environments by developing dynamic capabilities that help sustain innovation and change. The key explanatory construct is *modular architecture* - the intentional decomposition of systems (products or processes) into relatively independent sub-units with standard interfaces.

The dissertation is structured as three semi-independent papers plus an introduction and a literature review. The literature review describes current theories of modular systems and discusses the similarities and differences to related concepts such as nearly decomposable systems, loose coupling, and vertical decomposition. The literature review identifies three gaps in the current literature. First, there has been a limited degree of theorising on the concept outside the field of technology management. Second, the current literature is based largely on anecdotal case studies and there is little quantitative evidence of the strategic value of modularity. Finally, there is a lack of understanding concerning the implementation of modular architectures.

The first paper generalises from product to organisation design and derives five principles for modular organisational architectures. A hypothetical example is developed to illustrate how a large home appliances company might apply these principles to create a process platform consisting of reconfigurable building blocks. The chapter also proposes some extensions of current theory to more realistically adopt modularity concepts in organisation design.

The second paper is based on a study that explores the current product and process architectures at three leading manufacturers of vacuum cleaners. It identifies some of the key barriers to increased flexibility among companies in mature industries. It also considers the relative value of modularity for established companies pursuing incremental innovation versus entrepreneurial companies introducing more radical innovations.

The third paper presents the results from a survey questionnaire study of companies in the home appliances industry in the UK and US. The relationship between market context, product and process architecture, strategic flexibility and firm performance is examined by means of structural equations modelling. The results show a positive relationship between modular product architectures and performance, with product model variety as a mediating variable.

The thesis makes the following contributions to the existing literature: It complements extant theorising by generalising modular principles to organisation design. It contributes to methodology by developing a questionnaire for assessing modularity in product and process design. Finally, it provides one of the first empirical studies of the effects of modularity on strategic flexibility and firm performance.

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1 INTRODUCTION

1.1 BACKGROUND AND RESEARCH QUESTION

Uncertainty appears as the fundamental problem for complex organisations, and coping with uncertainty, as the essence of the administrative process.

Thompson (1967, p. 159)

How do large companies increase their ability to adapt on a continuous basis to a changing market context? The relevance of this question is rooted in the profound changes that have been observed in a wide variety of industries during the last three decades. Management scholars have noted that these changes have altered the basis of competition – competition is now dynamic rather than static (Thomas, 1996)¹. This phenomenon, which has been termed a hypercompetitive shift (D'Aveni, 1994), has been spurred by such factors as the emergence of modern information technologies including the PC and the internet, the opening up of global markets, privatisation of former state monopolies, liberalisation of financial markets, and new scientific discoveries that have created entirely new industries (e.g., biotechnology). Dynamic competition challenges firms to move from exploitation of established, historic assets to the creation of new strategic assets. Consequently, managers have increasingly been experimenting with new organisational forms that facilitate creation of new assets and continuous adaptation to uncertain and rapidly changing market conditions.

As pointed out by Ilinitch, D'Aveni & Lewin (1996), most of these experiments have been undertaken without any guidance from academic research. For example, practising managers would search in vain if they were to consult traditional organisational theory for useful advice. Many of the most influential theories in this field paint a rather pessimistic

¹ There are some sceptics who have disputed the claims about increasing pace of change (e.g., Eccles & Nohria, 1992). However, there is an extensive literature that provides evidence of wide ranging demographic, economic, and technological shifts. For example, the absolute rate of technological

picture of the viability (or even the need) for achieving strategic flexibility in large and mature companies. Authors within the population ecology perspective (Hannan & Freeman, 1977) consider inertia the most prominent feature of organisations, and argue that change takes place more by the growth of new firms than by reform within existing firms (Pugh & Hickson, 1996). Exponents of institutional theory (Powell & DiMaggio, 1991) focus on factors that lead to homogeneity among firms, rather than on how one can break with the forces of conformity in the environment. The garbage can model (March, 1988; March & Olsen, 1976) highlights the limits of rationality in loosely coupled systems, instead of providing any means for how one can reduce local rationality, increase co-ordination, or heighten the level of strategic thinking (cf. Lutz, 1982; Argyris, 1996; Moran & Ghoshal, 1996).

Until recently, the situation was not much better in other fields of management. For example, well-known concepts and tools, such as the portfolio model of multidivisional structure, Net Present Value techniques for budgeting, the strategic positioning framework, and the transaction cost model, are all better suited for a stable environment than one characterised by high uncertainty and change (Kogut & Kulatilaka, 1994; Ilinitch, A'Aveni & Lewin, 1996, p. 216; Bettis & Hitt, 1995; Teece, 1998). Within the more recent resource-based view of the firm, there is a body of research focusing on how past choices constrain current choices about technologies (a phenomenon termed path dependency or technological trajectories) (Patel & Pavitt, 1997)².

Needless to say, the starting point for this research is different. As pointed out by Sanchez (1993) the strategy of “doing nothing” - i.e., maintaining the status quo - is a very high risk strategy, because it is a gamble that the future will be exactly like the present. The

diffusion is indeed increasing, according to the studies cited in Bettis & Hitt (1995). Similarly, Thomas (1996) documented a hypercompetitive shift in a study of 200 US industries from 1958 to 1991.

² Among some proponents of the resource based view there is an even more fatalistic point of view, namely that prescriptive advice about strategy or organisation cannot *in principle* confer sustainable competitive advantage, since the prescriptions must be transferable to be adopted, and then by definition are imitable, which means that they will diffuse to competitors as well, eroding any advantage gained by the first adopter (Mosakowski, 1998).

only viable strategy for an organisation facing dynamic markets is therefore to seek to enhance the organisation's capabilities at continuous adaptation. As defined by Teece, Pisano & Shuen (1997), these "dynamic capabilities" include the capacity to sense opportunities and to reconfigure business processes, technologies, and complementary assets to achieve sustainable (or at least temporary) competitive advantage under changing market conditions.

Previous frameworks for strategic change (Tichy, 1983; Pettigrew, 1987, Nadler, 1988) placed the main emphasis on managing the transition from an existing state to a future state (Bechard & Harris, 1977), assuming that once existing routines had been "un-frozen" they could be "re-frosted". These approaches are appropriate in gradually evolving markets, where one can foresee what the required changes are and adopt organisational strategies, structures and human resources capabilities accordingly (Sanchez, 1996). However, with the advent of dynamic and even hypercompetitive conditions, the key issue is no longer the management of a transition between an easily identifiable start and end state, but ways of increasing the *capacity* to adapt to change on a continuous basis.

The concept of dynamic capabilities, and related models such as Sanchez' (1995) strategic flexibility perspective³, offers managers a prescriptive and pragmatic theory for the management of uncertainty. As opposed to many previous theories, these models assume that large firms can significantly increase their ability to respond to dynamic environments. At the same time, one should of course recognise the inertial forces that might complicate the implementation of the strategies and principles that these models prescribe. It is here that theories such as those proposed by the organisational theorists mentioned above become relevant and potentially useful. It is important to understand the observed variance in the diffusion and adoption of these new principles among various companies, and to take into account the various counter forces that may present themselves, both when considering what a firm's strategic options are, and in the process of implementing the strategies.

³ Unless explicitly stated, these terms will be used interchangeably, although there are some differences: The strategic flexibility perspective, developed by Ron Sanchez, is rooted in technology

Even though large companies may be capable of increasing their dynamic capabilities, they may not be able to change in any direction. Existing asset bases, technological trajectories and organisational routines surely limit the potential for change, an issue that I will discuss in chapter 4, which considers implementation of flexible product platforms in established companies. Nevertheless, the evolution of many industries during the last two decades bears evidence that most large companies have already increased their dynamic capabilities and undergone fundamental changes in the way they compete (Sanderson & Uzumeri, 1996) and in the way they are organised (Zenger & Hesterly, 1997).

1.2 SCOPE OF THE THESIS AND UNIT OF ANALYSIS

There is obviously a wide range of variables that may influence a firm's dynamic capabilities, from individual competencies to corporate level strategies, as well as "macro" factors in the industry environment and ties that exist between firms in the industry, through alliances and networks of various sorts⁴. This research is largely limited to intra-firm variables⁵, although I will deal briefly with the characteristics of markets and with industry-level factors in considering the strategic implications of the framework that is to be presented⁶.

The main unit of analysis in this research is *organisational architecture*, which one can view as a high-level framework that encompasses both of the subordinate concepts *product and process architectures*. In chapter 2, I shall offer a rigorous definition of product

management. The dynamic capabilities perspective was developed by David Teece, and contains a stronger focus on organisational economics variables.

⁴ See Lorenzoni & Lipparini (1999) for a discussion of using relational / network resources to increase dynamic capabilities.

⁵ Some past and current research on flexibility (e.g., Brown & Eisenhardt, 1997) has focused on the project rather than on the organisational level. However, dynamic capabilities are by definition *the firm's* ability to reconfigure itself in response to opportunities and threats in the market.

⁶ This is not a trivial delineation because it could be argued that modularity is primarily an industry-level phenomenon that depends heavily on the maturity of the common technological knowledge underlying the product. This issue is discussed in more detail in chapter 2.

and process architectures. Here I will comment briefly on the underlying assumptions and wider connotations of the concept.

Management scholars and practitioners are increasingly applying the concept of architecture. It can be seen as a reaction to earlier theories that often neglected the role of managerial planning and action. For example, the evolutionary strand of economics theory emphasised the “blindness” and “myopia” of actors making economic choices, and institutional theory and population ecology theory stressed the importance of external, macro level factors rather than purposeful organisational adaptation. The notion of architecture endows organisational actors with both foresight and motivation. It sees organisational actors as being able to improve organisational functioning in response to anticipated external demands and also to *improve their own processes* for generating and selecting solutions. This recursive process of purposefully changing the structures at many levels of a complex system is what differentiates organisational evolution from the evolution of biological systems (Baldwin & Clark, 2000).

Gerstein (1992) reviewed the history of architecture and asked what lessons we could learn from physical architecture that would help us to design more effective organisations. A key element is *primacy of purpose*. Architecture is defined as the art and science of creating structures whose function fulfil an intended purpose. Similarly, one can view organisational architecture as the conceptual design of key processes intended to deliver the firm’s strategic intent. In other words, the process of organisation design must start with a fundamental understanding the purposes to be served by the organisation.

Architecture is *future oriented*. The architect’s building “should preferably be ahead of its time when planned so that it will be in keeping with the times as long as it stands” (Rasmussen, 1991, cited in Gerstein, 1992, p. 14-15). One way of making organisational architectures future-oriented is to create “generative” platforms, that is, architectures that allow the firm to develop and grow by generating an infinite set of processes by replicating, scaling and reconfiguring a finite set of basic architectural elements.

Gerstein (1992) noted that physical architecture provides a framework rather than a rigid blueprint for the conduct of life. Architectures should facilitate, guide and provide context for individual action. Historically, this has been a key challenge for organisation design, which has oscillated between overly deterministic and overly indeterministic approaches. More recent theorising recognises the role of individual autonomy and improvisation but also sees a role for strategic foresight and planning (Sanchez & Mahoney, 1997). A new set of design concepts is emerging that provides a language for addressing the seeming contradiction of designing for autonomous action (Levinthal & Warglien, 1999).

Finally, architectures represent *unifying and coherent* structures (McDavid, 1999). A manager seeking to design a more flexible organisation must take into account systemic interdependencies that exist between technologies, work processes, knowledge assets, and formal organisational structures. An organisational architecture should therefore be as complete as possible and provide a conceptual framework for speaking about multiple system elements and how they interrelate.

Some recent academic and popular writing has proposed the use of *modular architectures* as an important strategy for increasing flexibility and dynamic capabilities (Sanchez, 1995; Pine 1993). This concept has been applied at different levels of analysis. Academics in the field of technology management have focused on the advantages of modular product architectures (e.g., Meyer & Lehnerd, 1997; Sanchez & Mahoney, 1996; Baldwin & Clark, 2000). Pine & Pietrocini (1993) discussed the notion of mass customisation and presented a case of Bally Engineered Structures, a producer of coolers, freezers, and refrigerator warehouses. They described how this firm's basic building block - a modular insulating panel - could be assembled into an almost limitless number of end products.

The modularity concept has also been applied to the design of business processes (Sanchez & Mahoney, 1996; Van Alstyne, 1997; Malone et al., 1997) and to overall organisational configurations. As I argue in chapter 2, a key factor is increasing *reconfigurability*. In describing the role of professionals in knowledge-intensive, team-based

organisations, Sørensen (1995) drew an analogy with chemistry by characterising such professionals as *polyvalent*. Polyvalent substances have the ability to link to many different types of atoms or molecules. Similarly, polyvalent professionals must be able to bind temporarily to a project team consisting of other specialists, some of whom have different backgrounds and expertise, and then un-bind and move on to the next project team.

Modularity has also been used to explain the notion of “lean enterprises”. For example, Fortune magazine stated a few years ago that modularity was the secret behind success stories such as Dell Computer:

In a leap of industrial evolution, many companies are shunning vertical integration for a lean, nimble structure (...). The new breed (...) are exciting hubs surrounded by networks of the world's best suppliers. Those manufacturing service units are modular: They can be added or taken away with the flexibility of switching parts in a child's Lego set (Tully, 1993, p. 52).

In sum, the main question addressed in this research is the role of modular product and process architectures in increasing dynamic capabilities. Although these concepts are central to much current theorising, managers frequently struggle with the implementation of modular systems (e.g., Marsh, 1997). Leading scholars on their hand disagree over the strategic benefits the modular systems might confer to the firm (e.g., McGrath, 1998; Galunic & Rodan; 1998). In other words, research that casts lights on these problems should be able to contribute to both theory and practice in a field of vital importance to the competitiveness of large firms.

1.3 CHOICE OF INDUSTRY

The research question is primarily pursued within the context of the home appliances industry. The home appliances industry has received relatively little attention from management scholars⁷. The industry is sometimes perceived as mature, conservative, and rather unexciting, a sentiment shared even by some industry insiders. When I first contacted Electrolux in connection with the case study (Chapter 4), the vice president of technology was surprised to hear that they might be doing anything worth an academic study. However, simply for the reason that the industry is less often studied than software, internet and telecommunications, it is interesting to ask whether the same principles apply to the home appliances industry as to these supposedly more dynamic industries. This issue is also of some theoretical import since new theories of strategic management are frequently proclaimed to be universally valid across different industries without qualification.

There are several factors that indicate that the home appliances industry is a relevant domain to study strategic flexibility. Considering the product models as the level of analysis, we observe that the pattern of product evolution in home appliances conforms to the “dynamic” pattern identified by Sanderson & Uzumeri (1997). That is, manufacturers offer a *high variety* of models (usually hundreds or thousands of different models) and frequently introduce *new variants* that gradually replace the existing models. Baden-Fuller & Stopford (1991) found that the number of washing machine models in Europe increased from 52 to 201 between 1976 and 1987. The number of models per brand increased from 2.4 to 5.6. Industry

⁷ Four valuable exceptions: Baden-Fuller & Stopfords (1991) study of strategies among European white goods manufacturers; Ulrich & Pearson’s (1998) analysis of the impact of product design on manufacturing cost of coffee machines; the case study of the development of the Braun coffee machine conducted by the Design Management Institute and included in Clark & Wheelwright (1993); and the recent doctoral work by Maurizo Sobrero (1995; 1999).

insiders⁸ estimate that the time from conceptual design to production has been halved during the last 10-15 years.

The periodic introduction of new technologies, the re-definition of market segments and the introduction of new sales and distribution channels (e.g., internet) lead to the typical pattern of rivalry observed in dynamic industries (McGrath, Chen, & Macmillan, 1998): one competitive move is followed by a countermove, as when a lead firm introduces a product aimed at a new segments, forcing the followers to consider whether to imitate the strategy or not. Whether to be first mover, or whether to *follow* a first mover are difficult choices because entering a new segment or developing a new product requires considerable investment, which may divert resources from the firms' core areas, and the newness of the product or market means that the payoff from the investment is highly uncertain (Mitchell & Singh, 1993).

Another indication of industry dynamism is the level of "disaggregation" of vertically integrated companies (Zenger & Hesterly, 1997). Disaggregation has probably proceeded more slowly in home appliances than other industries. However, some companies now outsource the development and manufacturing of many (in some cases all) components to suppliers. There is also an increasing use of suppliers and third parties in research and development of advanced components such as filters and electronic circuit boards. Each firm's critical resources thus increasingly reside in interfirm relations and routines (cf. Dyer & Singh, 1998; Lorenzi & Lipparini, 1999).

Although still dominated by large and global firms, some small companies and new entrants have been able to compete in some national markets as well as in global niches by exploiting innovative product design, re-interpeting conventional beliefs about customer preferences, and relying on extensive subcontracting of non-core activities. For example, the best selling vacuum cleaner in the U.K. is not produced by any of the large and mature firms, but by Dyson Appliances (see chapter 5), a company founded in 1991 with less than 700

⁸ Product engineers at Panasonic and Electrolux' plants.

employees⁹ compared to Electrolux' 6500. Norfrost, a company located in Northern Scotland that employs 500 people, is a world leader in making small chest freezers, and recently introduced a family of mini tumble dryers that are highly energy efficient (Marsh, 1998). In other words, the large and mature companies are being challenged by small, innovative firms, and their strategies for responding to this increased level of competition forms a key part of this research.

Nevertheless, there are some elements that may differ between home appliances and other (particularly more high tech) industries. Appliances are usually stand-alone products, whereas products such as computers, mobile telephones and video recorders form part of an open system and therefore need to be compatible with other parts in order to work properly. Technical standards ensure that computers can transfer data to each other (e.g., ICP protocols), that mobile telephone networks can link up with each other (e.g., GSM), and that video recorders can be connected to TV's (e.g., VHS). In such markets, compatibility and industry standards are major sources of competitive advantage as customers want to connect to other products or transfer data between them (e.g., to use palmtops in concert with PC's) and want to get access to supplementary products such as software. In contrast, home appliances are closed systems in that they are bought as separate entities. Until now, nobody has been concerned about whether the vacuum cleaner in the house is compatible with the washing machine or not. However, in the long term this situation is bound to change as appliances are connected to each other and with the internet. For example, at recent industry conventions, manufacturers have displayed prototype appliances that self-diagnose for faults and send requests via the Internet to the nearest service centre if a technician is needed

Although I have not seen studies comparing the absolute or relative pace of change in different industries, it is reasonable to assume that the pace of change is somewhat lower in home appliances than in the most hypercompetitive industries. Customer preferences,

⁹ This Dyson figure is for the time of the study, i.e., 1997. The Electrolux figure is for the Floor Care Division globally. As will be explained in chapter 4, Dyson Appliances is only making inroads into one of several segments that Electrolux competes in.

although highly diverse across different countries, are relatively stable over time (but not static or unalterable). Similarly, product architectures usually undergo only incremental improvement, such as incorporation of electronics in washing machines. There have been few radical shifts: motorised washing machines were developed early in this century; manual washing machines using some of the same mechanical principles existed even in the 19th century¹⁰. Contrast this with the relatively frequent technological shifts and dramatic company transformations in the telecommunications sector. Nokia is a case in point. Only 15 years ago, its main products were toilet paper and rubber boots. Today it is the global market leader in mobile telephone equipment (Autio, 1997).

By focusing on flexibility in the home appliances industry, one should therefore be aware that the findings may not be applicable to transformative change involving fundamental shifts in underlying competencies. However, the results may be applicable to other dynamic (non-network) industries, characterised by frequent, incremental change¹¹. This focus was deliberately chosen and informed by observations that I made in different industries while working for Accenture (previously Andersen Consulting) prior to commencing my doctoral studies in 1996. I observed that innovation (i.e., the conceptualisation, development and production of new products, processes, or services) frequently was a “programmed” activity, anchored in strategic plans and supported by formal working arrangements (designated projects, budgets, etc.) and subject to managerial supervision and monitoring. This contrasted with the main thrust of academic research at the time, which tended to portray innovation as an illegitimate activity (e.g., Dougherty, 1992) necessitating champions with considerable influencing skills (e.g., Howell & Higgins, 1991) and often occurring at the fringes of the organisation (e.g., Kanter, 1983). It is clear that radical change may occur in this way, and that the *initial strategic agenda building* (Dutton, 1988) for all types of change may involve political activity; yet these aspects did not conform very well to the types of change that I

¹⁰ This can be observed by visiting the home appliances section of London’s technical museum.

¹¹ This use of terms is consistent with that of Sanchez (personal communication, February 20, 1999), who distinguishes between dynamic and transformational market environments.

observed every day as a consultant, and the literature provided little guidance on how to facilitate the more continuous and incremental types of innovation. Luckily, during the last four or five years the emphasis in academic research has shifted, and I was able to draw on a relatively large body of relevant literature.

1.4 STRUCTURE OF THESIS

This dissertation is structured as three semi-independent papers, plus this introductory chapter, the literature review, and a chapter on methodology. The literature review defines the concept of modular architecture and discusses how it relates to key antecedents within organisation theory. The three papers that follow make use of different methodological approaches. Chapter 4 presents the results from three case studies. The purpose of the case studies was to “ground” the research in a concrete industry setting, to test the relevance of modular concepts in the home appliances industry, and better understand the nature of dynamic capabilities in this industry. Chapter 5 contains the results from a survey questionnaire study employing a more traditional, deductive methodology. The survey study examines the linkages between market context, degree of modularity in products and processes, and financial performance. Finally, there is one conceptual paper - chapter 6 - that seeks to extend current modularity theory to the organisational design. A summary of the research questions and deliverables for each chapter is presented in Table 1.1.

Table 1.1. Summary of research questions and deliverables

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Research question	How is the concept of modular architecture defined, and how does it differ from related concepts? What are the key antecedents to current theories of modular systems? What are the main theoretical perspectives regarding strategic flexibility and modular systems, and where are there gaps in our understanding?	What is the appropriate methodology given the objectives for this research project?	In home appliances, what are typical competitive challenges for established and new companies? To what extent have leading firms in the home appliances industry adopted modularity in response to these? What are the most important barriers for implementing modular architectures in “mature” industries?	What is the relationship between market context, modularity, strategic flexibility, and firm performance?	How can the concept of organisational modularity be operationalised? How can modularity be applied to increase flexibility of organisational structures and processes?
Main deliverable(s)	Summary of extant theorising Discussion key antecedents to current theories An agenda for research	Statement of methodological approach	Case evidence of implementation barriers Identification of some strategic implications	Statistical model	Framework for organisational modularity Proposed extensions of existing theories
Design and data	Literature review	Review of literature and discussion of chosen approach	Semi-structured interviews with managers Review of publicly available industry and company information	Survey questionnaire	Theoretical development
Principal analytical technique	Analytical framing, analysis, and synthesis	Analytical framing, analysis, and synthesis	Case analysis and grounded theory building	Statistical analysis (structural equations modelling)	Analytical framing, analysis, and synthesis

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2 LITERATURE REVIEW

This chapter reviews the academic literature relevant to the two key research questions formulated in chapter 1 concerning the role of modular product and process architectures in enhancing dynamic capabilities of large firms.

The chapter is divided into four sections:

- The first section describes some important historical antecedents to current theories of modular systems. It contains five sub-sections, each of which ends with a section summary and discussion.
- The second section reviews current work related to modularity and dynamic capabilities. It contains four sub-sections, each covering literature in one sub-discipline of management studies: technology management, software development processes, finance and accounting, and organisation design and learning. All of these sub-sections also contain sub-section summaries/discussions.
- The third section derives a definition of modular architectures from current theories and then contrasts modularity with related concepts such as near decomposability, vertical decomposition, loose coupling, and bundling/unbundling.
- The fourth and last section refers to current debates on the value of modularity and identifies areas where more work is needed. This section also concludes the chapter by defining an agenda for research.

As this literature review will survey a broad set of theories, it is not possible to do justice to the work done by any one theorist or group of theorists, particularly where their contribution is of more ancillary nature to the main issues at hand. The purpose was not to provide an exhaustive analysis of each theoretical perspective, but rather to summarise its main aspects, consider how it

sheds light on the research questions that have been formulated, and point out where there exists gaps in our understanding that this and other research may begin to fill.

2.1 ANTECEDENTS

As explained in Chapter 1, the key theoretical motivation for this research was to explore the relationship between modularity and strategic flexibility. Although these concepts are fairly recent, they build on preceding theory that should be acknowledged. As I will show, preceding theories have in many cases been integrated into or extended by current frameworks, but there also cases where the current frameworks represent sharp departures from previous theorizing.

Five frequently cited theorists are Herbert A. Simon, Friederik Hayek, J. D. Thompson, Karl Weick and Oliver Williamson, whose work has been particularly influential in the field that I am investigating. In the following section I provide a brief review of the contribution of each of these theorists. Note that I return to some of these theorists in section 3 below: After having described current research and derived a definition of modularity, I make explicit the similarities and differences between the concepts they introduced and the definition of modularity used in this research.

2.1.1 Simon's theory of nearly decomposable systems

In a 1962 essay, Herbert A. Simon sought to contribute to the development of a general systems theory that would be relevant to number of complex systems - including social, biological, and physical. Systems that are "complex" are made up of a large number of parts that interact and are interdependent to some degree. One aspect of complexity as defined by Simon is hierarchy, which means that the system is composed of subsystems that in turn have their own subsystems, until one reaches some elementary level. He notes that it is somewhat arbitrary where one leaves

off the partitioning - for the purposes of doing biological research, a cell may be treated as the elementary subsystem, whereas in biochemistry, it may be the protein molecule. Words might be the elementary units for an author, whereas for a linguist, they may be smaller units such as prefixes, word stems, etc.

Simon was particularly interested in explaining the evolution from simple to more complex hierarchies. He posited that the time required for evolution was critically dependent upon the existence of relatively stable intermediate forms, which he called “subassemblies”. In biological systems, subassemblies may be amino acids that gradually evolve into proteins. In a social system, subassemblies may be groups of individuals who combine to form communities. The basic function of subassemblies is to make the system better able to cope with unexpected environmental change. Disruptions are likely to affect only a few elements, and rebuilding the disrupted parts of the system will consume less time and effort if subassemblies - the building blocks - already exist.

Simon (1962) defined a *nearly decomposable system* as one in which the interactions among subsystems are weak (but not necessarily non-existent). In such a system, the short-term behaviour of each of the subsystems is relatively independent of the short-term behaviour of other subsystems. Additionally, in the long term the behaviour of any one of the subsystems depends only in an aggregate way on the behaviour of the other subsystems. For example, when studying two large molecules, we generally do not need to consider the interaction of nuclei of the atoms belonging to one molecule with the nuclei of the atoms belonging to the other.

Inspired by matrix algebra, Simon conceived of the idea of presenting a nearly decomposable system as a matrix of interactions. He used the example of heat transfer between different cubicles and rooms in an office building. The walls between the rooms are the boundaries of the major subsystems. Each room is divided by partitions into a number of cubicles, but unlike the walls the cubicles are poor insulators. Consider the case where there is at

some point a wide variation in temperature from one cubicle to another. If one takes a reading several hours later, one would find very little variation among the cubicles in a given room, but there may still be significant temperature variations among rooms. In other words, each room reaches an equilibrium temperature (an average of the temperature of its cubicles) nearly independently of the others. We would obtain a pattern similar to that in figure 2.1, which shows a *nearly decomposable matrix*¹².

	A1	A2	A3	B1	B2	C1	C2	C3
A1	x	100		2				
A2	100	x	100	2	1			
A3		100	x		2			
B1				x	100	2	1	
B2				100	x		1	2
C1				2		x	100	
C2				1	1	100	x	100
C3					2		100	x

Figure 2.1. A hypothetical nearly decomposable system illustrating the heat transfer example in the text. A1, A2, and A3 may be interpreted as cubicles within on room, B1 and B2 as cubicles in a second room and C1, C2, and C3 as cubicles in a third (source: Simon, 1962, p. 212).

2.1.1.1 Sub-section summary and discussion

Contemporary scholars studying modular systems have stayed true to Simon’s intent of developing a “general systems theory”, but have pushed the concept in a more normative direction. Specifically, they see modularity as a potential characteristic of nearly decomposable

¹² Nearly decomposable systems are composed of only a few kinds of subsystems that produce variety from being combined in different ways. Simon (1962) made the additional observation that this property allows one to construct *a simple description of a complex system*. A structure that has some redundancy, i.e.,

systems that contributes to higher degrees of system flexibility (see detailed discussion in section 3 below). If the concept of near decomposability can be applied at different levels of analysis, including technical, cognitive and sociological (cf. Miller, 1978), then the same general principles may also be applied in order to increase the flexibility of different types of systems. In addition to being a principle that applies across levels of analysis, there are also effects that *cross* levels of analysis. For example, a cross-level effect observed by Sanchez (1995) was the enabling effect of modularity in technological systems upon the modularity of organisational structures and processes.

Apart from the philosophical arguments advanced by Simon he also influenced practical aspects of studying and managing interdependencies. The idea of using a matrix to represent interdependencies was later adopted by some scholars and practitioners. Stewart (1981) presented a variation that is called the Design Structure Matrix or Dependency Structure Matrix (DSM), where each element represents a design parameter for a product or a task in a work process. The DSM is used to suggest better ways of decomposing the product and process structure.

In conclusion, Simon's (1962) essay on complex systems has been highly influential in organisation theory and management, and has also been the starting point for many theories on modular systems (e.g., Sanchez & Mahoney, 1996; Schilling, 2000). However, one should note the relative brevity of his contribution (a single essay)¹³. Simon did not consider the concept in the product design context nor did he discuss the potential pragmatic validity (Warren & Moore, in review) of using the concept in a more normative fashion. As I will discuss in more detail in section 3 below, current work on modularity extends the basic idea of decomposable systems by

contains several elements where some occur several times, can be represented in a matrix and reduced to one or more vectors.

¹³ Much of Simon's later work on human problem solving was based on the same general idea (i.e., hierarchization of problems) but did not, to the best of my knowledge, advance the basic thesis of near decomposability any further.

incorporating it into managerial and strategic frameworks for managing in dynamic environments.

2.1.2 Hayek's discussion of "spontaneous order"

Friedrich von Hayek was a member of the so-called Austrian school of scholars, which is known for its opposition to traditional economics and its emphasis on entrepreneurial and dynamic processes. Hayek has been particularly influential in arguing for the efficiency of markets in coordinating dispersed economic activities. He started from the assumption that the "relevant knowledge" to solve complex problems is often only found in tacit form, distributed among large numbers of individuals (Hayek, 1936). He posed the question of how a number of people, each acting individually and possessing only partial knowledge, were able to achieve nearly optimal collective outcomes. Because the outcomes seem ordered and "rational", it is tempting to attribute them to the deliberate direction of somebody who possesses the combined knowledge of all the individuals involved. Yet for some types of collective action, there is no central authority involved, a phenomenon that Hayek referred to as "spontaneous order" - *human action without human design*. He pointed out that he is not discussing whether planning should be done or not, but whether it should be done centrally by one authority or divided among many individuals. In a famous essay, Hayek (1945) used allocation of resources as one example. Conventional economics assumed that this was mainly a problem of logic: Given certain resources, what is the efficient way of allocating them among different groups or individuals? Hayek felt that the theories of the day ignored the difficulty of conveying all the relevant knowledge from the field to enable central decision makers to make optimal decisions. Instead, he pointed to the benefits that individuals gain by being able to exploit their unique knowledge of people, local conditions and special circumstances. (Using current terminology we would call this type of knowledge tacit, contextual, or clinical in nature.) Hayek stated that the economic problem of society mainly

is one of rapid adaptation to changes in local conditions, which means that decisions must be left to people who are familiar with those circumstances. But he added that this is only part of the problem: The “man on the spot” cannot make his decisions solely on the basis of local knowledge and consequently needs information about the larger system to fit his decisions into a larger pattern. In studying resource allocation, he showed how the price system acts to co-ordinate the separate actions of different people. If a resource (say, a commodity) becomes more scarce, it is communicated through a higher price, signalling the need for decision makers to economize on the use of the resource or to switch to a different one, an effect that will spread rapidly throughout the world. The most significant fact of the system is the economy of knowledge with which it operates: individuals will be able to make decisions simply on the basis of a few symbols. Tens of thousands of people are made to use the resource more sparingly and thereby co-ordinate their utilization of the commodity, and this is achieved without detailed knowledge of the causes of the price shift, without any expert having calculated the correct price in local markets, or any central authority having planned how to implement the required changes in advance.

2.1.2.1 Sub-section summary and discussion

One should note that Hayek (1945) developed his approach as a theory of markets, rather than as a theory of firm organisation. Firms are not a market-like mode of organisation, yet they are confronted with some of the same challenges, such as how to co-ordinate disperse individuals possessing only partial knowledge (Sautet & Foss, 1998). Is it possible to imagine an institutional framework that would support both planned and spontaneous ordering within firms? Hayek (1973) later made the distinction between general rules and specific commands, and stated: “by guiding the actions of individuals by rules rather than by specific commands it is possible to make use of knowledge which nobody possesses as a whole” (pp. 48-49). By making the “high-frequency dynamic” of operating activities quasi-independent from the “low-frequency dynamics” of strategic planning (Williamson, 1985), one can imagine a system where a high-

level *planned architecture* may enable *spontaneous* adaptation to emerging market developments through variations and configurations of pre-existing resources. This is precisely the interpretation of modular systems offered in Sanchez & Mahoney (1997), who see modularity as a concept offering a conceptual fusion of intended and emergent strategies. An architecture in this case may perform some of the same co-ordinating function that the price mechanism does in the market. Just like the price mechanism, it contains a standard interface that allows module to co-ordinate with each other without communicating large volumes of information¹⁴ (Langlois, 1999).

Hayek's (1945) interest in spontaneous order is echoed in much of the current work within complexity theory. As described by Holland (1995) the key motivation for developing complexity theory was to gain a better understanding of how coherence (i.e., order) emerges in systems consisting of independent but interacting agents. The systems considered by complexity theorists include economies consisting of economic actors (buyers, sellers, intermediaries, etc.), ecosystems consisting of different organisms and their environments, and biological and chemical systems such as the human immune system consisting of antibodies and antigens. Scholars in this field have added much rigour to the analysis of spontaneous ordering by being able to simulate computationally how complex systems adapt.

In sum, key aspects of Hayek's argument have been adopted by current scholars, who have extended his work in different directions. One should note, though, that most current theorists see adaptation in an organisational context as depending on a combination of (central) planning and local adaptation. In the absence of established architectures (i.e., documented interfaces), trial-and-error processes will typically lead to the creation of non-modular systems (Langlois, 1999). Whereas the price system already exists in the market system, similar mechanisms will first need to be intentionally created to enable co-ordination within

¹⁴ Standard interfaces within a modular architecture are designed based on the principle of "information hiding", which is similar to the "economy of knowledge" principle described by Hayek (see section 2.2.2 below).

organisations. I will discuss this issue in more detail in chapter 4, which considers modularity in the context of organisation design.

2.1.3 Weick's theory of loosely coupled systems

Rational assumptions of organizational functioning rely on such concepts as analysis of costs and benefits, exercise of authority, and implementation of preconceived plans. Karl Weick (1976) wanted to counter the prevailing tendency of providing highly rational pictures of how organizations work. In particular, Weick thought that applying these assumptions would render the nature of educational institutions incomprehensible. (March & Olsen (1976) had characterised educational institutions as “organised anarchies”.) As an alternative, he proposed the concept of loose coupling. As March & Olsen, Weick developed his concept by observing decision making processes in educational institutions.

By loose coupling, he intended to convey the image of events that are responsive to some degree yet preserve some of their own identity and some evidence of their physical and logical separateness (Weick, 1976, p. 3). He provided the example of a counsellor's office in a school, which may be loosely coupled to the principal's office. They are somewhat attached, but retain enough separateness that their attachment may be circumscribed, infrequent, weak, or slow to respond. He suggested that one can use the concept for a variety of situations. For example, one can think of loose coupling in terms of intentions and actions; he noted that planning is often loosely coupled with subsequent action that may be intended to implement the plan. He suggested that with this concept in mind, administrators would be less baffled “when things never happen the way they were supposed to” (Weick, 1976, p. 4).

Loosely coupled systems are ambiguous and fleeting structures and Weick (1976) consequently saw interdependencies as being largely subjectively construed. “There is a rather barren structure that can be observed, reported on, and retrospected on in order to make any

sense” (p. 11). Co-ordination is thus seen as a process of social action rather than as a structure (Dougherty, 1998). Co-ordination between organisational members does not rely on rules or plans but on a process of continuous, mutual adjustment, supported by interpretations and sense-making of how the elements of their system inter-relate (Weick & Roberts, 1993). Although particular events may be largely unpredictable, people who work collectively construct their own actions while envisaging representations of the actions of others. If they do so actively, it may enable “heedful interrelations” where they notice and respond to events, however unexpected they may be.

Weick also considered the potential benefits and liabilities of having loosely coupled systems. If all the elements of a large system are loosely coupled to each other, then any one element should be able to adjust and modify its behaviour in accordance with local circumstances, without affecting the whole system. Moreover, if there is a breakdown in one portion of the system, then this breakdown can be sealed off so as not to affect other portions of the system. On the other hand, if a defective portion only weakly influences the functioning portions, then influence back from these functioning portions will also be weak; making repair of defective elements difficult. Weick also pointed out that if some elements of the system come up with novel and advantageous solutions, it may be difficult to diffuse these solutions to other parts of the system.

2.1.3.1 Sub-section summary and evaluation

The term “loose coupling” has been adopted by many management scholars, including those studying modular systems. Yet the theoretical framework proposed by Weick is controversial. Lutz (1982) pointed to problems with the definition of the concept, the underlying assumptions, and the selection of cases to illustrate loose coupling in educational institutions.

Some have questioned whether educational institutions really consist of loosely coupled elements. Closer inspection reveals that educational institutions in fact have a number of tightly coupled elements, such as rigid and bureaucratic regulations for certifying teachers, for dealing with student grievances, or for grading student performance. Those aspects of university functioning that Weick called loosely coupled, Lutz (1982) characterised as completely *uncoupled*. For example, it is common to observe educational institutions where there is no feedback loop attaching administrative behaviour to the outcomes of the original goals. As stated by Lutz (1982) “If a subsystem is allowed to be unaccountable to the total system, it can selectively ignore messages sent from other subsystems when it chooses” (p. 667).

A limitation of the loose coupling concept is its ambiguity. Some years after the concept was introduced, Orton & Weick (1990) surveyed the literature and found a multitude of idiosyncratic interpretations: a) Some scholars had used the concept to describe causal uncertainty, i.e. unclear means-ends connections (due to selective perceptions, bounded rationality, etc.); b) Others had used it as a typology, i.e., to categorise organisations that have relatively independent sub-units or hierarchical levels, etc. c) Then there were scholars who had used loose coupling to describe gaps between activities, between intentions and actions, or between goals and decisions¹⁵. It is primarily the latter interpretation that has received criticism. The loose coupling literature typically portrays administrators as having little authority and their decisions as being relatively independent of the implementation of pre-defined institutional objectives. Critics see this as a way of explaining away responsibility and accountability for failing to achieve goals.

Argyris (1996) pointed out that descriptive models often have normative consequences in that they serve to reinforce the status quo. Descriptive models may provide a rationale for maintaining dysfunctional practices. Indeed, Lutz (1982) argued that many scholars (and

university administrators) had interpreted Weick's description of educational institutions in a normative way:

If it is true that a university is inherently organized in such a manner and would not be a university if organised otherwise, then we must learn to live with the problems suggested by [the model]. If it is not true, if loose coupling is merely an empirical description of some things that could be changed without damage to academe, then perhaps we should get out of the garbage can! (Lutz, 1982, p. 653).

Lutz (1982) further argued that Weick had failed to provide any empirical support for his ideas, other than brief observations and anecdotes. He also questioned the idea that loose coupling leads to higher adaptability, and proposed that tight coupling may be a better strategy if an organization is seeking to enhance its adaptive capacity. Scholars looking at governance of educational institutions from a normative perspective seem to agree with this argument. For example, many of the reform proposals put forth in the recent book on university governance by Burton Clark (1998) imply *tighter* coupling: Clark recommends strengthening the authority of central administrators; creating stronger external linkages (to business and industry); and improving co-ordination between different departments.

My overall impression is that the loose coupling literature has had rather minor influence on current theories of modular systems. In fact, the underlying assumptions of irrationality, improvisation and sense-making are in many ways orthogonal to the assumptions underlying current theories of modular systems. It is unclear what role Weick (1976) sees for management, if any. He observed the phenomenon that loosely coupled "events" somehow assemble themselves into a system that performs a task for somebody, but he does not provide any explanation for how

¹⁵ Orton & Weick (1990) listed many more interpretations, which they group into five classes. I only

this can happen, or who makes it happen, and instead offers it as a research question for other to pursue (p. 14). Loose coupling was not originally intended as a normative concept (Weick 1976, p. 6). Consequently, if one applies interpretation (c) above I find the concept useful only for describing *existing* reality in many complex organisations. Theories of modular systems (e.g., Sanchez, 1995) are in contrast normative and “architectural” frameworks that propose modularity as a managerial strategy for increasing organisational adaptability. As I will show below (section 3) this leads to a set of propositions that differs sharply from those in Weick (1976).

Although some modularity scholars have adopted the term loose coupling, one should keep in mind that they probably use it only in sense (b) defined above, referring to relationships between different sub-units of a system (e.g., Sanchez & Mahoney, 1996)¹⁶. Some product development scholars also use the term loose coupling, but in a straightforward, technical manner to describe component interfaces, without any of the philosophical connotations of Weick’s framework. For example, Ulrich & Eppinger (1995) used the concept to indicate whether a physical component can easily be substituted with another component (i.e., whether it has a standard interface). They characterised a component as loosely coupled if it could be easily substituted and as coupled if it could not be easily substituted¹⁷. This is also the way I will apply the concept in the remainder of this thesis.

2.1.4 Williamson’s description of the multi-divisional firm

The main assumptions in the “institutional economics” framework developed by Oliver Williamson (1975; 1985) derive from the early work by Coase (1937). Coase argued that transactions should be the key unit of analysis and that firms exist to economize on transaction

mention a few of these here to show the diversity in the literature.

¹⁶ Given the ambiguity of the loose coupling concept, I would argue that it is slightly confusing when modularity scholars refer to it without specifying which of the key dimensions they are thinking about.

¹⁷ In this thesis I refer to this characteristic as a “standard interface”.

costs, which are the costs associated with economic exchange, such information gathering, bargaining, contract writing, and follow up/ monitoring. One of the main contributions of Williamson has been to explain how transaction costs leads to “internalization” - that is, specifying when transactions are going to be gathered within the boundaries within a firm rather than in the market. He contends that there are three key factors leading to internalization: 1) uncertainty about outcomes that are difficult to convey by market prices (e.g., uncertainty related to product quality, reliability, delivery), 2) recurrency (i.e., when the transaction occurs frequently between buyer and seller), and 3) asset specificity (i.e., when investments of time and money are required, which are idiosyncratic to the particular transaction, and thus binds seller and buyer). When transactions exhibit these characteristics, they are more likely to move from markets to firms. Whereas market transactions are governed through the price mechanism or through explicit, complete contracts, transactions in firms are governed through “incomplete” contracts such as the employment agreement (which is incomplete because it does not specify all contingencies that may occur and leave many details to be elaborated later, when necessary). Firms are also characterized by the existence of formal authority, which acts as a curb against opportunism, which is another concept of central importance to Williamson. Opportunism is a potential problem when incomplete contracts substitute for complete contracts. But pay, promotion and control systems make sure that organisational participants work toward common goals and that conflicts can be handled by resorting to formal authority¹⁸.

From a time where transactions were primarily conducted in markets, more ramified forms of organizations gradually evolved. The first form was simple peer groups of workers, then came simple hierarchies. As described in Chandler (1962), the (usually single-product) “U-form” enterprise emerged toward the late 1800’s, decomposed along functional lines with departments

¹⁸ Williamson (1975) used the term hierarchy to describe a system where each level has greater degrees of formal authority than its subordinate levels. Note that Simon (1962) used the term hierarchy for all

for sales, finance, manufacturing, etc. The U-form was a means of dealing with the increased complexity that resulted when simple hierarchies grew in size. It allowed economies of scale in that similar activities were grouped together in the same division, and lessened administrative load as functional managers could concentrate on a more limited set of responsibilities. It also created a host of problems, however, which became more evident as these enterprises continued to grow. One tendency was for functional managers to favour their functional perspective instead of enterprise-wide goals, resulting in sub-optimisation. The adding of more staff resulted in more levels of the hierarchy, which made information flows less efficient and subject to deliberate distortion. Williamson and Chandler also noted a lack of separation between strategic and operational responsibilities. Operational decisions were forced to the top, creating a great communication load. Senior executives thus became engrossed in operational details and lost sight of broader strategic issues.

The multi-divisional (M-form) was first adopted by DuPont Company and General Motors in the early 1920's. It substituted quasi-autonomous operating divisions for the functional divisions of the U-form as the key basis for dividing up tasks and assigning responsibility¹⁹ (Williamson, 1975). These divisions could be organised along brand, product, or geographic lines. Two important elements of this organisational innovation were: 1) operational and strategic activities were more explicitly separated, with a staff function supporting senior executives in the overall tasks for allocating and acquiring resources; and 2) responsibility for operational decisions was assigned to essentially self-contained operating divisions.

Williamson (1975) holds that *internal* organisation can be explained by basically the same principles as the market versus hierarchy issue. Thus the M-form is deemed superior in that it economises on internal transaction costs and attenuates opportunism. In examining how

complex systems, consequently in his work the term does not imply the existence of formal authority relations.

¹⁹ However, in many cases, each division was subsequently divided along functional lines.

different activities are organised at a more detailed level, he similarly places the main emphasis on accountability (ability of general management to maintain internal control and monitor performance) and transactional relations (in the latter concept he includes needs for on-going coordination among sub-units). For example, grouping a set of tasks within a work group is efficient if the employees are engaged in recurring exchanges under conditions of uncertainty. The marketing function might be integrated within a division if it requires a high degree of coordination with preceding stages of production. Williamson also mentioned economies of scale as an important grouping criterion. If a firm produces several products, all of which shares a common first production stage, economies of scale may warrant the consolidation of the process in one centre, to be handled by a separate division. Plants using different production processes would normally be split off in different divisions, unless they manufacture products that are complements that require joint marketing. Divisions are normally profit centres, but a division handling an early stage of a production process might be a cost centre, assessed on least cost rather than net revenue²⁰.

2.1.4.1 Sub-section summary and critique

Schilling (2000) drew on transaction cost economics (TCE) in explaining how modularity may reduce the need for vertical integration. She argued that modularity, through standard interfaces, decreases asset specificity, and thereby transaction costs (i.e., search, monitoring, and enforcement costs associated with the transaction). A standard interface makes assets less specific, in that they can be combined with many more components (and usually, components from many more suppliers) than interfaces that are specific to a particular product model (or

²⁰ A profit centre would be in a monopoly situation and thus have incentives to charge high prices to the other divisions. A cost centre as described would instead transfer products at marginal cost to later stages of production.

firm). Interpreted in this way, TCE would predict a movement toward market-based exchanges with multiple partners as a result of increasing modularity.

Sutcliffe & Saheer (1998) studied how the decision to internalise is affected by different types of uncertainty. They conducted an experimental study with vignettes depicting a hypothetical situation where a firm had to decide whether to integrate or outsource parts of its operations. The results suggest that managers decide in favour of vertical integration when the source of uncertainty is proximate and controllable, such as uncertainty regarding possible opportunism on behalf of suppliers. This finding is consistent with Williamson's arguments. However, they found that managers are *less* likely to opt for vertical integration as the level of technological uncertainty increases. They concluded that in circumstances of rapid environmental change, maintaining strategic flexibility becomes the key concern. Managers therefore seek to reduce commitments by *limiting* the vertical scope of the firm.

Williamson's (1975) main interest was in explaining aggregation of transactions into ever larger firms. Now this trend has reversed and large corporations are being *disaggregated* into smaller, semi-independent units. Part of the reason may be that new manufacturing techniques have lowered the minimum efficient scale of operation. Zenger & Hesterly (1996) also point to innovations in organisation design, performance measurement/ monitoring and information technology. It used to be difficult to measure the performance of sub-units within organisations in an adequate way (e.g., simple measures like output volume were often used for factories). Improvements in cost accounting (e.g., activity based costing), IT-based control systems, and the introduction of benchmarking and quality management techniques have made it possible to measure the performance of smaller units on more performance dimensions (e.g., defect rates, customer satisfaction, costs) and compare the performance to other internal units as well as to outside firms. Sub-units such as teams are increasingly the basic building blocks of large organisations. The contributions of these sub-units may be "priced" and their employee incentives

more closely tied to sub-unit performance. Consequently, Zenger & Hesterly (1996) concluded that internal exchanges thus become more market-like. Vice versa, they also point to an “infusion” of hierarchical governance in market based exchanges, such as through the use of alliances. These may be supported by formal contracts that establish quasi-hierarchical governing mechanisms for employees belonging to different firms taking part in the alliance. The result is a *continuum* of governance choices, rather than a discrete option of market versus hierarchy that Williamson (1975) envisaged.

The transaction cost approach places its main emphasis on static efficiency (economising on transaction cost) rather than on adaptation to changing environments. It treats product structure as an exogenous variable, although Williamson briefly mentioned how different production processes may lead to different divisional decompositions²¹. The options that Williamson (1975) discussed in terms of decomposing an organisation (mainly functional versus divisional) now seem rather limited, considering the proliferation of new organisational forms, supported by new information technologies. Consequently, this approach is of limited relevance to the two research questions pursued here. Yet, as the above examples show, TCE may be used for understanding related issues, such as the diffusion of modular organisational forms, the relative flexibility of markets versus hierarchies, and the broader transactional implications of increasing product and process modularity²².

2.1.5 Thompson’s framework of modes of co-ordination

Thompson’s 1967 book “Organizations in Action” provided a foundation for understanding key contingencies affecting organisation design. It showed how a firm’s internal organisation

²¹ Yet Williamson rejected the notion that technological interdependencies determine governance forms. In his treatment it is always the nature of the transaction involved that is the determining factor for organisational design.

²² Langlois (1999) also explored connections between transaction cost theory and modularity.

reflected the underlying production technology as well as the need for absorbing uncertainty in the external environment of the firm. The book was particularly influential in proposing interdependency as a key factor affecting organisational structure. Thompson defined interdependency²³ as “the extent to which a task requires organisational units to engage in work flow exchanges of products, information and/or resources and where actions of one unit affect the actions and work outcomes in another unit” (p. 54). Thompson (1967) further distinguished between three kinds of interdependence that can exist in an organisation (see figures 2.2 - 2.4): pooled, sequential, and reciprocal.

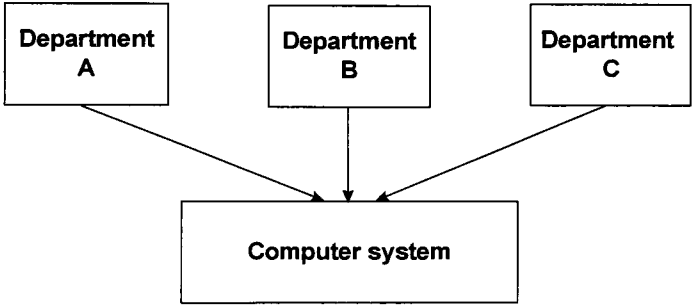


Figure 2.2. Pooled interdependence

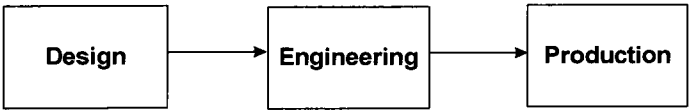


Figure 2.3. Sequential interdependence.

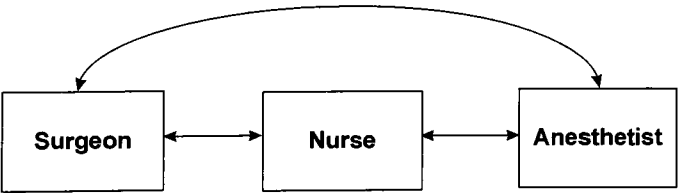


Figure 2.4. Reciprocal interdependence.

²³ This definition deals with *internal* interdependence. As pointed out in Staudenmayer (1997), Thompson

Pooled interdependence denotes situations in which “each part renders a discrete contribution to the whole, and each is supported by the whole (p. 54). Typically it involves otherwise independent units or activities that either make use of or produce a common resource, for example, three departments sharing a computer network. Pooled interdependence is considered least costly in terms of communication and decision effort because it does not require any serial ordering of activities, and predetermined rules and standards may be used to manage the performance of the activity or resource that the units are sharing. *Sequential interdependence* is used to describe a relationship between activities that are distinct and serially ordered. One activity depends on another activity’s outputs before it can begin. Many work processes exhibit sequential interdependence. For example, in a product development process, the outputs of the conceptual design stage are the input for the detail engineering process, whose outputs in turn are inputs to the manufacturing process. Co-ordination usually requires scheduling and timing to make sure that work flows remain uninterrupted: If the first activity in a process is performed, the second must follow up to reach the overall target. Finally, *reciprocal interdependence* describes a two-way relationship. One group’s output may not only be another group’s input, but the reverse may also be the case, creating the need for joint problem solving while the task is being performed. An example would be the communication and mutual adjustment occurring between the medical specialists taking part in a hospital operation. Reciprocal interdependence imposes the highest co-ordination cost since no unit can accomplish its task without the active (and simultaneous) contribution from the other.

2.1.5.1 Sub-section summary and discussion

Thompson (1967) noted that multiple criteria can be used to decompose organisations. As a general proposition, however, he posited that organisations would attempt to organise units to

(1967) was less specific about organisation-environment interdependence.

minimise co-ordination costs. Because co-ordination by mutual adjustment is the most costly of the three, the first priority would thus be to minimise the use of this co-ordination mode by localising interactions and confine them to one or more semi-autonomous groups²⁴. This general view of interdependency management is one that is maintained in current theories of strategic flexibility and modularity. However, current theories also go beyond Thompson's framework in several respects. According to Thompson, standardisation (i.e., the establishment of rules and routines) requires situations that are stable, repetitive and few enough to permit matching of situations with the appropriate rules. For this reason, Thompson (1967) tended to see mutual adjustment as the more flexible coordination mechanism, and pooled interdependence, which relies on standardisation, as the least flexible. Later work has led to a broader understanding of the nature of standardisation and the ways it may be used. One of the key features of the modularity approach is the conceptual separation between architectures and their constituent elements (e.g., product components, work activities, or units). As I will discuss below in more detail, this work shows how some types of standardisation (e.g., of interfaces between units) in fact increases overall systems flexibility. Whereas Thompson only considered decomposition at a relatively high level (i.e., organisational decomposition) and seemed to view the basic task structure as a relatively static variable, more recent work treats task structure as a manipulatable variable (von Hippel, 1990). Consequently, re-design of tasks may provide new opportunities for changing the mode of co-ordination being employed. With reference to Thompson's typology, one can say that current theories predict that higher degrees of flexibility would result from decomposing product and process architectures in a way that facilitates *pooling* of shared resources and minimises *reciprocal and sequential interdependencies* across different units. It is necessary to apply a more fine-grained analysis of task interdependencies to show exactly how

²⁴ Stabell & Fjeldstad (1998) pointed out that different modes of co-ordination may in themselves be criteria for decomposition, because they relate to distinct logics for value creation. They also implied that there may be diseconomies associated with combining different value logics within the same unit.

this is accomplished. In section 2.2.1 below I describe the logic behind the so-called design structure matrix (DSM), which is a tool for representing interdependencies between tasks at a detailed level.

Thompson (1967) pointed out that organisational structures must be developed and maintained according to technological requirements yet at the same time be consistent with input and output requirements and the realities of the “task environment” (by which he meant customers, suppliers, and competitors). He noted that if the task environment should undergo change, organisational survival would depend on adaptive and directive action to adjust the organisation’s structure and systems. Finally, he pointed out that interdependence among units was embedded in the logic by which a firm (or unit) was creating value. Different rationales for value creation are associated with different levels and types of interdependence necessary for accomplishing the rationale (Gulati & Singh, 1998). Beyond these observations, however, he did not consider in much detail how a firm might gain advantage from *changing* its criteria for decomposition or co-ordination to implement a new or revised rationale for value creation. Some recent work incorporates a more dynamic and market-oriented perspective on interdependency management. I believe it is particularly useful to remind oneself of the distinction between “existing interdependence” and “potential interdependence”, i.e., between those interdependencies that exist today and those that *can or should* be developed to achieve competitive advantage²⁵ (Ensign, 1998). Scholars in strategy and economics have studied how multidivisional companies may create economies of scope among different businesses units by sharing or transferring assets, or by co-ordinating production processes to increase revenue or reduce risks (Foss & Iversen, 1997). For example, consider a multidivisional company that

²⁵ Scholars within the so-called sense-making perspective (see Staudenmeyer, 1997) have argued that interdependencies are not objectively given but subjectively construed. Even if one takes a less radical stance on this issue, one can probably agree that interdependencies to some extent depend on perceptions (both individual and shared) of interrelationships among different units, resources, etc. One implication of

traditionally has operated with a minimal degree of interdependence between several product divisions. It may be the case, however, that significant advantage could be achieved from creating *new interdependencies* between activities in some or all of the company's product divisions (e.g., by sharing components across models, consolidating back-office operations, introducing joint marketing or branding, etc.). The practitioner literature on cross-functional teams attests to the fact that much practical work in large organisations is focused precisely on *conceiving of and designing* new interdependencies (while shedding existing ones).

An important focus for recent research has been the impact of new information technologies on co-ordination. A series of well-known papers on this topic stem from Professor Malone and his associates at the MIT Centre for Coordination Science²⁶. Malone & Crowston (1994) pointed out that large numbers of people use computers to co-ordinate their work, such as e-mail systems that route and distribute messages, and groupware systems that display information and help multiple authors work on the same document. One of the key assumptions underlying this work is that these information technologies not only change the nature of how people communicate but also dramatically reduce the cost of co-ordination. They argued that a "second order" effect of reduced co-ordination costs will be more extensive use of "co-ordination intensive" organisational forms, such as decentralised networks and project teams. As mentioned above, Thompson (1967) considered reciprocal interdependence the most costly mode of co-ordination, but Malone & Crowston (1994) argued that this mode would become more common with the diffusion of new information technologies²⁷.

such a view is that there will be inter-firm differences in how well one is managing existing and potential interdependencies.

²⁶ In section 2.2.4 I discuss definitions of interdependency further.

²⁷ On this point their views depart from those of some modularity scholars. In arguing for an increased use of "adhocracy", Malone & Crowston (1994) based their arguments on observed reductions in co-ordination cost (determined by the ease of communication/collaboration). Modularity scholars have discussed a number of other factors that may influence organisation design. For example, Baldwin & Clark (2000) discussed the issues of ownership and valuation: Workers belonging to different firms may well be able to communicate and collaborate effectively in real-time, but if the working relationship is based on reciprocal

In sum, Thompson's (1967) provided the groundwork for much subsequent research on organisation design. He viewed interdependencies as inherent in tasks and thus reflecting technologies. Although alternative conceptualisations have been proposed, this view of co-ordination is still the prevalent one, and is the one I will make use of in this research as well.

2.2 CURRENT LITERATURE

The following part contains a survey of recent research on modularity and dynamic capabilities. Current research is carried out in different sub-fields and grounded in different theoretical orientations. I have grouped the literature into four main perspectives, based on the main variables that are addressed (technology management, software engineering management, accounting and finance, and organisation learning and design)²⁸.

2.2.1 Technology Management

The product development process has traditionally been divided into four serially ordered phases: concept development, system-level design, detail design, and product testing (fig. 2.5).

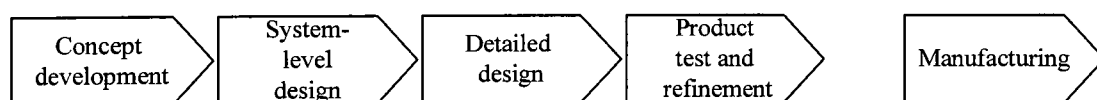


Figure 2.5. The product development process.

interdependence it may be difficult to value their distinct contribution to the final product. This would be a factor (relatively independent of co-ordination cost as defined by Malone & Crowston) that would tend to lead firms to either create a standard interface (i.e., reduce the level of reciprocal interdependence as defined by Thompson) or internalise the entire set of activities involved in the process.

²⁸ I should add that the grouping of the literature was done for practical reasons; some scholars conduct research in multiple areas or combine two or more of these perspectives in their work.

The initial concept development phase is often seen as critical, in that it includes key product design activities such as the identification of functional requirements, determination of product features and performance targets, and choice of architectural approach (Ulrich & Eppinger, 1995). These activities influence both manufacturing cost by defining components, materials, etc. as well as potential revenues by defining the features, quality, and styling of a product. The effect of design on cost is more well documented than the effect on revenues. Ulrich & Pearson (1998) used an approach called *product archaeology* (i.e., analysis of physical products) to assess the product design of automatic drip coffee makers from different manufacturers. They took the coffee makers apart, looked at different parts, and estimated the cost of manufacturing the different models by considering parts cost as well as complexity. They estimated that product design drove approximately 50 percent of the average manufacturing cost of the products. They also maintained that product manufacturing cost in many cases could be reduced without compromising perceived product quality (in fact, some of the high-price, high-quality coffee makers in their study had the lowest estimated manufacturing cost).

The overall goal for product design activities is to link the needs in the market with the possibilities of available technologies. More formally, it has been defined as a deductive mapping of *functional requirements* to *design parameters* (Suh, 1996; Shirley, 1992). The first step is to define a set of functional requirements based on the market needs. Then a physical entity is created that satisfies the stated functional requirements with the least expenditures of resources. The design parameters are variables that specify the structure of the physical entity. For example, the design parameters for a refrigerator door might include specifications for position and attachment to the refrigerator, height and width, material, shape, colour, and so on. Two possible functional requirements for a refrigerator door are: 1) access to stored food, and 2) minimal energy loss (Suh, 1996). Often there will be multiple functional requirements, which can create considerable complexity for designers. A common way of dealing with complexity is to

decompose the design into sub-problems. The solution to each sub-problem is, at the most basic level, a physical object or component. There are different ways of decomposing a product design. A *modular design* is one in which the solution to one sub-problem is relatively independent of the solution to other sub-problems. More formally, modular designs involve the specifications of design parameters that maintain the independence of functional requirements. Then each defined module of the design (e.g., a component) is concerned with the performance of only one functional requirement. The result is that a given design parameter can be adjusted to satisfy its corresponding functional requirement without affecting other functional requirements (Suh, 1996). For example, for the refrigerator door, in a traditional design with a vertically hinged door, the two functional requirements appear to be interdependent (coupled) rather than independent (de-coupled): When the door is opened, cold air escapes, resulting in energy loss. A design that does not couple these requirements would be the horizontally opening door used in freezers. Since cold air is heavier than hot air, most of the air will stay in the freezer. However, functional requirements are often stated in terms of a band of tolerance: the traditional design of the refrigerator might be satisfactory if we state that the second functional requirement is that the energy loss should be less than 10 calories per opening of the door (Suh, 1996).

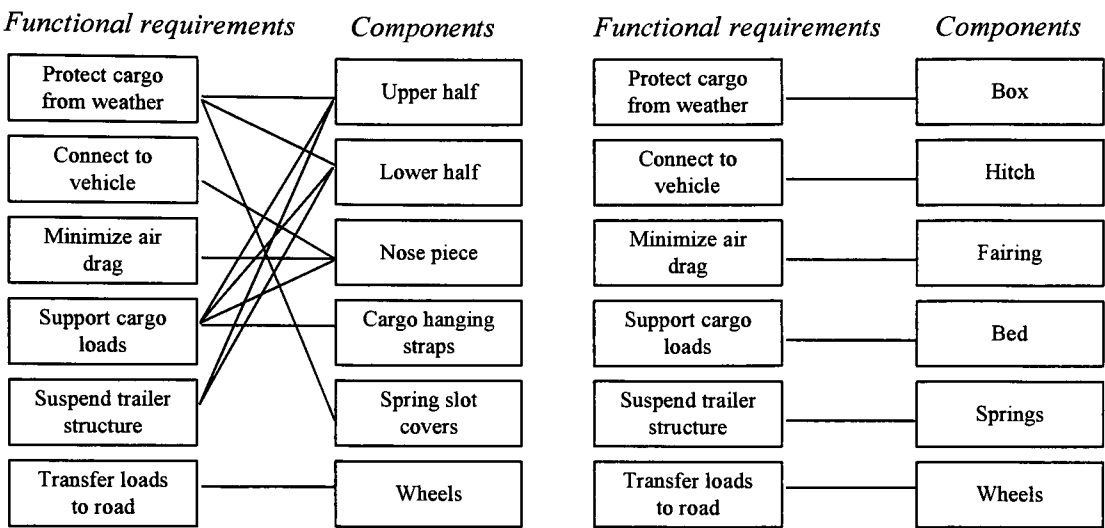


Figure 2.6. An example illustrating the difference between a complex/ integral product architecture and a modular architecture for a trailer.

In addition to having a one-to-one mapping of functional requirements to the physical components (figure 2.6), modular architectures also have *standard component interfaces* (figure 2.7) (Ulrich & Eppinger, 1995; Sanchez, 1995). This is accomplished by eliminating incidental interactions between components. Interactions are confined to those critical to the function of the component (Ulrich & Eppinger, 1995). As incidental interactions are eliminated, the design becomes more modular. In contrast, integral designs have coupled interfaces and/or complex and overlapping mapping of functional requirements to physical components (Figures 2.6 and 2.7).

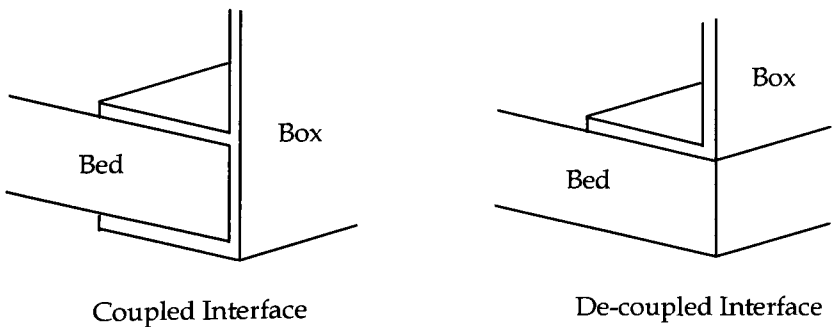


Figure 2.7. The coupled interface of an integral architecture embodies a dependency between the thickness of the bed and the vertical gap in the box connection. The de-coupled interface of a modular architecture involves no such dependency (adopted from Ulrich & Eppinger, 1995).

In the product development literature it is common to use a matrix to show interdependencies between design parameters (the variables that specify the physical entity). This is done by asking for each parameter: “If this parameter is changed, what other parameters might have to be changed too?” The example in Figure 2.8 shows possible design parameters for the bed and box. Interactions are indicated by an X²⁹. The crosses in a row of a particular parameter indicate the parameters that affect this one, while crosses in the column of a parameter indicate the parameters that are affected by it. For example, there is an interdependency between the design parameters for the thickness of the bed and the box connection (if they are to fit). (Other design parameters not mentioned here, such as the material of the two parts, might be interdependent.)

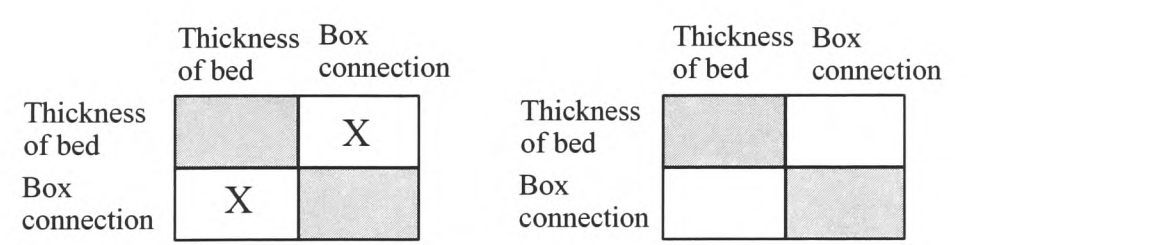


Figure 2.8. Design structure matrices for (geometrically) coupled and uncoupled interface.

The Design Structure Matrix normally shows one type of relationship at a time. Yet there might be multiple types of interdependencies between components. Eppinger et al. (1994) represented multiple component interdependencies as a vector of 4 scores or dimensions, representing spatial, energy, information and material interactions. To capture multiple interdependencies it is possible, however, to assign a number representing the strength of the

²⁹ There are geometrical interfaces between the chassis and all modules, which have been ignored for simplicity.

interaction (e.g., 1 for observed interdependency on one dimension and 4 for interdependency on all of 4 dimensions considered).

Some recent conceptualisations allow for modules that satisfy more than one functional requirement³⁰. For example, for an automobile, functional requirements related to generic characteristics such as noise, vibration and ergonomics necessarily affect multiple modules. One can measure a product architecture by the number of functions per subsystem and place them on a continuum from modular to integral. Thus more modular architectures would have components with (on average) a low number of functions per subsystem (module), whereas integral architectures would have a high number of functions per subsystem (Ulrich & Eppinger, 1995).

Modular architectures isolate functional requirements and minimise incidental interactions between any given component and the rest of the product. This increases the likelihood that the component will be commonly useful (Funnemark & Olofsson, 1997). A company manufacturing multiple (but technologically related) products may thus utilise the same components in other models and products, wherever the functional requirements are the same. This feature is referred to as *component commonality*. The sharing of components across model/product *generations* is referred to as *component carry-over*. When customers themselves can substitute some key modules, a product is referred to as being *upgradable*.

For a company manufacturing multiple products, an alternative to a modular architecture would be to have a separate architecture for each product. Although integral architectures normally are far less economical, there are circumstances when integral designs may be preferred:

- If a firm expects a low rate of change or does not have a product line with several models that are functionally related, the required modularisation might consume too much development resources to justify the benefits (Funnemark & Olufsson, 1997).

³⁰Sources: Ron Sanchez, personal communication, March, 1998; Johan Fredrickson, personal communication, February, 1999.

- For firms pursuing radical innovations, the underlying scientific knowledge may be insufficient to allow definition of a stable functional decomposition and identification of the component interaction (Baldwin & Clark, 2000). Modularity requires a certain level of technological maturity. Designers need to know the strength of functional and component interactions well enough to know how to split the overall product into independent modules: the less mature the technology is, the more time and effort will be required in testing and “bug-fixing” toward the end of the design process³¹.
- For firms targeting high-end market segments, it may sometimes be necessary to use integral architectures to reach the highest possible performance (Ulrich & Eppinger, 1995): Using integral architectures, product designers can optimise components for a specific application rather than having to worry about using or developing standard components intended for re-use in other models or products. The performance improvement that is achieved is often related to reduced size or mass, as modular designs contain redundant physical structure and do not exploit function sharing in the way as integral architectures do (Ulrich & Seering, 1990, cited in Funnemark & Olufsson, 1997).

2.2.1.1 The platform concept

The term product platform is sometimes used instead of the term product architecture and similarly refers to the subsystems/modules (embodying a core technology) and the interfaces between the subsystems/modules for a basic product design. The platform concept is often used to highlight that the architecture has been intentionally designed to allow leveraging of several follow-on models (sometimes called derivative products or models as they are derived from an initial platform). This is achieved in a quick and cost-efficient manner through mixing and matching of existing components or by combining carry-over of the majority of the components

³¹ On the other hand, Baldwin & Clark (2000) suggested that the added value of modularity in dynamic

with development of few new components (this latter case may be termed a platform extension). Platform renewal occurs when the architecture itself undergoes change in that new subsystems are added and interfaces re-defined (see Figure 2.9 and 2.10). In the manufacturing context, a platform sometimes refers to a sub-system of the product that has geometrical interfaces to several other components, which leads to a production processes where the other components are mounted onto the platform in a sequential order, as in car assembly processes.

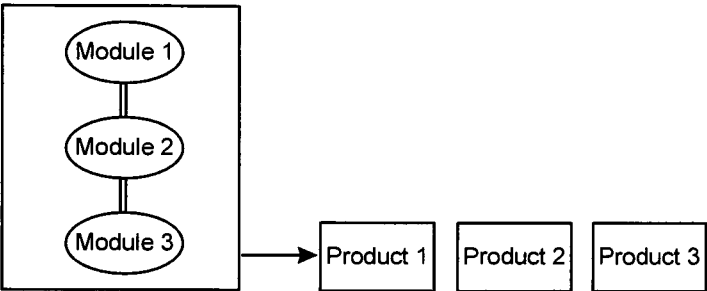


Figure 2.9. Initial platform architecture: Common modules (and/or subsystems) and interfaces for multiple products. Adapted from Meyer et al. (1997).

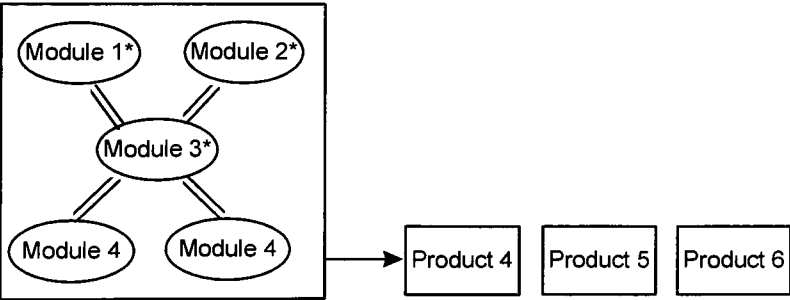


Figure 2.10. Platform renewal / change: A new architecture, where modules and/or subsystem from prior generations may be carried forward with new subsystems and interfaces in the new design. Adapted from Meyer et al. (1997).

The notion of platforms was anticipated by H. A. Simon (section 2.1.1), albeit at an abstract level. In nearly decomposable systems, most sub-units or variables are strongly related only to one or a few other sub-systems. Yet he noted some exceptions: There may occasionally be

markets often offset the problems caused by premature modularization.

a sub-system that is strongly linked to variables in most of the other subsystems. For example, in an economic system consisting of prices and quantities of commodities, the prices of most commodities relate to only one a few other commodities. But the consumption subsystem of the economy would influence prices of all commodities. Based on this insight, table 2.11 shows how the concept of a platform may be represented in a Design Structure Matrix. We see that the platform has interfaces to multiple modules (in this particular case, to all). When applied to product design, the key principle is that the interfaces between the platform and the modules remain constant over a given time period, allowing component upgrades and substitutions.

Platform			Modules											
1	2	3	A			B			C			D		
x	x	x	o	x	x									
x	x	x	x	o	x									
x	x	x	x	x	o									
x	x	x				o	x	x						
x	x	x				x	o	x						
x	x	x				x	x	o						
x	x	x							o	x	x			
x	x	x							x	o	x			
x	x	x							x	x	o			
x	x	x										o	x	x
x	x	x										x	o	
x	x	x										x	x	o

Figure 2.11. Design structure matrix illustrating the platform concept.

A platform can be thought of in broader terms as design rules intended to facilitate *sharing or transfer* of resources across sub-units of a system and across multiple generations of products or processes. It is thus related to techniques for achieving *economies of scope* in organisations, such as knowledge management systems, shared services, etc. As I will consider below, the notion of platform is also analogous to key principles underlying object-oriented programming that support the re-usability of code.

2.2.1.2 Product family management and platforms

Modular architectures enable the design and production of products with many variations at the same or lower cost than integral architectures. The higher product variety and more frequent product introduction that result from modularity require product development processes that can effectively support the transfer and leveraging of technologies across several projects. These capabilities are different from the ones required in a firm that only has one product or project (Nobeoka & Cusumano, 1997). Sanderson & Uzumeri (1997) contend that for many manufacturers, the planning of product evolution and model variety has become one the most critical strategic management task. They call this type of planning product family management, recognising that most companies divide their line of products into subsets called product families. Different companies may use different definitions, depending on the industry, but the key idea is that the models within a family share a core technical concept or a product platform.

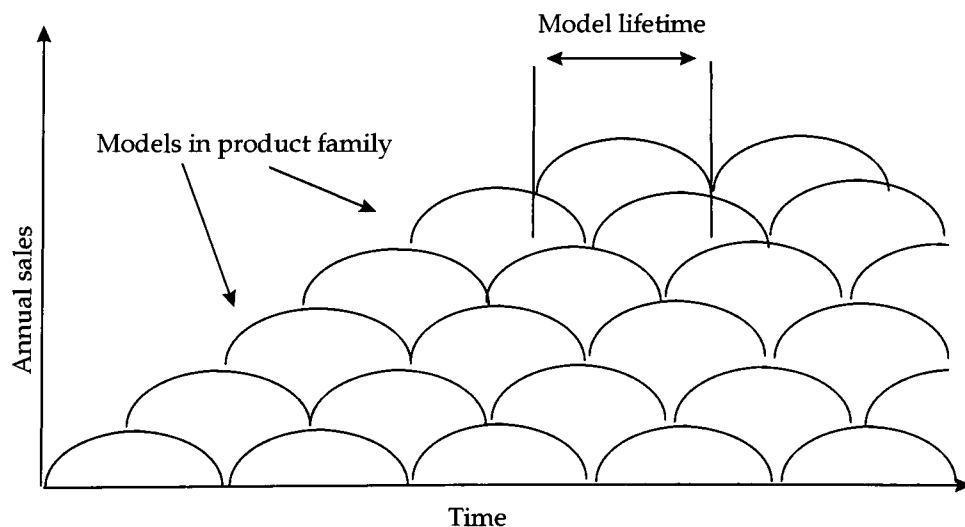


Figure 2.12. The product-family life cycle pattern in dynamic industries. Adopted from Sanderson & Uzumeri (1997).

The Sony Walkman is often mentioned as an example of effective product family management in a dynamic product market context. During the 1980's, about 200 different models were introduced - 20 each year - based on only 6 tape transport mechanisms. These different models were adapted to local market needs. For example, the Sports version was sold in the US but not in Japan, and remote control was a feature on mainly the Japanese models (Sanderson & Uzumeri, 1997). Although many of the new features that Sony introduced were imitated by competitors, it is noteworthy that some of Sony's models achieved greater longevity than competitor models. Sanderson & Uzumeri called these models "business classics" - products that have longer market lives than others. They considered business classics an important stabilising element in dynamic product markets, which are otherwise characterised by very frequent product replacements. Having one or more business classics in a portfolio of product models frees up design resources and makes sales more predictable. In the case of the Walkman, the average life time was 2 years for Sony's models and only 1.18 years for the competitor's models. The Sony sports Walkman was on the market for nearly a decade and the professional version that Sony introduced remained unchanged for more than 6 years. But it is difficult to predict which models that will become business classics, or to prescribe a specific product design strategy. Yet Sanderson & Uzumeri maintained that companies can increase their chances of hitting upon a business classic by investing in product variety and replacing unsuccessful models faster than low-variety competitors.

2.2.1.3 Sub-section summary and discussion

The technology management literature has contributed a number of insights regarding the process of adapting to more dynamic environments. Perhaps the most important contribution is the focus on design itself - the process of adapting structures to a purpose (Perkins, 1986). This concept is increasingly relevant in other fields of management as well (e.g., Liedtka, 2000). Several critics have pointed out that strategic management and organisation theory suffer from a lack of

frameworks that can inform managerial action. The predominant mode of theorising is descriptive and focused on understanding past causes of current phenomena. The role of managers in effecting organisational change is frequently downplayed or neglected. Moran & Ghoshal (1996) thus concluded that current theory is more concerned about “the unintended consequences of organising than about organising for [an] intended purpose” (p. 70).

Design is not about how things are, but how they might be (Simon, 1962). The technology management literature portrays product designers in the active role of solving problems, i.e., interpreting requirements, documenting constraints, visualising future solutions, and testing alternative approaches. Many of the frameworks discussed in the technology management literature are intended as tools for supporting this process.

Another important element is the explicit focus on customer needs. As described above, the design process starts by analysing customer requirements and then proceeds by creating a blueprint for realising those requirements. In contrast, the role of the customer is either unclear or invisible in many of the other perspectives covered in this chapter. For example, Weick (1976) did not consider what effect loose coupling might have on the stakeholders or users of the services provided by organisations. Williamson (1975) described cost minimisation as the key criterion for organisation design, rather than customer value. In line with more recent approaches I argue below that the focus on customer needs can and should be extended to organisation design. One can envisage that business process design might proceed in more or less the same fashion as product design.

The technology management literature also has some limitations. Due to its prescriptive nature, it may overstate the freedom companies have in altering product architectures. There are obviously technological and industry-wide forces that both constrain and enable the range of choices that are viable with regard to product design. The degree of modularity of any given product architecture is only partially under the control of single firms, because it depends on

generic technological and scientific knowledge (including formal knowledge of interdependencies), which is publicly available and diffuses relatively quickly among the population of firms in an industry. Consequently, some authors have analysed modularity predominantly as an industry level phenomenon. However, although the overall range of modularity is affected by industry-wide trends, empirical evidence shows clearly that there is inter-firm variation in the degree of modularity (cf., Nobeoka & Cusumano, 1997; chapter 6, this thesis).

The technology management literature assumes that product designers will be able to figure out what the existing and potential interdependencies are, given the right approach and the appropriate analytical tools. Scholars belonging to the so-called sense-making school (e.g., Weick, 1999; Perrow, 1984) typically portray interdependencies as poorly understood and subjectively construed. The implication is that it might be difficult to design an optimal structure *a priori* to minimise future interdependencies (Staudenmayer, 1997). However, this objection is less serious than it may seem. It is obviously impossible to have perfect knowledge of all current and potential interdependencies. Modularity scholars simply assume that given a certain minimum level of technological maturity, one should be able to gain a level of understanding of interfaces that is adequate to current needs and thus allows the firm to enhance its strategic flexibility on one or more dimensions (e.g., through increasing product variety and change)³². If the underlying technology is new or still evolving, it may be possible to modularise only at a high level or in certain parts of the overall product structure. As the firm's knowledge increases over time through experimentation, testing, customer feedback, etc., it will be possible to gradually increase the level of modularity at increasingly detailed levels of the overall product structure³³.

³² Source: Sanchez (personal communication, June, 2000).

³³ In fact, using the Design Structure Matrix, Eppinger et al. (1994) found that engineers were able to predict 80% of the interdependencies in an engineering project.

2.2.2 Software engineering management

Software engineering is a field that has gradually evolved from using integrated designs and ad hoc approaches to highly structured and modular development techniques. In the 1960's, computer programming was largely performed by "hackers", that is longhaired and unkept technical wizards who would work their computers with no form plans, designs, or processes, and just "hack away" at coding (Cusumano & Selby, 1997). This approach worked well for small computer programmes that one or a few people could write. Yet with larger and more complex programmes, it typically led to programmes that were resistant to change and difficult to understand for other people than the creator (and therefore difficult to maintain). This state of affairs sparked a concerted effort among computer scientists to develop more disciplined and consistent styles of programming. As described by Taylor (1990), the most elementary support for modular programming came with the invention of the sub-routine in the early 1950's. A sub-routine is created by pulling a sequence of instructions out of the main routine and giving it a separate name. Once defined it can be executed simply by including its name wherever it is required. This led to a natural division of labour since different programmers could write different sub-routines and then assemble them afterwards into a working programme. During the late 1960's this approach was further refined into *structured programming*, which relied explicitly on a functional decomposition of the total programme into individual components, which in turn would consist of sub-components, and so on, down to the level of subroutines. Whereas structured programming was primarily concerned with the modularisation of procedures, more recent developments focused on modularisation of the data, that is, the information operated on by the procedures. By modularising data along with procedures, each subroutine would have its own local store of data that it alone could read and write, which minimised unwanted interactions between subroutines (Taylor, 1990).

This strategy had its roots in ideas conceived of during the development of the OS/360 operating system for the original IBM 360 line of computers³⁴. The team responsible for the development of OS/360 originally thought that interdependencies would best be managed by maintaining a formal project workbook, which everybody would have a copy of, so that every programmer could determine how changes elsewhere would affect his or her part of the project. The only problem that appeared was that within six months, the workbook was about five feet thick. In addition, the daily changes averaged 150 pages, which had to be distributed to every person who used the workbook. The manager of this project, Frederick Brooks, is known for the insight that the cost of communication among workers will eventually outweigh the benefits of division of labour as more and more workers are added to a project (Brooks, 1975, cited in Langlois, 1999). To deal with this problem, the team adopted the principle of *information hiding*, which states that a programmer is most effective when shielded from, rather than exposed to, the details of a system other than the parts that he or she is responsible for³⁵.

Object-oriented programming (OO) illustrates how this can be accomplished. The basic module is the object, which is simply a set of procedures (called methods) and data (called variables). Each object has a range of behaviours that it can exhibit and each has to maintain information about its status. Unlike the basic units of previous programming languages, objects are modelled on real world concepts or physical entities. Different objects may thus represent employees, products, or customers. For example, consider an object representing an automatic guided vehicle in a factory (Taylor, 1990). The methods represent the possible behaviours, such as loading, moving to a location, unloading, etc. The variables would contain information about inherent characteristics (e.g., pallet size) as well as its current state (e.g., location). Objects interact by sending and receiving *messages*. For example, the object representing an automatic

³⁴ This section borrows from Baldwin & Clark (2000) and Langlois (1999), who cite the book written by Jeffrey Brooks (1975), the manager of the OS/360 project.

³⁵ This principle was originally developed by D. L. Parnas (Baldwin & Clark, 2000).

guide vehicle may receive a message from another object requesting it to move to another location. Note that data inside an object is accessed only by the object's methods: Other objects do not need to "read" an object's inner data structure while interacting with it. This is an application of the information hiding principle, which shields objects from damage by incorrect handling by other objects, and (more importantly) spares other objects from having to keep track of the internal structure of the object with which they communicate.

Software normally contains several objects of one kind. For example, a factory may have several guided vehicles. Instead of redefining the same methods in every single instance, in OO there exist *classes* (e.g., automated vehicles), which are templates that define entire collections of instances (e.g., vehicle 1, vehicle 2, etc). Classes can also be defined in terms of each other, which is a principle called inheritance. This means that if a class is defined as a special case of a more general class, it automatically inherits the methods and variable definitions of the general class. Classes can be nested and inheritance will automatically accumulate down through all the levels. The result is a hierarchical structure (called class hierarchy). This reduces complexity and duplication: the methods and variables that are common to all instances are defined in the generic class. It also speeds up the implementation of changes: A change can be applied simultaneously to a whole class, while leaving other classes unaffected. Alternatively, a change can also be carried out in a subclass and override the method of the more general superclass. I summarise some of the key principles of OO in Table 2-1.

The object-oriented approach led to a revolution in software development. Programmes used to be built from scratch in a craft-like fashion, and were typically tailored to one specific operation or company. By modularising the development language, it became possible to assemble computer programmes much faster by reusing objects from previous projects. OO also

made it easier to transfer code between different programming teams³⁶. In fact, there is now a market for reusable prebuilt software components that brings together component producers and component consumers (Goodyear et al., 1999). Component producers may be either third party vendors or internal development teams that repackage parts of their code for mass-market use. Component producers build applications by assembling components that may be purchased from the market (and possibly combined with components acquired from internal object repositories). The emergence of this market has been facilitated by electronic distribution and payment via the Internet, as well as adoption of industry-wide standards. The major vendors of software components belong to a consortium, the Object Management Group, which is responsible for establishing standards that secure interoperability between objects sold by different vendors (ibid.).

³⁶ Data from an unpublished study may illustrate that this transition: Before the advent of object-oriented programming, a client of Accenture once investigated the level of knowledge sharing and transfer among its programmers. It found that 80% of the re-use of code occurred *within* programming teams, and that the remaining 20% occurred when the same individuals joined other teams (source: Benjamin Porter, associate partner, personal communication, May, 2000).

Table 2-1. Object Oriented Programming.³⁷

Characteristic or principle	Description
Objects	Packages of procedures and variables Represents entities in the application domain
Class	Template for defining the methods and variables for a particular type of object. Classes contain <i>instances</i> (objects) with identical properties apart from different data in their variables.
Class hierarchy	Taxonomy of classes. Methods and variables of a class are available to its subclasses
Encapsulation	Technique for packaging data with corresponding procedures into objects (i.e., independent units).
Inheritance	A mechanism by which a classes can make use of methods and variables defined for all classes above them
Messages	A signal from one object to another
Information hiding	Technique of making internal structure of a module inaccessible to other module by means of standard interface
Composite objects	Objects that consist of combination of simpler objects.

2.2.2.1 Software development processes

Although development *languages* are more modular than before, there is still variation in how software companies approach the software building *process*. Microsoft's development practices have been well documented thanks to the study reported by Cusumano & Selby (1997). Despite (or perhaps because of) its dominant market position, Microsoft was a late adopter of modular software development techniques³⁸. Indeed, at the time of this study, Microsoft was still

³⁷ Adapted from Parsons & Wand (1997) and Taylor (1990).

³⁸ I here refer to high-level modularity in development processes, not the development language being used. Microsoft uses the development languages C and C++ to write programs. C++ is usually considered an object-oriented program, but it allows considerable latitude in conforming to object-oriented

practising what Cusumano & Selby characterised as a scaled up hacker-like approach, in that programmers adhered to few of the structured software engineering approaches used elsewhere, despite working on immensely complex programmes consisting of millions of lines of code. As in conventional integrated engineering approaches, Microsoft teams tended to view the notion of a product architecture as the final output of a development process (Cusumano, 1997, Cusumano & Selby, 1997) rather than as a top-down *a priori* decomposition, which is how architecture is defined in the modular approach³⁹. As would be expected from extant theory, co-ordination between development teams at Microsoft relies on real-time communication to solve reciprocal interdependencies, an approach that Cusumano & Selby label “synch-and stabilise”⁴⁰. Microsoft uses multiple small teams, consisting of three to eight programmers, which work in parallel. These teams start with a relatively general outline specifications, rather than detail specifications, and operate nearly autonomously in that they have freedom to develop or even invent new features. In order to co-ordinate the work of interdependent sub-units, teams synchronise with each other. Rather than doing this once at the end of a project, the teams synchronise in increments as the project proceeds. By putting together a partially completed software solution, errors are detected and corrected, and thus “stabilises” a part of the design until the next milestone is reached. The use of this approach is facilitated by the fact that nearly all Microsoft

methodology (Taylor, 1990). Thus there is variability in both application development processes and the structure of the resulting software products.

³⁹ Apart from this culture of iterative programming, the lack of modularity may also be due, to some extent, to strategic choices. For example, Microsoft has been accused of deliberately designing its software packages (e.g., Windows) so as to be incompatible with modules developed by other firms (e.g., Netscape’s browser). Microsoft has also resisted adopting solutions based on open standards, such as Java introduced by Sun Microsystems.

⁴⁰ Microsoft’s development approach is similar to the “experiential strategy” for speeding up product development identified by Eisenhardt & Tabrizi (1995), which relies on frequent iteration (i.e., rapid prototyping), extensive testing, and frequent milestones. *Rapid prototyping* is practised by many software firms (as well as by many firms manufacturing physical products). In the context of OO, rapid prototyping means quickly assembling a prototype based on existing objects to address a particular problem. Based on feedback from testing the prototype is gradually developed into the full production programme.

teams work at the same physical site, use the same development language as well as the same metrics to guide decisions and track progress.

2.2.2.2 Sub-section summary and discussion

The software industry yields a number of insights regarding the benefits of different approaches to product design and to organising product development processes. The Microsoft case indicates that it is *possible* to tackle complex development projects surrounded by high degrees of market uncertainty by using relatively unstructured development principles. Yet the costs of this approach may be too high for the majority of software firms. Cusumano & Selby (1997) argued that it had facilitated innovation and adaptation to emerging customer needs. Yet in many cases rival firms seem to be able to come up with products that match, or in a few cases, greatly surpass, the performance of Microsoft products⁴¹. Cusumano & Selby (1997) admitted that the approach has weaknesses and that Microsoft will need to do more advanced planning and architectural design to minimise problems in development, testing, and operation.

The development of the Linux operating language can be mentioned as a contrast to Microsoft⁴². Linux is famous for being a radical innovation created by a loose community of software engineers. It was initiated in 1991 by Linus Torvald who was then a student in computer science. He developed the kernel of the operating system, which he posted on the Internet along with a request for help with further development. During the time that followed, thousands of engineers around the world would contributed to building at least 645 distinct software modules that today form the commercial version Linux. This story is remarkable in several ways. For

⁴¹ In a 1999 independent test (www.spec.org) the Linux server software was measured to perform operations three times faster than Microsoft 2000.

⁴² Several other software programmes have been developed in a similar fashion, including Emacs's Lisp Library, the Apache server software, and more recently, Gnome, a graphical user interface for Linux. Kogut & Turcano (2000) believe that this model constitutes a new mode of innovation that eventually may

example, the development process lead to a breakthrough product yet it incurred no fixed costs. Engineers contributed their time without receiving payment or ownership, because their code was open for inspection (and revision) by anybody. In this particular context, though, the more critical questions centre on how the development process could proceed in such a spatially distributed manner yet lead to an end product with a high degree of internal coherence. Kogut & Turcano (2000) pointed to the fact that Linux was written in Unix and that all the engineers in the community shared knowledge of the principles underlying Unix. This supported rapid communication and recombination of modules. Secondly, although it was spatially distributed, the process was governed by some degree of hierarchy, in that Torvalds would review and accept newly posted contributions (he was supported in this by sub-committees for key modules). The Linux case shows how a pre-established architecture may enable module developers to work simultaneously and independently. As opposed to in Microsoft, little or no communication was necessary between those responsible for developing the different components of Linux. As described above, this is one of the defining characteristics of a modular task structure – no or a minimal amount of intermodule interaction (Sanchez & Mahoney, 1996; Baldwin & Clark, 2000).

2.2.3 Finance & accounting

Cost accounting perspectives. Several authors have attempted to identify the main cost drivers in product development and manufacturing and to develop indices and metrics that product designers can use to assess individual product models and product platforms. In table 2-2 and 2-3 I reproduce four indices proposed in this literature. The first two were proposed by Martin & Ishii (1996, 1997); Funnemark & Olofsson (1997) discussed how they could be applied in a study of alternative printer configurations. The key objective is to consider how commonality affects the cost of providing variety at the model/product level. The underlying assumption is that

extend the locus of innovation from experts within a few large Western firms to a global community of

commonality achieved through modularity should decrease part complexity and increases part volume, which in turn should affect indirect costs. Part complexity affects the cost of logistics, inventory, material handling, and set-up (i.e., preparation of the production line). Part volume affects purchasing power and volume discounts. As shown in table 2-2, Martin & Ishii (1996, 1997) used the number of unique subsystems in product models as proxies for product variety in their commonality and complexity indices. Using these indices during the development of new product versions, one can evaluate how the inclusion of alternative components will affect commonality and complexity.

contributors.

Table 2-2. Product level indices (Martin & Ishii, 1996, 1997; Funnemark & Olofsson, 1997)

Commonality index (CmI)	$C_{mI} = 1 - \frac{u}{\sum_{j=1}^{N_v} n_j} \quad 0 \leq C_{mI} \leq 1$			
where:				
u = number of unique subsystems and/or modules				
n _j = number of subsystems and/or modules in model j				
N _v = total number of versions and derivatives offered.				
<i>A lower number indicates higher degree of standardization.</i>				
Complexity index (CxI)	$C_{xI} = \sqrt[3]{10 \cdot n_j \cdot (n_j - 1) \cdot u}$			
where:				
u = number of unique subsystems and/or modules				
n _j = number of subsystems and/or modules in model j				
<i>A lower number indicates lower degree of complexity.</i>				
Example	Number of versions (N _v)	1	3	3
	Number of subsystems (n _j)	9	9	8
	Unique subsystems (u)	9	13	10
	Commonality index	1,0	0,78	0,98
	Complexity index	18,6	21,1	17,6

A conceptually similar approach was suggested by Meyer, Tertzakian & Utterback (1997), but they focused on overall product platform assessment (and, potentially, comparisons between different platforms). Their indices focus on the relationships between the costs of developing an initial product platform and the costs and sales of subsequent products derived from the platform. They measured R&D leverage by the index called platform efficiency, which

is the engineering cost incurred in developing a derivative product, divided by the engineering cost incurred in developing the initial platform. This index seeks to estimate how much a model costs to develop as a fraction of the cost of developing the product platform. Furthermore, by comparing product sales to product development cost, one gets an index of platform effectiveness, which provides an understanding of the commercial leverage achieved from product platforms. Note that one can use this measure at the product level or aggregate data to the platform level (by comparing the sum of sales of products within a platform divided by the R&D costs for creating those products). Meyer et al. (1997) observed that these indices are sometimes inversely correlated: Whereas efficiency increases due to re-use of components, effectiveness may be hurt if sales (the numerator in the second equations) go down as a result of prolonging the life of a platform.

Table 2-3. Platform Level Indices (Meyer et al. 1997)

<i>Platform efficiency</i>	=	$\frac{\text{R\&D costs for derivative product}}{\text{R\&D costs for platform}}$
<i>Platform effectiveness</i>	=	$\frac{\text{Product sales}}{\text{R\&D costs of products}}$

Financial perspectives. Ciborra (1996) conducted a case study of Olivetti and concluded that strategic management in the computer industry mainly consists of placing bets about what will be the next primary technology. But he also noted that the process was facilitated by having a technology platform and organisational architecture that are easily reconfigurable. A platform that is easy to reconfigure reduces the need for accurate forecasting. Consider the example of the original PC provided by Thomke & Reinertsen (1998, p. 12):

During the design of the PC, there two viable design solutions for long-term storage. The Radio Shack TRS-80 successfully offered a cassette recorder, while the Apple II used a floppy disk drive. Both technologies were accepted in the marketplace, and it was unclear if either would become dominant. IBM could have performed market research to resolve this risk, but generating consumer preference data that could be relied upon was unlikely. Instead, IBM's PC offered both a cassette port (a socket that a cassette player could plug into) and a floppy drive. (...) As the market developed, consumers expressed a clear preference for the easier-to-use floppy disk and the cassette port was eliminated in IBM's next product, the IBM PC-XT.

In other words, flexibility was built into the product architecture, which made the product more tolerant of changes in the market. This fits well with the strategic flexibility approach, which can be thought of as a system for creating options (based on technological and organisational resources) for managing the evolving uncertainties of the present and future (Sanchez & Mahoney, 1996). However, flexibility comes at a cost, in this case the extra product design effort and the physical components for a cassette port. This makes it important to consider the cost of added flexibility relative to the benefits in terms of increased robustness to market changes.

New investment and accounting practices have emerged during the last decade that better capture the value of flexibility under uncertainty compared to traditional methods such as discounted cash flow approaches. A key development has been the concept of real options (Sanchez, 1993; McGrath, 1997; Kogut & Kulatilaka, 1994). Unlike financial options, which are issued for investments in financial instruments (e.g., shares, or loans at a fixed interest rate), real options concern investments in physical and human assets (e.g., development of a new technological capability). Like financial options, they confer the right or ability to choose whether to exercise the option at a later point. The real options approach provides new decision criteria compared to discounted cash flow approaches such as Net Present Value (NPV) in that it provides more accurate estimates for the value of being able to adapt and revise decisions in response to unexpected market developments, and for the value of developing resources that are generalisable across multiple projects (Trigeorgis, 1996; Kogut & Kulatilaka, 1994). NPV

methods typically consider single projects in isolation and tend to underestimate the benefit of a “wait-and-see” strategy where one can make the decision to exercise the option or not contingent on a favourable outcome (e.g., sufficient demand a the newly developed product).

Trigeorgis (1996) described a number of real options including growth options, options to alter operating scale, options to abandon operations, and options to switch inputs and outputs. In fact, the choices that management must make with regard to which products to develop, when to commercialise the products, and how to configure the value chain, can all be conceptualised as real options.

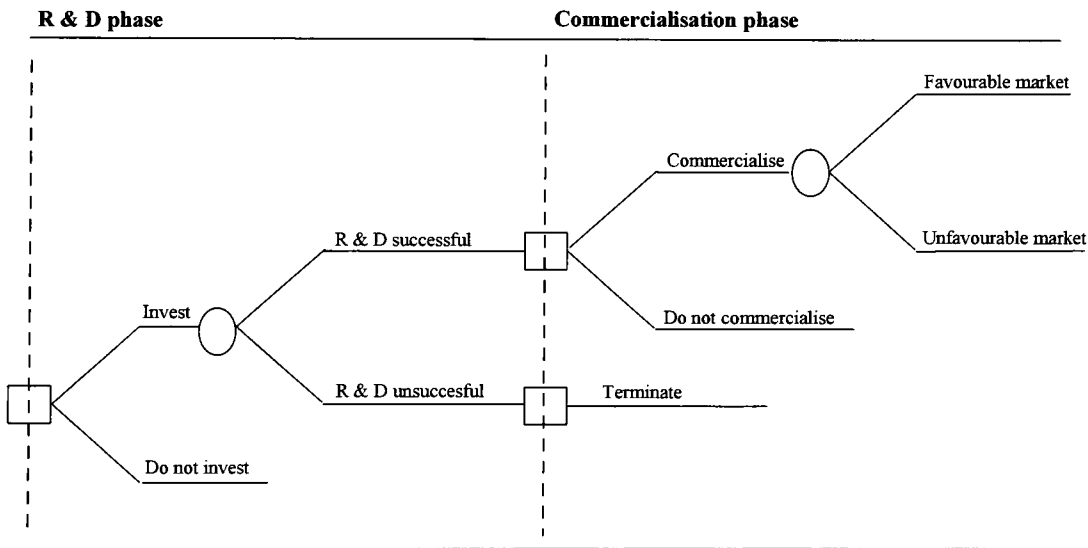


Figure 2.13. Typical investment decisions and outcomes during a product development process.

Sanchez (1993) and McGrath (1997) discussed this approach in the context of product development and technology positioning⁴³. The price of the option in this case is the cost of development. The exercise price of the option is the cost of commercialisation, which creates the

⁴³ Garud, Kumaraswamy & Nayyar (1998) pointed out that the purchasing of a real option in itself influences the exercise data, price, and value of the underlying asset because of “co-evolutionary dynamics”. For example, firms who consider development and commercialisation sequentially (as in McGrath’s (1997) model) rather than simultaneously might experience that the technological knowledge

right to extract the return from the exploitation of the technology. Since these decisions are sequential, one can delay the choice of whether or not to exercise the option until uncertainty has been resolved. For example, one can wait until one has more information about the actual demand for the product or the level of competition in the market. If one decides not to exercise the option, one has in this case only lost the sunk costs associated with the discontinued project. Compared to obligations, having options thus gives the firm the flexibility to capture potential future gains while avoiding future losses (Sanchez, 1993). The value of financial options increases with the price volatility of the underlying asset. In the same manner, the value of real options increases with the uncertainty about future outcomes. The greater the uncertainty about future net revenues (or commercialisation cost), the more valuable becomes options that let the firm defer commitments and make them contingent on future outcomes.

The degree of modularity will influence the value of the options in several ways. If a firm reduces the cost of production or commercialisation through the use of product platforms with standardised components, the resulting economies of scope will lower the “price” of each option as well as increase the number of viable new options (Sanchez, 1993). Modular designs might also influence the size and onset of the revenue streams. For example, development time may be reduced by using rapid prototyping, which gives the firm valuable feedback from customers, and by introducing incremental improvements to already existing platforms, which will make the adoption of the new products go faster (McGrath, 1997). Another feature of modular systems is the ability to add differentiating components at a “late point” in the production or distribution process (Sanchez, 1995). This is analogous to the example of R&D investments mentioned above, in that one can defer critical decisions until market uncertainty has been resolved⁴⁴.

atrophies or that it leaks out and benefits a rival firm. These factors suggest that one needs to consider the competitive context carefully before selecting the approach to value R&D investments.

⁴⁴ In Trigeorgis’ (1996) terminology these would be classified as two different options. The R&D investment case is an “option to defer” or a “growth option”, whereas adding features at late point in

Baldwin & Clark (2000) looked at options at the product level and attempted to model mathematically how product designers' decisions lead to economic value. As product designers select modules and make decisions about the total number of modules, their size, complexity, and performance, one can assume that they are seeking to maximise the net option value of the design - the present value of the expected payoff minus the costs incurred at different stages. Building on conventional options valuation techniques, Baldwin & Clark also calculated the theoretical option value of integral (one-module) versus modular designs. They proposed that this relationship can be expressed as a square root law:

$$\text{Value of modular design} = \sqrt{\text{Number of modules} * \text{Value of integral design}}$$

For example, a 25 module design would be expected to be 5 times more valuable than a one-module design ($V_m = \sqrt{25} * V_i$). Although this equation ignores the cost of creating a modular architecture, it still provides a useful framework for considering the economic consequences of alternative design choices.

The underlying assumption is that the value associated with different parts of a system can be broken up if product designers modularise the design. A modular design creates at least as many options as there are modules, whereas an integrated product design creates only one option - the whole system. Designers with modular architectures have the option to reject any module if it fails to clear a performance benchmark, usually set by the performance of the previous design (This logic is identical to that in Sanchez (1993) and McGrath (1997), except that it is applied to the product, rather than the project, level.) Stated more simply, designers can reject a new design for a module if it is no better than what is already available, otherwise it will be incorporated in

distribution would be similar to an "option to switch" product inputs or outputs, depending on market demand.

the product. We see that modular architecture (incorporating multiple modules) is bound to yield a higher value because it provides many more options. Indeed, Baldwin & Clark (2000) made the analogy with stocks: having a portfolio of product option permits the best outcomes of several alternatives to be combined.

Table 2-4. Baldwin & Clark’s theoretical option value example

This reasoning is based on calculating mathematical expectations, which are probability-weighted averages. Baldwin & Clark (2000) derived the power law relationship by dividing the option value of modular designs by the option value of integral designs. These equations for options value are:

One module	$V_1 = E(X_N^+)$ For a standard normal distribution, $E(X^+)$ equals .3989* and $E(X_n^+) = .3989 \sigma_n^{1/2}$	Where: E = Expected value X = the outcome of the design process (a random variable⁴⁵)¹ N = Number of task parameters The + sign on X means that the expectation only covers outcomes above zero. σ = standard deviation of value distr. Assumption: The expectation for each module, denoted E(X_i) is zero.
Multiple modules	$V_j = E(X_1^+) + E(X_2^+) + + E(X_j^+)$ Each module’s value is: $E(X_i^+) = .3989 \sigma^2(N/j)^{1/2}$ Assumption: N tasks are partitioned into j modules.	Where: E = Expected value X = Contribution to overall system value of the ith module. Assumption: The value of each module corresponds to a random variable with a normal distribution.

⁴⁵ The term “random variable” simply refer to the fact that it is uncertain at this point in the design process and thus does not have a specific value but a set of potential values with an associated probability distribution. X is a random variable with zero mean and variance of σ²N. N is the number of design parameters and thus corresponds to the number of tasks in the design (N is also proportional to the complexity of the system). In other words, the variance of outcomes depends on the number of task parameters in each design (larger designs have more upside and downside potential).

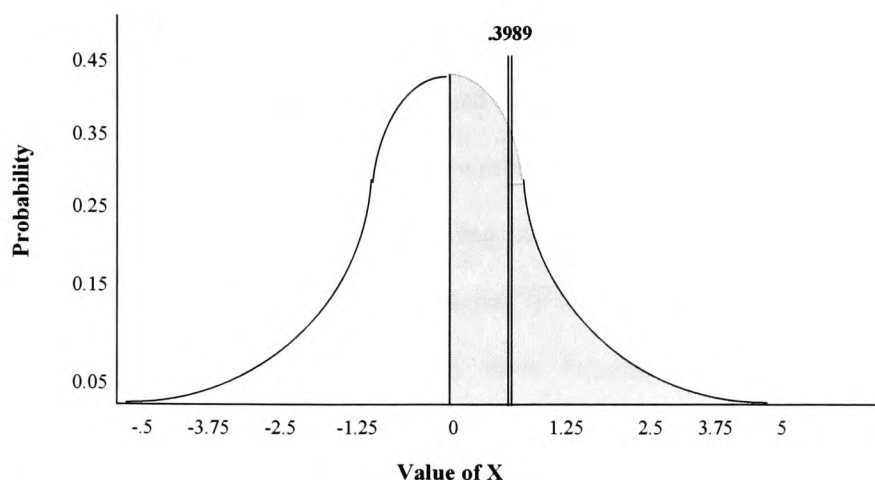


Figure 2.14. The shaded area under the curve equals the expectation of X (the value of the outcome - i.e., module performance) given that X is greater than zero. Designers can decline to incorporate a module whose performance is worse than that of the current mode (set to zero). According to financial theory, a random-variable payoff can have a single point value, which is .3889 for a normal probability distribution with mean zero and standard deviation equal to one (adopted from Baldwin & Clark, 1996, p. 12).

2.2.3.1 Sub-section summary and discussion

Scholars applying a financial perspective have contributed a rigorous foundation for thinking about strategic flexibility and dynamic capabilities. The approaches reviewed can be used as decision criteria and for estimating the value of flexibility in different circumstances.

The creation of product architectures can be understood as an investment in options, because it enables the development of a host of derivative products at a lower incremental cost. The option value of such investments is often underestimated⁴⁶. Part of the problem is the use of budgeting methods that only consider projects in isolation (Kogut & Kulatilaka, 1994). It is common for companies to use financial indicators that fail to take into account the value derived from leveraging platform technologies. For example, surveys cited by Meyer et al. (1997) showed

⁴⁶ The real options logic may help counter some managerial decision biases identified in the literature. One common observation is that the existing asset base in companies tends to skew decision making in a conservative direction, by focusing managers on product development projects that represent short term and low risk options. The tendency that previously incurred costs influence decision makers to become more loss averse is called a reverse sunk cost effect (Zeelenberg & van Dijk, 1997).

that measures of R & D performance in many companies are short term oriented and focused on single products. The indicators they proposed therefore focus on the ability of existing platform to generate a continuous stream of derivative products at a low incremental cost over an extended period of time. This can be done by looking at the sales of products belonging to a product platform, relative to the cost of R & D needed to develop the initial platform and the cost of developing the follow-on products. The same argument applies to budgeting and cost management in manufacturing systems. As pointed out by Shirley (1992), today it is rarely meaningful to ask the question, What does a product cost? Although there are variable costs that can be uniquely identified with each item of production, one also needs to consider the “joint” costs of developing and manufacturing a family of products, and the “common” costs of developing and manufacturing modules that are shared by all products in the system.

An important insight gained from the real options perspective concerns the relationship between cost and flexibility. An emphasis on cost reduction is usually viewed as antithetical to the encouragement of product innovation. But if we conceptualise the investments needed to commercialise a technology as the “exercise price” of an option, we see that lowering production costs essentially increases the value of options held (by reducing the exercise price), as well as the number of options available to the firm given a certain level of investment (Sanchez, 1993).

As pointed out by Kogut & Kulatilaka (1994), the real options logic is not limited to specific technologies - investments in broader organisational capabilities such as quality improvement and cycle time reduction are also platforms in that they support strategies into a wide range of opportunities. However, the current techniques for valuing real options are mainly focused on options that are either inherent in the investment, such as the right or ability to abandon a project, or specific technologies, such as flexible manufacturing systems. It becomes more complicated to apply these techniques with options that arise from broader organisational capabilities that need to be created through conscious planning and design. In the present context

the main point is simply to illustrate that the financial logic represents a way of interpreting and analysing modular systems that complements the other perspectives described in this chapter. Although it might be difficult to value exactly the real options that a firm may possess or acquire, an important contribution of this perspective is that it forces managers to consider the specific factors that lead to flexibility in their firms' input and output markets, as well as the cost of acquiring the resources that may provide the firm with more strategic options (Sanchez, 1993).

2.2.4 Organisational design and learning⁴⁷

2.2.4.1 Knowledge requirements for modularisation

Modularisation requires knowledge of existing and potential component interactions - what some authors call *architectural* knowledge (Henderson & Clark, 1990; Sanchez & Mahoney, 1996). Yet for complex products, it is not uncommon to find that there is incomplete knowledge of component interactions. For example, Sabbagh (1995) described the development of airplanes and how interdependencies are discovered. As one of his informants expressed it:

You have five thousand engineers designing an airplane...It's very difficult for those engineers to coordinate...and it's very costly. You end up with an airplane that's very difficult to build. The first time that parts come together....they don't fit (p. 59).

In other words, interdependencies are often discovered during development. These interdependencies⁴⁸ are typically resolved by means of iteration: once they are discovered, the

⁴⁷ The application of the modularity concept to organisation design is discussed in detail in chapter 4. This section thus places its main emphasis on organisational learning.

⁴⁸ As explained in Sanchez (1996), possible interferences may stem from, for example, the way components are connected to each other (the attachment interface), how power is transferred between them (transfer interface), how signals are exchanged (control and communications interfaces), the spatial location and volume of components (spatial interface), or from the way a component generates heat, magnetic fields or other effects that must be accommodated by other components.

engineers responsible for the different components first identify who is working on components that might interfere with their component, and then alter their respective designs until a workable compromise is found. Some studies of product engineers suggest that they in fact spend the vast majority of their time managing interdependencies by communicating with other engineers (Staudenmeyer, 1997). This process tends to result in idiosyncratic solutions: component designs are adapted to each other in an ad hoc manner rather than in accordance with an articulated, overall plan. Over time, engineers may learn rules of thumb this way about the components that might interfere with each other, but this knowledge may not always be formally documented or shared within the company.

Although linkages between different physical components may not be codified, they are often reflected in the communication channels that develop within a company (e.g., “A reports to B”; or “go to Y if you have problems of type X”). Thus, knowledge about component interactions is often implicit and embedded in social networks and procedures within the firm.

This contrasts with the way most firms handle *component-level* knowledge. The core concepts underlying physical components tend to be managed explicitly and be the main focus of attention as a firm develops its technology. Henderson & Clark (1990) argued that once a dominant design (i.e., architecture) has emerged in an industry, experimentation and learning about alternative configurations tend to cease and learning then focuses on making incremental improvements in components. But if architectural knowledge is implicit and embedded in practices and procedures (such as communication channels), it will be hard to recognise and difficult to change. It will also seriously hamper the ability to create modular systems that support reconfigurability and commonality. Whereas components in integral designs are optimised for one application, designers cannot proactively design modular components for re-use and reconfiguration (i.e., multiple applications) without knowing how the components are to interface with other system elements.

Cole (1995) have pointed out that individual and organisational knowledge are relatively independent constructs. The often tacit knowledge of individuals does not automatically get translated into organisational knowledge. The knowledge required to create modular architectures (i.e., that related to component interactions) may also be dispersed among several individuals in different functions. People in sales who handle product warranties and complaints may form an impression of where quality problems tend to occur (some of which may be due to poorly functioning interfaces⁴⁹). Manufacturing workers may observe how a new design (e.g., a physically smaller circuit board) leads to electromechanical interferences between certain components. These workers may be functionally distant from the engineers determining the product architecture. An integrative codification process is therefore necessary to convert tacit into explicit knowledge (Bonora & Revang, 1993). Once the knowledge has been codified, the product structure may be decomposed according to modular criteria. Codification is thus a prerequisite for modularisation, in fact, it is impossible to decompose a system that does not have an explicit structure⁵⁰.

Once the product architecture has been established, there is the question of how to represent and maintain the knowledge. Although modularisation enables variety through reconfigurability, it does not necessarily mean that all modules can be combined with each other; in fact there typically remains a number of technical “constraints”, i.e., rules that specify combinations that are allowed or not allowed. For example, in a car manufacturing company a constraint may be: “All cars with turbo engines must be fitted with ABS brakes”. Within engineering, there is a stream of literature focusing on “configuration systems”, which are IT

⁴⁹ For example, at the jeep division of a U.S. auto manufacturer, an internal study found that the majority of quality problems were due to poor interfaces, e.g., the attachment interface between head lamp and chassis (personal communication with Robert Thomas, associate partner, Accenture).

⁵⁰ This requirement is shared with practically all other approaches to quality and process improvement. (e.g., a basic premise in the quality movement was that you could not improve a work process that had not been standardised (Cole, 1995)). At the same time, it extends the argument by emphasising architectural knowledge.

systems that support engineers in correctly configuring products by composing a set of predefined modules. Jensen (2000) called engineering knowledge about module interactions for *interaction knowledge* (similar to the term architectural knowledge used above).

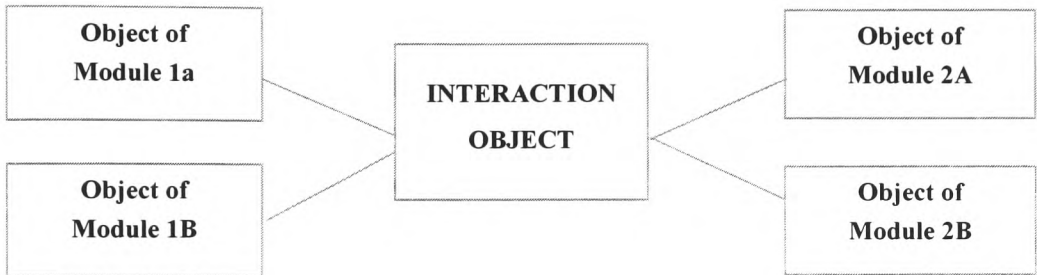


Figure 2.15. Architectural knowledge represented in an object oriented configuration system.

Configuration systems can represent modules as objects. Jensen (2000) proposed that interaction knowledge be contained in separate “interaction objects”, which models the interactions between two or more modules. The interaction objects should contain all generic knowledge required for making a decision about which module to combine with any other module. The interaction between engine size and brakes may be captured in a generic way by formulating a rule relating engine effect to required brake power (to achieve the same stop length during braking). This interaction object will remain the same even if new engines and braking systems are added as potential options⁵¹. As an example, if a diesel engine is ordered, it would be fitted with ABS brakes depending on the engine effect.

⁵¹ In one truck company where I worked as a consultant, constraints were listed for each component without specifying the underlying engineering knowledge used to derive the constraint. This system was ambiguous and extremely hard to maintain. For example, it was usually difficult to say how much effort (e.g., hours of redesign) that was required to remove the constraint; some constraints were related to fundamental, technical interferences and others merely to incompatible geometrical interfaces or even traditional customer preferences. When new options were added, it was also difficult to generalise existing constraints. This lends some anecdotal support to Jensen’s (2000) call for maintaining “interaction knowledge” in easily accessible configuration systems.

2.2.4.2 Process decomposition, platforms, and capabilities

Process capabilities are based on knowledge about technologies and procedures used to produce and deliver products or services. In the mass production paradigm, process capabilities were often designed for specific product requirements and efficiency was achieved by achieving a precise linkage of the two. By de-coupling process capabilities from existing product requirements, they become more generic and flexible since they can be re-used and leveraged across different products (Boynton & Victor, 1991). Even though product life cycles are becoming shorter, the underlying knowledge about how to produce them may thus be relatively stable and applicable to a variety of end products.

Most approaches to enhancing process capabilities start with the identification and codification of processes. This has been part of most applications of total quality management and business process reengineering. More recently, consulting firms have started building and maintaining on-line repositories and databases of organisational processes (usually also with “best practice” solutions to common problems). An example of such a database is the Process Handbook, originally developed by scholars associated with the MIT Centre for Coordination Science (Malone et al., 1999)⁵². The Process Handbook represents processes by using a generic structure or a “process grammar” (Pentland, 1995), inspired by object structures in object orient programming. Processes are decomposed into activities, which may in turn be further decomposed into sub-activities. For example, one might examine a basic food service transaction, which consists of the following steps (Figure 2.16): Order the food, cook the food, serve the food, eat the food, and pay for the food.

⁵² The process handbook was later developed into a commercial offering and is now managed by a company spun off from MIT (Thomas Malone, personal communication, June, 2000)

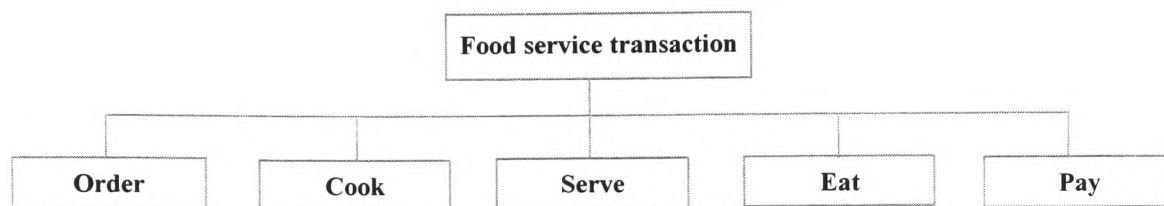


Figure 2.16. Process decomposition. Adapted from Pentland (1995).

As in object hierarchies, each element inherits features from its parents (although each element is itself a complex entity). For example, in a food service process one sub-activity may be grilling, which inherits the basic process decomposition of its parent (order, cook, serve, pay, etc.).

In addition to describing the activities in work process, the Handbook also attempts to capture the relationship between the activities. Pentland (1995) described three generic types of dependencies:

- one activity produces a resources that is consumed by another activity (e.g., cooking produces food which is then served)
- two activities share the same inputs (e.g., two meals must be cooked using the same stove)
- two activities share the same output (e.g., two different servers waiting on the same table).

The basic assumption is that such dependencies will require some kind of co-ordination by the actors in the process (e.g., through resource allocation, scheduling, etc.). By identifying dependencies one can also derive a set of constraints that can be used to evaluate the feasibility of proposed new process designs generated from resequencing and recombining the basic activities represented in the Process Handbook.

2.2.4.3 Effect of modularisation on learning processes

Sanchez & Mahoney (1996) considered the strategic flexibility an attempt to facilitate both component-level and architectural-level learning by creating a system of loosely coupled learning processes under the embedded co-ordination of a modular product architecture. Sanchez & Mahoney (1996) distinguished between four different modes of learning in product development processes:

- Component level - incremental learning that leads to limited functional improvements
- Component level - modular learning about new kinds of component technologies
- Architectural learning about new ways of configuring existing components
- Radical learning that leads to changes in both components and product architectures.

Their approach thus intentionally separates component and architectural level learning. This is a departure from earlier literature, which usually argued that close and frequent interactions (i.e., tight coupling) between research and development (R&D) and other functions would lead to more effective product innovation, by providing R&D with information about market needs and the other functions with new knowledge about possible technologies (e.g., Leonard-Barton & Sinha, 1993). However, Sanchez & Mahoney (1996) maintained that tight coupling will compromise architectural learning. The high-pressure, day-to-day development processes concerned about incremental improvements will typically constrain the time and resources that can be devoted to identifying future and radically new architectures. Instead of tight integration they proposed that the processes of component level and architectural learning be *periodically coupled* in order to re-define new overall product architectures.

Apart from technological systems and product development, it is also possible to imagine a modular framework for organisational learning more generally (see e.g., Mathews, 1996). For example, one can distinguish between intra-module, inter-module, and systemic learning. Intra-

module learning occurs when, for example, the outputs from one organisational unit improve over time as a result of experience⁵³. This type of incremental learning is captured in the well-known concept of the learning curve (Argote, 1993). Alternatively, it may involve more radical re-conceptualisations of the individual units' products or work processes. Systemic learning occurs when the overall organisational architecture is changed, which may include addition or removal of modules and changes in the interfaces that govern interaction between modules. As different modules interact with each other to produce joint outputs, there will also be inter-module learning that may suggest more effective ways of collaboration and co-ordination, which can be integrated into future re-designs of the organisational architecture⁵⁴.

2.2.4.4 Sub-section summary and discussion

One can view the creation of modular architectures as a process of *knowledge integration* (cf. Grant, 1996). It involves the development of *articulated knowledge* (Sanchez, 1997) about component interactions through codification of tacit knowledge often held by individual organisational members. When an overall architecture has been established, the on-going maintenance and development of knowledge is made more efficient by the fact that knowledge itself can be decomposed (cf. Simon, 1962). If this decomposition follows the basic structure of product and process decompositions, one achieves a correspondence between task requirements and the formal structure in the organisation, which should facilitate knowledge integration (cf. Grant, 1996).

⁵³ Huber (1991) used the following definition: "An entity learns if, through its processing of information, the range of its potential behaviours is changed" (p. 89).

⁵⁴ Mathews (1996) described "inter-holonic" learning to be "changes in rules followed by any holon, induced through its interactions with holons on the same level. This conceptualisation is therefore not entirely consistent with Sanchez & Mahoney's theory, which holds that the architecture of a modular system should be frozen and only updated on a periodic basis.

Sanchez & Mahoney (1996) further described how modularity in products and processes enable modular learning processes that separate component and architectural-level learning. One likely implication of this framework is that component level learning becomes more distributed. Baldwin & Clark (1998) described the emergence of a dual structure in the modular marketplace, in that companies will tend to specialise either as designers of modules or as architects that create (and control) interfaces. For example, in the automobile industry much of the technology development is decentralised to the subcontractors that manufacture the various components of a car - the electrical system, cooling, braking, seats, dashboards, bumpers, etc. (Boisot, 1998). The large assemblers control the interfaces as specified by their platform concepts, and their learning processes are directed more toward developing architectural knowledge (Sanchez & Mahoney, 1996).

The notion of process decomposition has become well understood and widely disseminated, thanks to an extensive practitioner literature on re-engineering and total quality improvement. A natural next step is to catalogue and categorise business processes in different firms. I would expect modularity scholars to be sympathetic to the general objectives and principles of the Process Handbook project. However, some minor differences in terminology and definitions should be noted. Although the Process Handbook deals explicitly with interdependencies, the conceptual framework seems to only partially overlap with the definition of interdependency used in the modularity literature. The process handbook basically refers to workflow interdependencies, i.e., relationships between activities that arise as a result of some resource that they have in common as an input or an output. The product development literature distinguishes between modularity in design and in the physical product⁵⁵. Product architectures that are modular in design may be tightly integrated as a physical product in the sense that the

⁵⁵ Baldwin & Clark (1994) distinguished between modularity-in-design, modularity-in-production, and modularity-in-use. In general, modularity in designs should enable modularity in production processes, but it is helpful here to keep them conceptually separate to gain definitional clarity.

components all depend on each other (e.g., if you take out the hard disk of a computer, it will not function properly). One can consider as an example the activities in the food transaction described by Pentland (1995). From a work flow perspective, the different activities are interdependent to some extent in that one activity consumes resources produced by the other. However, from a modular (design) perspective we would normally define two activities of a work process as modular if they have standard interfaces that permit parallel processing, substitution and recombination, etc. of the components or activities. Thus modules in the actual process may exchange inputs or outputs as long as these conform to the overall architectural specifications for interfaces. One could say that modular designs are more like menus listing alternative dishes, or recipes allowing different ingredients, if they allow mixing and matching of several foods/ingredients to produce different dishes. The cooking process may physically integrate the ingredients during the production process, perform different activities using the same equipment etc. but this does not affect the degree of “modularity-in-design”.

2.3 DEFINITION OF MODULAR ARCHITECTURE

Based on the above discussion we can define a product architecture as having three key characteristics:

- It is an overall framework that specifies all known component interfaces.
- It is developed *in advance* of development efforts (developing architectures thus depend on the ability to *foresee* product and process interdependencies).
- It results in a codified, organisational asset (as opposed to tacit, private knowledge)

In addition, we can define a *modular* architecture as one that:

- minimises interdependencies between different modules by having only one (or a very low number) of functions per module (Ulrich & Eppinger, 1995).
- contains standard interfaces that allow changes in modules within a range of variation that has been specified (Sanchez, 1995).
- as a result, allow component *reconfigurability*, in that components can be substituted with other components as long as they conform to interface specifications.

In a similar way, we can define a *process platform* as a high-level decomposition of a firm's processes containing specifications of standard process interfaces. As with product platforms the process platform will usually have a hierarchical structure, with core processes decomposed into sub-processes, which in turn may be decomposed into activities and tasks, etc. In table 2.5 I summarise this definition and the key causal claims made by modularity scholars (in particular, Sanchez, 1995).

Table 2-5. Key causal claims underlying this research

Stages or actions	Inputs and outcomes	Description
Selection of system	Complex system  <i>basis for</i>	System containing several interrelated parts, that is “nearly decomposable” <i>Allows several alternative decompositions (i.e., number of modules and boundaries)</i>
Decomposition of structure and creation of design rules (architecture)	Modular Architecture  <i>allows</i>	Modular = System containing relatively independent parts with <i>standard interfaces</i> Architecture = Codified structure adopted to purpose <i>Purpose: decomposition that optimises customer requirements while minimising cost and maximising flexibility</i>
Application of modular operators ⁵⁶ (substitution, exclusion, etc.)	Combination Recombination  <i>contributes to</i>	Modules are combined to form a particular product / process configuration Modules are recombined (reconfigured) in new configuration <i>Confer firms with: Economies of substitution Economies of scope Real options (strategic product options)</i>
Adaptation / change	Dynamic capabilities / Strategic flexibility	Firm abilities to respond to changes in markets and technologies

⁵⁶ See section 2.3.2 below.

To summarise the arguments made regarding the benefits of modularity, one can distinguish between two major effects⁵⁷, illustrated in Figure 2.17. On the one hand, modular architectures increase *flexibility* by allowing component variety and substitution, the relationship marked (a) in the figure. On the other hand, through higher component commonality and carry-over, modularity also contributes to increased *efficiency*, the relationship marked (b) in the figure⁵⁸.

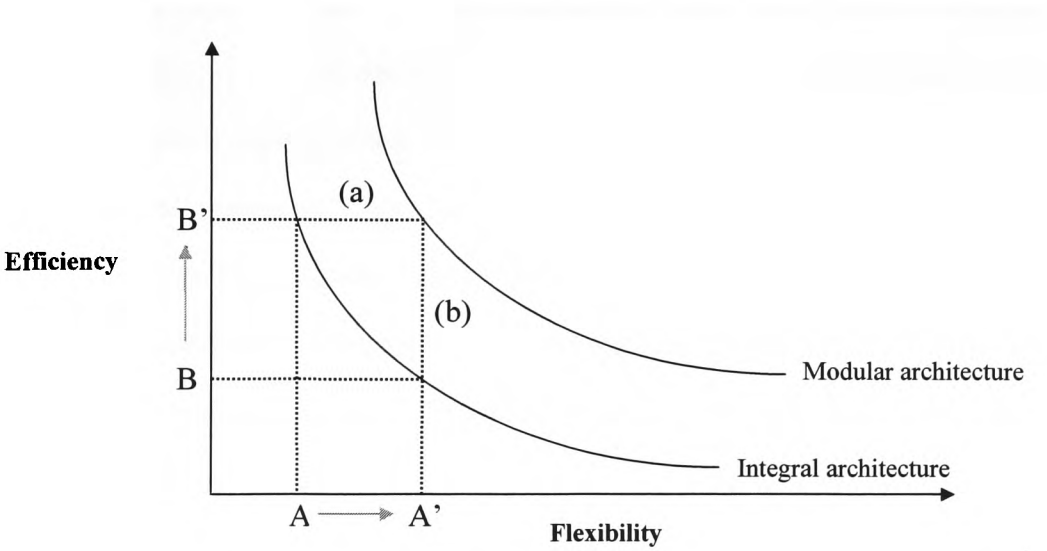


Figure 2. 17. The predicted effects of modularity.

It is true that *integral architectures* sometimes may lead to high degrees of flexibility as well (e.g., if a firm is able to quickly, and repeatedly, develop integrated designs in response to new market needs). But for the reasons discussed above (section 2.2.1), this approach will normally be far less economical. In this sense one can consider (the degree of) modularity as a measure of the degree of efficiency by which a firm achieves a given level of flexibility.

⁵⁷ In the interest of simplicity the figure only covers “first-order” effects, cf. discussion above.

2.3.1 Comments regarding definitional issues

It has been argued that by adding the criterion of reconfigurability, it becomes difficult to find real life examples that conform to the definition of modularity. There are occasionally papers published where a less stringent definition is used (i.e., a definition that includes non-reconfigurable systems as “modular”). However, the definition proposed here has several advantages. First, it is consistent with current usage of the term by the majority of scholars working in the field (e.g., Sanchez, 1995; Baldwin & Clark, 2000; Garud & Kumaraswamy, 1995). Secondly, as pointed out in chapter 1, I build on what is essentially a normative framework. There is no requirement that a normative concept should reflect the current reality in firms - whereas descriptive frameworks usually present abstractions or characterisations of *average or typical* cases, normative theory seeks to define a concept of an ideal form or some principle or practice that is predicted to lead to performance improvements if adopted by a firm. Thirdly, I also believe that the definition I propose is helpful for descriptive purposes. As described above (section 2.2.1), integral and modular architectures differ as a matter of degree and may thus be considered opposite ends on a theoretical continuum (Table 2.5⁵⁹). Note that by using a less stringent definition it would be impossible to distinguish between higher or lower *degrees* of modularity. Given that there is some variability among organisations, cases characterised by a moderate degree of modularity would be grouped together by cases characterised by a high degree of modularity⁶⁰. The right end column represents the definition proposed here. By excluding this column, or collapsing it with the middle column, one would confound the important difference drawn here between decomposed systems and systems having standard interfaces.

⁵⁸ As this figure illustrates, one does not presuppose that modularity will completely remove the trade-off between flexibility and efficiency, but that the curve will be shifted outward allowing higher degrees of both simultaneously.

⁵⁹ For the sake of simplicity, Table 2.5 only includes product design examples and three main intervals.

⁶⁰ I thank Ron Sanchez (personal communication, June 12, 2000) for pointing this out to me.

Table 2-6. A continuum illustrating degrees of modularity

		
Integrated architecture		Modular architecture
<i>Consumer perspective</i>		
• One standard product package is offered	• Consumers can choose some components to match their needs	• Consumer can configure products individually • Components can be substituted and upgraded by user (i.e., “plug-and-play” modularity)
<i>Design/ manufacturing perspective</i>		
• Unique "optimized" design approach • Interfaces determined during development process • Components have interacting functions	• Some components are standardized • Limited component sharing and carry-over • Components have distinct functions	• Interface specifications are specified at beginning of development • Extensive component sharing and carry-over • Components have standard interfaces
<i>Interpretation</i>		
• System is integrated	• System is “configurable”	• System is reconfigurable

Similar arguments can be made for other levels of analysis, for example, organisational. If we are to properly differentiate between different organisational forms, it is not enough to distinguish vertically integrated firms from firms that have “disaggregated” and thus outsourced some non-core functions. Emerging models promise even higher degrees of modularity. One example is modular business networks, i.e., groups of small firms in temporary alliances organising themselves into customer-specific value chains (e.g., Wolters & Hoogeweegen, 1999). Such firms may establish standard protocols for initiating and exiting from their short-term

relationships and thus will come to represent a system that is not only extensively decomposed but also highly reconfigurable.

Rather than seeking theories that perfectly describe the status quo, we need conceptual frameworks that capture some elements of current trends while matching some elements of a plausible future⁶¹. I believe the definition proposed here achieves that purpose.

2.3.2 Similarities and differences with related concepts

To improve clarity in terminology, it is often helpful to compare a theoretical concept with other concepts that pertain to a similar phenomenon. In this section I therefore discuss to what extent the concept of modularity overlaps with the concepts nearly decomposable systems, hierarchical decomposition, loosely coupled systems, and un-bundling.

Nearly decomposable systems. Some have questioned whether current definitions of modularity really are consistent with H. A. Simon's definition of nearly decomposable systems. One should keep in mind that scholars today make no claim to this end, beyond stating that their work *builds* on that of Simon⁶² (e.g., Sanchez & Mahoney, 1996; Schilling, 2000). Nevertheless, it may be useful to consider how these concepts relate to each other in order to improve the clarity of the conceptual framework proposed here.

Simon's main purpose was to identify characteristics of *all* complex systems. The term nearly decomposable systems means complex structures that are organised in a hierarchical fashion and that have sub-systems that are relatively independent on some dimension. The concept of modular architecture goes further than this in two important respects. Whereas Simon's primary interest was in describing natural systems, modularity scholars are describing constructed systems. As explained above, the notion of architecture means a system that has been

⁶¹ I here paraphrase March (1995).

intentionally decomposed in a way that isolates functional requirements in separate modules that have well documented, *standard interfaces*. In other words, not all complex systems that are decomposable have modular architectures (Shilling, 2000).

Modularity, through the notion of standard interfaces, also adds the potential for reconfigurability, the ability to exchange and substitute different modules with one another. Simon did not explicitly discuss reconfigurability in his 1962 essay (he did mention combination of modules - but not re-combination). Nevertheless, I would argue that the concept of modularity as defined here is a logical extension of the approach that Simon outlined. After all, he was interested in explaining the characteristics of complex adaptive systems that help them to evolve fast. He mentioned genetic evolution as one example, and pointed out how the existence of stable intermediate forms (sub-assemblies) speeds up the process of evolution. The basic argument is that environmental disturbances may be localised within specific subsystems, which increases the survivability and adaptability of the overall system.

However, his example only illustrates some of the effects of modularity as defined here. Other aspects of biological evolution may be used to illustrate the concept of *reconfigurability*. Consider the structure of genes and how their function is altered (Watson et al., 1983). Early on in this century, it was found that genes contain segments of DNA and that DNA was made up of four chemical bases called nucleotides (A - adenine, G- guanine, C - cytosine, and T - thymine)⁶³. Several years later, it was confirmed that DNA molecules were strictly linear in that they convey genetic information solely by the sequences of the four bases⁶⁴. It was also found that they are arranged in pairs, with one base for each of the two strands in a double helix. Watson et al. (1983) observed that DNA chains are both highly regular and highly irregular: the “backbone” of the

⁶² To the best of my knowledge, Simon never used the concept of modularity.

⁶³ The human DNA has about 50,000 genes containing 3×10^9 nucleotides.

⁶⁴ Sequences of three of these nucleotides are called codons (AAA, AAC, AAU, etc.). The four nucleotides can be arranged in various combinations to form 64 codons ($4 \times 4 \times 4 = 64$). 61 of the 64 code for the 20

DNA contains *identical repeating* groups of sugar phosphate residues (phosphodiester bonds). The four different bases can be attached in any order to the backbone, but the *linkages* that bind the nucleotides together are very simple and always the same: a carbon atom of one deoxyribose residue to one carbon atom of the successive nucleotide. This is analogous to a platform in that many components (i.e., base sequences) have the same interface (i.e., chemical bond) to a common structure (i.e., the backbone of DNA).

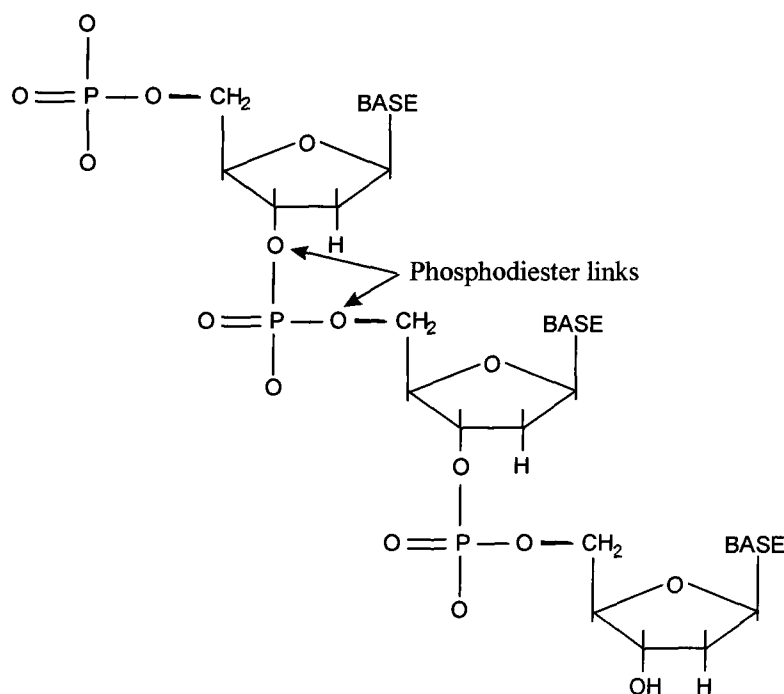


Figure 2.18. Regular phosphodiester bonds between sugar and phosphate groups that form the backbone of DNA. Adopted from Watson et al. (1993).

different amino acids (many amino acids are specified by more than one codon), and the three that do not code for stop signals that indicate termination of the chain.

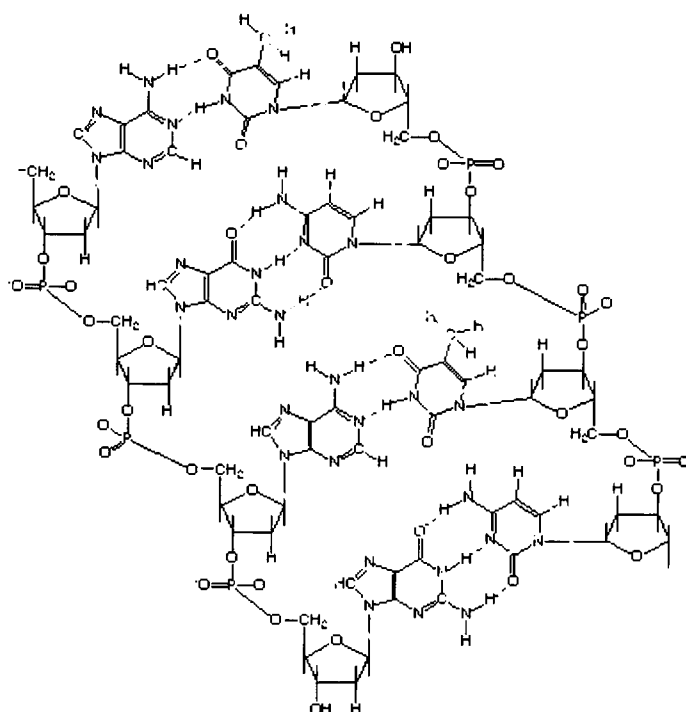


Figure 2.19. The backbone of the two strands of the double helix linking nucleotides.

Different types of *mutations* are the source of genetic variation⁶⁵ - as well as the cause of some genetic disorders affecting the nervous system. Mutation takes place when an organism undergoes spontaneous genetic change during replication (i.e., the DNA strand is not copied exactly). Mutation is basically a change in the linear sequence of the nucleotides of DNA⁶⁶. For example, one base may be added, lost, or substituted by another. This results in the DNA passing on other types of genetic information (i.e., coding for different amino acids in its protein product). The *rate* at which mutation occurs determines genetic variability at the molecular level. The *significance* of a gene mutation depends on the amount of effect on the organism (i.e., the trait or

⁶⁵ The other possible source of genetic variation is “epigenetics”, i.e., chemical groups that modify the function of the bases of the DNA strand.

characteristic produced), the adaptive advantage or disadvantage of the mutant, and the role of the mutant in interaction with the population environment. In other words, one can say that mutations represents a “reconfiguration” of the gene structure that results in a modification of function, which may either be adaptive or maladaptive.

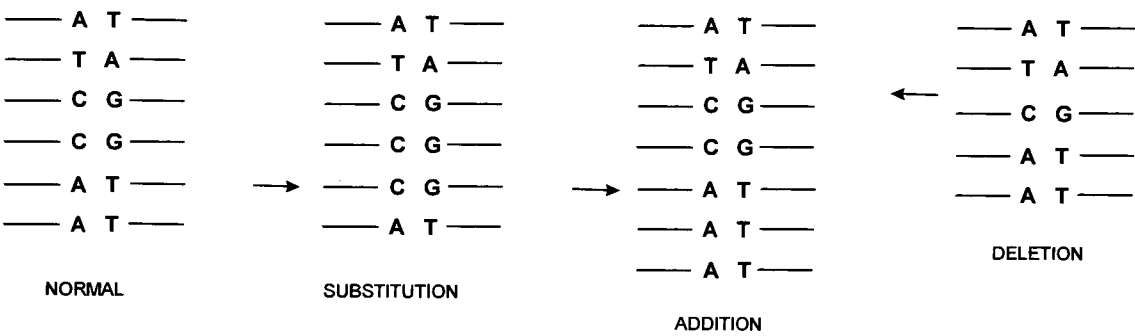


Figure 2.20. The three mechanisms of mutation: substitution, addition and deletion of a base pair in a DNA strand (the pair corresponds to the two strands of the double helix).

Note that in addition to having a hierarchical structure that permits reconfiguration, the actual mechanisms for reconfiguring the DNA are limited to a small set of standard *genetic operators*. Biologists have documented that these operators, applied at different stages and in different combinations, can generate all possible evolutionary paths for the structure of DNA. Baldwin & Clark (2000) built on this finding and suggested that all modular systems may have a finite set of underlying operators by which they change existing structures into new structures. For example, reconfiguration may be represented as an application of the operators substitution (e.g., upgrade of an existing module) or addition (e.g., a module is added to the configuration).

In sum, not all complex systems that are decomposable have modular architectures as defined here. Decomposable systems simply mean complex structures (including natural systems)

⁶⁶ In addition to genetic mutation, chromosomal mutation also occurs (i.e., variation in chromosome number or structure).

that are organised in a hierarchical fashion with relatively independent sub-parts. The notion of modular architecture adds the criteria of intentionality and reconfigurability⁶⁷.

Loosely coupled systems. The points that Weick (1976) made about system adaptability were similar to those made many years earlier by March & Simon (1958 /1993), who noted that the rate of innovation can be increased by the creation of self-contained units (p. 220). Scholars also make essentially the same argument when proposing that component upgrades can be made faster in modular product architecture. Nevertheless, there are at least three fundamental differences between Weick's (1976) theory and current theories of modular architectures:

- The technology management literature describes modularity as an *intentional and strategic* decomposition of product designs. It does not appear that Weick was talking about *intentional* decoupling in the architectural sense, but what we could call “emergent decoupling”, that is, elements that come together over time and gradually become a stable (yet fragile) entity⁶⁸. As scholars within the sense-making perspective have pointed out, structures can emerge even without explicit guidance. Organisations naturally enact their own “decompositions” by treating some units as separable from others (Cohen & Levinthal, 1993). However, proponents of modular systems would argue that a purely emergent process is unlikely to result in a decomposition that is optimal in terms of satisfying organisational goals.
- It is clear that Weick considers linkages to be tacit in nature (e.g., Weick, 1976, p. 3 and p. 13). He pointed out that loosely coupled systems are inherently ambiguous. Organisational members therefore have to devote considerable time and effort to construct social reality in order to make sense of unclear boundaries. In contrast, the modularity approach rests on the assumption that

⁶⁷ An even closer analogy to the process of product and process design would be *recombinant DNA*. Recombinant DNA is the experimental joining or recombination of pieces of DNA from two different species. This can be done by many different techniques such as cleaving DNA by microbial enzymes and chemically synthesising DNA (Watson et al., 1983). Whereas mutations are random, recombinant DNA thus represents what we could call intentional reconfiguration of genetic material (done with the purpose of eliminating diseases of genetic predisposition or creating new organisms).

ambiguity can and should be reduced (e.g., through specifying functional requirements and interfaces). As stated by Haeckel (1999, p. 105-106):

Ambiguity about purpose or principles undermines coherent action. It leaves unanswered questions about which of two or more meanings should apply in a given case (...). Good system designs takes as a principle the importance of reducing ambiguity.

- Although modularity deals with systems of relatively independent sub-parts, the architectural approach to modularity actually presupposes *tight* linkages between some system elements. For example, it requires tight coupling between (current or future) functional requirements and modular decompositions. It is unclear whether the systems described by Weick have this quality, presumably they can be loosely coupled from external demands. Although this feature has been explained as a method by which organisations “buffer” themselves from environmental changes⁶⁹, it is hardly a prescription for making organisations more *responsive*. In fact, loose coupling between stakeholder expectations or requirements and organisational policies and programmes is often used in the literature as an explanation for how functions and policies become marginalized and disconnected. For example, a company may adopt the rhetoric of being “customer focused” without making any substantive changes to the way products or services are defined or delivered, how resources are allocated, or how its people are evaluated and compensated⁷⁰.

⁶⁸ Langlois (1999) observed that “unselfconscious processes of trial-and error learning” rarely result in a modular system.

⁶⁹ This view dates back to Thompson (1967).

⁷⁰ In discussing what firms do to increase their market orientation, Day (1999) observed that a popular method is to create councils and steering groups. But he concluded that this method is generally ineffectual as the groups rarely have the required resources or mandate for making real changes in the organisation.

An easily decoupled structure or policy is often used to create the appearance of conformity to external expectations while at the same time insulating much of the organisation from those same expectations. Although the structure or policy exists, there is no guarantee that it will regularly interact with other organisational policies and functions or that employees will be accountable to it. (Weaver et al., 1999, p. 1999).

In sum, it is difficult to use amorphous concepts such as loose coupling to explain how organisations increase responsiveness and adaptability. It is particularly confusing when used as a characterisation of entire systems rather than of system elements. A flexible firm is likely to have both loosely coupled and tightly coupled elements.

Hierarchical decomposition. Williamson's principle of hierarchical decomposition was based on observations of the multidivisional form as it was adopted by large firms during the 1960's⁷¹. Interestingly, Williamson (1975, p. 149) observed that "organisational innovations may now be in the making that will obsolete [the M-form] in part - but which academics will identify as noteworthy only after several years." In fact, Zengerly & Hesterly (1996) made exactly this point in describing the current "disaggregation" of vertically integrated firms. They argued that the current structural shift toward smaller and more decentralised forms is analogous to the shift that occurred in the 1950's and 1960's from functional to multidivisional structures.

Despite these similarities, there are also a couple of differences that should be noted. Williamson saw cost minimisation as the key driver for organisation design. As I have described already, modularity scholars would argue that minimising transaction costs is less important than having organisation designs that are capable of reconfiguration. Moreover, although Williamson (1975) briefly mentioned the effect of production methods on organisation structure, his

⁷¹ Williamson's principle of hierarchical decomposition was an elaboration of Simon's notion of hierarchies in complex systems, consequently some of the comments above in relation to nearly decomposable systems apply here as well.

perspective is always transactional/economic. He did not consider product structure in any depth or ponder the effect of task interdependencies within a multidivisional company. This is an important point, as some firms that adopted the multidivisional form appear to have divisionalised their structures without changing the underlying task interdependencies. Hoskisson (1987, cited in Argyres, 1995) found that M-form adoption was associated with worse performance for vertically integrated firms and improved performance only for *unrelated* diversifiers. For vertically integrated firms with technologically interdependent product structures, the multidivisional form might simply have added coordination costs as managers were forced to work across new boundaries to develop and maintain product offerings (cf. Argyres, 1995). By highlighting the interdependencies between product (technology) structure and organisation design, the strategic flexibility approach suggests that modularisation needs to precede organisational disaggregation.

Bundling - Unbundling. A bundle is a group of products or features offered as a package (i.e., priced and delivered as one unit). The opposite is unbundling, the separation of an aggregated group of products or features into individual items. Some scholars have studied how modularisation has enabled unbundling as a product evolves over time. For example, Langlois & Robertson (1992) tracked the development of music reproduction technologies from the early phonograph to today's hi-fi systems. They found that many products start out as integrated systems but then become more modular as the interfaces are better understood and as leading firms manage to establish industry-wide standards for key modules. For example, the early phonograph was an appliance, where the turntable, pick-up, amplifier and speaker were all part of the same system. These components later became separate modules, often manufactured by different firms. A more recent trend, however, is towards "re-bundling" of the modules that were once unbundled, in the sense that hi-fi equipment is increasingly offered as complete packages or systems.

Thus to some extent one can say that modularisation enabled unbundling. However, one should keep these concepts separate as (un)bundling refers to a commercially driven “decomposition”, which may not be equivalent to the technical decomposition of the product (although the technical product structure should allow for as many degrees of freedom as possible in the commercial offerings). Note that in the example just mentioned, we would expect that the underlying product structure of audio systems remains modular (at the design level) even if components are bundled into a stereo system.

The extent of bundling generally increases as a technology matures. Once product performance reaches a threshold level, the added performance of a uniquely configured system does no longer compensate for the search costs associated with having to select individual options. It is also possible that modularisation may directly spur what we could call “complexity-reduction” bundling: If the product consist of a high number of components, the flexibility afforded by modular architectures may sometimes lead to so much product variety that it becomes difficult for some customers to orient themselves and choose an optimal product configuration. By analysing customer preferences for combinations of product features and keeping track of configurations of sold products, companies can “bundle” regularly sold configurations into standard packages and thus reduce the customer-perceived complexity of their product offering.

2.4 CURRENT DEBATES AND RESEARCH AGENDA

Despite the growing literature on modularity there are some areas that have received relatively little attention. This section identifies three key gaps in the literature where future research could contribute to a more complete understanding. These gaps were the motivation for the research that is reported in the chapters to follow.

2.4.1 Implementation and actual use of modular principles

As any prescriptive framework the modularity approach should be confronted with the complexity inherent in real world phenomena to examine its pragmatic validity to practitioners. It is difficult to interpret data about performance implications - any failures of implementation may result from a host of factors including inappropriate understanding of the principles, poor execution, or the principles themselves might turn out to be invalid or counter-productive in some contexts not foreseen by the theory. In 1997 *Financial Times* presented a survey of engineering and assembly companies in the United Kingdom. They cite an IBM study that concluded that there are good commercial reasons for adopting modular principles⁷². However, they also reported that many businesses are finding difficulties implementing the techniques. The IBM consultant who was interviewed concluded: "Overall the picture is pretty mixed when it comes to introducing these ideas" (Marsh, 1997, p. 16). Previous research on the implementation of flexible manufacturing systems during the 1980's generally showed that companies had a tendency to underestimate the importance of human and organisational issues. This research also indicated that implementation of innovative work practices were more strongly related to outcomes such as plant productivity than implementation of new technical systems (e.g., factory automation). By analogy one can extend this line of reasoning to the issue of strategic flexibility. It is possible, for example, that companies have attempted to introduce modularity solely as a redesign of products, ignoring the fact that product structures are often embedded in complex tacit knowledge and relations (Henderson & Clark, 1990). It is also possible that modular systems are implemented with a different strategic logic than the one assumed in the academic literature, for example, newspaper reports seem to indicate that the key rationale is often cost reduction rather than flexibility.

⁷² The article only covers mass customisation but the ideas described are consonant with the strategic flexibility perspective outlined in Sanchez (1995).

As formulated by Sanchez (1995), the strategic flexibility approach is based largely on ideas drawn from technology management, although he did take into account that increasing flexibility will require (and simultaneously enable) changes in organisational structure and in decision making processes. However, we do not yet have a very sophisticated, empirically based understanding of how technical, human and organisational factors interact to enhance strategic flexibility. Nor do we have a good understanding of the barriers that might complicate the introduction of modular systems. For this reason, it is difficult to prescribe a course of action to managers. Case based research of companies trying to implement modular systems should provide a better picture of the complexities that managers face and thereby contribute to future strategic change frameworks intended to guide managers through implementation programmes.

According to recent theorising, both successful implementation and resulting competitive advantage might depend on the degree of complementarity that is achieved between variables such as technology, corporate culture, human skills, and organisational structure. Resource complementarity is said to exist when a resource produces greater returns in the presence of another resource than it does alone (Powell & Dent-Micallef, 1997; Miller, 1996). Even though the main focus is on product modularity, the strategic flexibility approach (Sanchez, 1995) does emphasise that flexibility arises from a *set of capabilities*. These capabilities can be thought of as constellations or systems of complementary resources. If a firm makes changes to only a single or a few elements of a system it is therefore unlikely to gain a significant advantage. It is relatively, common, however, for companies to respond to more dynamic markets by making piecemeal and incremental adjustments, with insufficient attention to the need for simultaneous technical, structural, and behavioural change (e.g., Majcharzak & Wang, 1996; Dougherty & Cohen, 1995). Current prescriptive models of strategic change therefore emphasise the need for a holistic approach to change management (Worren, Ruddle & Moore, 1999). Creating resource complementarity implies that technical and structural re-design can not be done in isolation but

must be accompanied by interventions aimed at aligning culture and behaviour to the new strategic intent. Better strategic change frameworks might result if research documents the value of complementary resources in enhancing flexibility.

2.4.2 The strategic value of modularity

According to the resource-based view, competitive advantage is created by exploiting firm-specific resources. By resources it is meant anything the firm makes use of in its process for creating, producing and offering products, including skilled manpower, trade contacts, brand image, technological know-how, efficient work practices, or organisational culture (Wernerfelt, 1984, Barney, 1991). The importance of a given resource is a combination of four factors:

- 1) value (i.e., whether it helps the firm exploit opportunities or neutralise threats),
- 2) rarity (i.e., whether competing firms possess the same resource)
- 3) imitability (i.e., whether competing firms who don't have the resource can obtain it at no significant cost disadvantage)
- 4) substitutes (i.e., whether competing firms can acquire substitute resources that perform same function).

According to Barney (1991), a resource that is valuable, rare, inimitable, and without substitutes will confer a sustainable competitive advantage to the firm. A resource that is valuable and rare, but easy to imitate and with substitutes, will only generate a temporary competitive advantage - which lasts until competitors have either developed the resource internally or acquired it in factor markets.

Ghemevat & del Sol (1998) made a similar distinction between specific and generic (flexible) resources. A resource is specific to a given firm if its value to the firm exceeds its value to other firms. Resources may also be specific to certain uses if the value of the resource

decreases if the firm applies it to other uses. According to this framework, investments in specific resources require greater strategic commitment: specific resources are by definition more valuable to the firm than to other firms, which means that it is more difficult to abandon the resources by selling them in factor markets. Acquiring generic resources does not imply any irreversible commitment by the firm. On the other hand, generic resources are also available to competitors, and will not confer any sustainable competitive advantage to the firm. According to Ghemawat & del Sol (1998) it is therefore necessary to build product market positions around commitments to some firm-specific resources.

It is worth noting that this framework leads to diametrically opposite conclusions about strategic management compared to the strategic flexibility approach (Sanchez, 1995). Some authors view the market in terms of a dual structure consisting of module designers and architects (e.g., Baldwin & Clark, 1997). These authors highlight the potential advantages from being the architect that establishes industry standards, such as IBM with the PC and Microsoft with the Windows operating system. However, there is no clear consensus regarding the strategic implications of adopting modular systems. In particular, there is disagreement regarding the value of the use of modules based on industry-wide standards. In certain industries, such as software, standards create “network externalities” in that the value of owning the product increases with the number of other users of the product and complementary technologies. For example, the value of owning a computer running a certain software is dependent upon the number of other people who own the same computer, since the installed base of computers will determine the amount of software available (Langlois & Robertson, 1992). On the other hand, the “commitment” school within strategic management emphasises the risk of relying on technologies that are generic or easily imitated, and maintain that it is firm-specific resources that provide competitive advantage.

IBM’s decision about the first PC is a case in point. For Langlois & Robertson (1992), the decision to adopt an open, modular architecture was the main reason why IBM succeeded.

The IBM PC became the industry standard, whereas models launched by competitors (e.g., Texas Instruments and DEC) are now forgotten. According to Langlois & Robertson (1992) the competitors' models failed because they were based developed in-house and based on proprietary technologies. In contrast, Ghemevat & del Sol (1998) conclude:

“The simultaneous implementation of outsourcing and open architecture was a major mistake because it let hundreds of competing firms “clone” the PC by using the same peripherals, operating system, and processor architecture as IBM” (p. 33).

However, relying on firm-specific assets may be difficult in many industries (and particularly in industries exhibiting network externalities). As pointed out by Løwendahl & Revang (1998), assets are becoming parts of the environment and are therefore no longer under company control:

In many sectors today, companies can access the same assets, machinery, engineers, knowledge, and capital. (...) It can then be hard to develop unique assets as a competitive weapon. “ (p. 757).

According to the strategic flexibility perspective (Sanchez, 1995), it may be possible to develop distinctive competencies even without unique resources. Strategic flexibility depends jointly on the inherent flexibilities of the resources themselves, and on the firm's flexibilities in applying those resources to alternative courses of action. In other words, if the tangible resources are standardised the firm may gain competitive advantage from a *superior ability to co-ordinate the deployment of resources* to reach key competitive outcomes. For example, two firms using the same standard components may differ markedly in the speed at which they develop new products, or in their ability to make effective use of market information and interpret customer needs. The internal processes and routines that give rise to such capabilities may be much more difficult to imitate than physical products. The inimitability of capabilities is due to the fact that they are

built on tacit knowledge, which is often causally ambiguous⁷³. This makes it hard for outsiders (and sometimes even for insiders) to observe and identify the particular skills, systems or work practices that are causally related to successful outcomes. However, although it is likely that dynamic markets diminish the value of traditional sources of sustainable competitive advantage, it is not clear whether companies are able to compensate for this by developing inimitable internal processes. Nor is it clear to what extent companies should speed the process of modularisation if it leads to more standardised products that provide less differentiation. Research is therefore needed that looks at not only the link between modularity and (product) flexibility (two constructs that are related by definition), but tries to link modularity to firm's competitive position and business results, in order to establish whether there is a trade-off between relying on strategic flexibility and achieving sustainable competitive advantage.

2.4.3 Implications for organisation theory and design

Modularity is a general systems concept and thus applicable in many different contexts. Sanchez & Mahoney (1996) and Baldwin & Clark (2000) have already developed conceptual models for how *product development processes* may be designed according to modular principles. Yet so far, modular principles have not been applied to organisation design more generally⁷⁴. (Sanchez & Mahoney (1996) mentioned this possibility in a footnote.) In the same way as modular architectures represent a distinct alternative to integral architectures in product design, they may represent a new approach to organisation design. A key challenge is therefore to examine in more depth how different aspects of product modularity “map” to the process context. In generalising principles from technology management to organisation theory one may find that many concepts

⁷³ See Szulanski (1993) for a discussion of characteristics of work practices that affect their transferability.

⁷⁴ A possible exception is Haeckel (1999), whose work I cite in chapter 4. However, Haeckel did not closely examine how product level concepts transfer to the organisational level but used modularity more as a metaphor.

and principles are the same or at least analogous in the two domains. On the other hand, it may also be necessary to modify or extend some concepts. Research exploring modularity in organisation design should contribute to a better understanding of flexible organisational forms. It may also lead to theoretical frameworks that can serve as the basis for prescriptive approaches to organisation redesign that can be used by managers seeking to enhance the dynamic capabilities of their firms.

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3 METHODOLOGY

3.1.1 Introduction

Because this thesis is based on three separate papers using different methods, the details regarding methodology and data analysis are explained in the respective chapters. This chapter focuses on the more general epistemological, methodical, and practical issues that I was confronted with during the study, and the solutions that were chosen to deal with them.

3.1.2 General issues regarding styles of research and logics of inference

It is common to distinguish between two main types of research in management. Inductive or exploratory research, which seeks to develop theoretical frameworks, and deductive research, which seeks to *test* the propositions made by the theories. Deductive theory testing is usually done by adapting methodologies originally developed for the natural sciences, such as experimental or correlational methods, but theories in management can also be tested using qualitative methods (e.g., by using multiple case studies). Although qualitative and quantitative methods stem from two different and conflicting research traditions, they in fact share the same purpose and underlying logic - that of producing valid inferences by the systematic use of well-established methods of inquiry (King, Keohane, & Verba, 1994). Inductive or exploratory research sometimes concentrates within the conceptual plane, for example by elaborating existing theory, but it can also be *data-based*. Several authors have described methodologies intended to help researchers induce theory from empirical research such as case studies (e.g., Glaser & Strauss, 1967; Eisenhardt, 1989). These methodologies are based on using sources of data such as interviews and field observations, and theory is generated by a continuous interplay between analysis / interpretation and data collection. The central argument in favour of this approach is the intimate connection with empirical reality and the ability to learn from the “in vivo” concepts

used by managers or other participants. Some authors (e.g., Eisenhardt, 1989) argue that the essence of inductive methods is to start from “a clean slate” in order to stay open to serendipitous findings and avoid restricting the research process to existing theoretical models. Even though this view is associated with Glaser and Strauss’ (1967) classic text, Strauss & Corbin (1998) later argued that the initial position was too extreme and that more recent work have provided a more balanced picture by describing the useful role of extant theory, both in sensitising researchers to interesting phenomena and in enabling useful comparisons with the data that have been collected. In many cases the purpose of the investigation may even be to elaborate on existing theory rather than generate new theory.

3.1.3 Research design of the present study

As pointed out by Hackinan (1992), it is the research question should drive the choice of methodology - not vice versa. Consequently, the methods employed in the present research should be explained with reference to the goals for the research. As noted in Chapter 1, the primary purpose of this study was to examine the role of modular product and process architectures in enhancing the dynamic capabilities of firms in the home appliances industry. In chapter 2, three gaps in the literature were identified, which were the initial motivation for formulating the secondary goals of the research, which are: 1) investigating implementation and actual use of modular principles in home appliances companies; 2) testing the relationships between market context, degree of modularity in product and process architectures, complementarity, and firm performance, and 3) considering how modularity concepts can be used in organisation design. The first research goal lends itself to inductive and exploratory analysis, because the purpose was to extend, rather than test, extant theory. As reported in chapter 4, this analysis relied on case studies conducted in three companies. By “grounding” the key constructs in concrete company settings, I compared academically produced constructs with the implicit theories of managers and developed a more refined theoretical understanding as a result.

With regard to the second research goal, a straightforward deductive approach was most appropriate. A survey questionnaire was developed to measure the key constructs: market dynamism, modularity, complementarity, and firm performance. This part of the research then followed the usual survey methodology in terms of item development, sampling of companies, and statistical analysis (see chapter 5). At the time of the development of the questionnaire, I was not aware of any existing scales that are supposed to measure the degree of modularity in products or processes. Consequently, it was necessary to develop new measures. The preceding field work was used as an input to this process. The selection of items was based a judgement based both on the existing literature and on particular issues that were uncovered during the field research as being central. Moreover, the way the items were formulated was also influenced by the terminology used by the managers that were interviewed during the case studies. Some constructs had been measured before (e.g., environmental dynamism and firm performance) and in these cases, items were adopted from the existing literature where appropriate. The development of the questionnaire is further detailed in chapter 5.

The third research goal was pursued by means of analytical framing, analysis, and synthesis (see chapter 6). The initial part of this part of this paper is based on analogical reasoning as it seeks to generalise principles for product design to the organisation design context. Although the paper presents no empirical data, the tools and frameworks that are developed are informed by the case studies that I have conducted, as well as the experience that I have gained as a consultant working for large Scandinavian companies.

3.1.4 Boundary conditions

As a relatively young field, there are relatively few classificatory systems in management studies that are consistently applied. In fact, management scholars are often criticised for including broad samples of heterogeneous firms in empirical studies, and for failing to specify boundary

conditions in their theorising. If theorising and empirical research are not bounded by some groupings of firm characteristics, it implies that the researcher assumes (often implicitly) that the results are generalisable to all firms.

In this thesis I am utilising the strategic flexibility approach developed by Sanchez (1995) to explain organisational responses to environmental uncertainty. Modularity is a generic concept and thus applicable to all systems. Sanchez⁷⁵ once confirmed that the approach should apply to all firms, independently of industry differences. Given equal degrees of environmental uncertainty, one should expect equally modular product and organisational designs across industries. However, I will be somewhat more prudent in the claims I make, given that some scholars argue (e.g., Stabell & Fjeldstad, 1998) that there are fundamentally different value creation logics in different industries. Although it is possible that modular principles apply equally well across industries, there are also reasons to suspect there may be underlying differences that affect how modularity is applied, and the impact that it has on firm performance.

In this research I have tried to deal with the problem of generalisability in the following way. For both practical and theoretical reasons, I decided to focus on one industry only in this research - the home appliances industry. Advantages and disadvantages that arise from the selection of this industry are discussed in chapter 1. Although I assume that the empirical results that are obtained may be representative not only for home appliances but other types of manufacturing firms dealing with mature technologies, no attempt is made to generalise the findings to industries known for utilising highly different technologies, strategies or organising principles. One difference that may have a central impact on strategic flexibility - size⁷⁶ - is dealt with explicitly

⁷⁵ Personal communication, February 21, 1999.

⁷⁶ Firm size is an important control variable for three reasons: large companies generally have more products and models and therefore greater need and scope for co-ordinating using modular architectures; they usually have older products and hence more mature technologies/components for which interfaces are more likely to be known, and they also tend to rely more on formal systems (the notion of architecture implies well articulated knowledge through explicit rules and documentation).

by including it as a control variable in the empirical study reported in chapter 5. Also note that firm size is discussed in chapter 4, which compares the relevance of the modularity concept in three companies: two established global companies and one (relatively) recent start-up.

3.1.5 Limitations of the study

Under research conditions with no resource constraints (e.g. time, funds, etc.), one should obviously seek to develop and test theory using the most rigorous methodology available in order to maximise the validity of the descriptive and causal inferences. In terms of deductive case research, for example, a good approach would be to select companies that vary on both the independent and the dependent variable (in this case, the independent variable would be modular architectures and the dependent variable financial performance or strategic flexibility). For example, collecting data on a control group of companies that do not employ modular architectures (yet which faces dynamic market conditions) would enhance the ability to draw causal inferences regarding the hypothesised links between modularity and dynamic capabilities. However, when faced with resource constraints (i.e., data collection within a specified budget and time period), it is necessary to make trade-offs and prioritise certain types of validity in order to meet research objectives. Although it is rarely explicitly acknowledged in the published research⁷⁷, the process of obtaining data is rarely a linear one, particularly for case research. In contrast with a statistically “correct” approach, it does not present the researcher with an unbiased universe of data points to “sample” from, nor instruments to “measure” relevant variables objectively. A serious constraint in this regard is the difficulty of obtaining access to companies. The majority of managers have very limited time for activities that don’t contribute directly to their key responsibility (i.e., managing), and many are also concerned that participating in research will release competitively sensitive information. This was also a major problem in the

⁷⁷ An important exception is the book by Andersen, Borum, Kristensen & Karnøe (1995).

current study. For example, most of the managers that were invited to take part in the case research did not even bother replying to my request, let alone show a positive interest⁷⁸. For example, at one point I contacted 10 insurance companies in writing; not a single company responded to my letter (despite using an official Oxford University letter head). Partial access was finally granted to three companies after managers were telephoned and convinced of taking part in a limited set of interviews. This process took several months. The first contact was made with Electrolux in June 1997 yet the main round of interviews did not take place before seven months later.

The fact that some firms refuse to participate means that the selection of firms may be biased, for example, it is possible that low performing firms were more reluctant than others. Moreover, even after initial access was negotiated, the degree of access to different managers within the companies was uneven, in the sense that some were not available for interviews whereas others shared information freely with the researcher. In other words, the case data are incomplete, making descriptive and causal inferences difficult. Nor are the firms necessarily representative of other firms in the industry, making generalisations difficult. It should be mentioned that I was able to gain a satisfactory degree of access to Electrolux, at least using the criterion proposed by Eisenhardt (1989), which is to stop adding observations when theoretical saturation is reached. However, for the other two companies it would have been desirable to include many more managers within each company, particularly at Dyson Appliances, which was the most interesting company from a theoretical point of view, since it relied on unique technology management and strategic principles. Unfortunately, after my second visit, Dyson Appliances informed me that no further interviews would be possible and they also refused to take part in the subsequent survey study.

⁷⁸ Mahoney & Sanchez (1997) have suggested institutional-level mechanisms to improve access. Based my experience from this study I believe that implementing such mechanisms would improve the quantity and

Nevertheless, there are some reasons for optimism despite these limitations. “Running the perfect experiment” is *never* possible in management studies, given the nature of the phenomena and the problems of access. However, that does not mean that the data that are collected are useless, only that the conclusions will be relatively more uncertain than if a larger sample could be included and better measuring methods employed (King et al., 1994). It is also important to consider that the purpose of the case research reported in chapter 5 was to “ground” the theory in concrete settings (rather than test specific propositions) and the results should be interpreted as hypotheses requiring further testing. Even though single case studies cannot be used for causal inference (unless they are dis-aggregated into multiple observations), they can be quite useful as tools in the research process in developing new constructs and formulating new hypotheses. As Eisenhardt (1989) remarked, creative insight often arises from the juxtaposition of contradictory and paradoxical evidence. Although I wasn’t able to complete as many interviews as I would have liked, the ones I did complete turned out to be highly informative. For example, I discovered that many managers were sceptical about some of the claims in the current academic literature on strategic flexibility. This finding suggested that the existence of significant implementation barriers (which are not addressed in the prescriptive literature), and also inspired the later deductive mode of research aimed at statistically testing some of the causal propositions in the academic literature.

For the survey study it was easier to follow the prescribed approach. Great care was taken in defining the target group of companies (manufacturers of branded home appliances products) and the individual respondents (divisional manufacturing and marketing managers), and 2 research assistants were hired to create mailing lists based on screening of lists supplied by a UK industry association and a US industry magazine.

quality of data available to faculty and doctoral students in this field.

The ideal approach would have been to statistically establish the reliability of the items first (item-to construct reliability as well as interrater reliability) by sending out a pilot questionnaire. However, although I considered this option I chose not to pursue it since it would have added considerable time and cost (in fact the development of the respondent database was the most costly and time-consuming part of the whole data collection effort). The second limitation is that I only had a budget to send out 500 questionnaires whereas the ideal approach would be to send out twice as many to increase the sample size. Again, the concern was not the mailing cost but the cost and difficulty of identifying relevant respondents. However, in the end these constraints did not preclude me from going about the data analysis in the way anticipated. It should also be added that similar limitations hold true for most other studies, even the ones published in leading journals.

On a final note, I return to the problems of gaining access to companies for field research. Lack of managerial interest in collaboration may signal that the research topic is of marginal relevance to practical concerns. Somewhat paradoxically, however, such problems may also confirm the value of the research topic rather than discredit it. Professor Lex Donaldson⁷⁹ once remarked that managers were more than willing to come to his MBA classes to talk about issues such as human resource policy or corporate culture, but that it was almost impossible to get them to talk about their product development plans or corporate strategy. This anecdote fits well with what I experienced myself during my study. When I first explained my research topic to the managing director of Electrolux Floor Care, he replied: "If we were to explain this to you, we would be giving away our whole system for competing".

⁷⁹ Professor Donaldson made this remark at the Competence-based management conference in Oslo, May, 1998. An alternative interpretation is that human resource policies and corporate culture are as important (or even more important) to performance, but that they are highly inimitable whereas it is easy for

competitors to copy or pre-empt product strategies if they receive proprietary information about plans or strategies.

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4 MODULAR PRODUCT PLATFORMS IN THE HOME APPLIANCES INDUSTRY

ABSTRACT

The use of modular product and process platforms has become a key element of product family management in many industries. In this paper I investigate the use of modular platforms in the home appliances industry. I first discuss the level of dynamism in this industry by considering the pattern of product-model evolution (i.e., model change and variety). I then report on data from case studies in three leading vacuum cleaner manufacturers. Two of the manufacturers made partial use of the platform concept, and described several benefits from using platforms, including cost reductions and faster introduction of improved components. However, these are large and complex companies and I noted significant implementation barriers that currently preclude the optimal utilisation of modular platforms. Finally, I discuss recent design milestones and the emergence of a radical innovation – the cyclonic vacuum cleaner. The platform approach may be very effective if combined with processes dedicated to continuous upgrading of platforms and architectures. However, modularity seems poorly suited to explain how some companies (particularly small, entrepreneurial firms) sometimes succeed in shifting customer buying criteria and thereby open up new market space.

4.1 INTRODUCTION

A number of authors have described how companies have used modular product platforms to increase their ability to adapt to dynamic product markets - markets characterised by heterogeneous customer needs and continuous change. Companies that employ modular designs are able to increase product variety and quickly introduce model upgrades at a low incremental cost, by re-using some components while substituting others with newly developed components (Garud & Kumaraswamy, 1995). Well-known examples include the first IBM PC (Langlois & Robertson, 1992; Thoinke & Reilertsen, 1998), the Sony Walkman (Sanderson & Uzumeri, 1997), Motorola's pagers (Boynton, Victor & Pine, 1993), the Toyota Corolla (Cusumano & Nobeoka, 1998) and the Honda Accord (Sawhney, 1998).

In this paper I investigate the relevance of the modularity concept in the home appliances industry. There were three research questions motivating this study:

1. What is the relevance of the concept, that is, to what extent is the home appliances industry "dynamic"?
2. To what extent do leading appliance manufacturers employ modular product and process architectures?
3. What do industry participants perceive to be the main barriers to implementation of this concept?

I address the first research question by describing the competitive dynamics in the home appliances industry and the key challenges faced by home appliances companies. This discussion is mainly based on a review of industry-specific research and industry magazines, supported by interview data. I address the second and third research question by reporting on the results from cases studies in three leading manufacturers of vacuum cleaners. These case studies illustrate the

challenges of implementing and deriving benefits from modular systems in a mature industry. In addition to two established companies (Electrolux and Panasonic), I included a contrasting case – a successful new entrant (Dyson Appliances). This was to done to assess the relevance of the concept for entrepreneurial firms in the industry. I end the paper with a discussion of the organisational and strategic implications of the case study findings.

4.1.1 Product architecture

A vacuum cleaner develops suction by means of a fan, which as it spins, discharges a powerful stream of air in the opposite direction. This sets up an equally powerful inflowing current of air, which picks up and carries with it dust particles and small debris brushed up from the floor or carpet by rotating brushes in the floor tool.

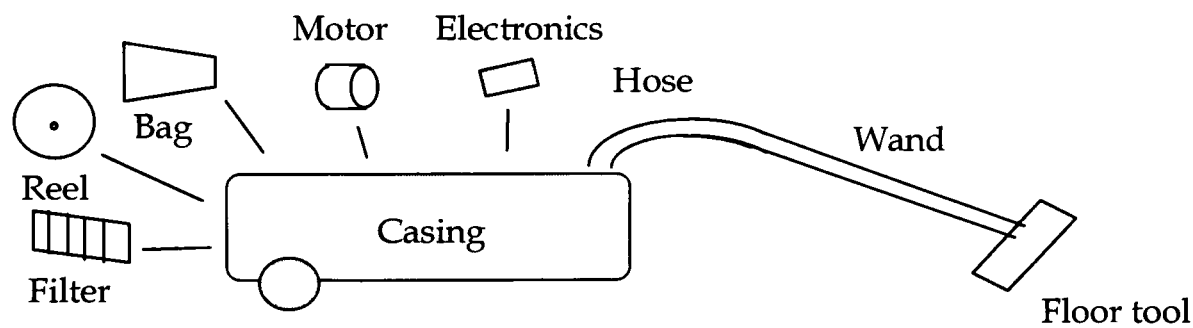


Figure 4.1. The main components of a conventional vacuum cleaner.

The first vacuum cleaners were introduced around 1912, although it took a few more years to produce an easily moveable canister model that was suitable for ordinary home use. The basic functionality and structure of the product has been remarkably stable since then. The main components are the casing, floor tool, wand and hose, motor, dust bag, and cord reel (see fig. 5.1). The functional requirements (FRs) and design parameters (DPs) for a conventional vacuum

cleaner are listed in Figure 5.2 (detail FRs and DPs are omitted)⁸⁰. There are numerous manufacturers and hundreds of different models, but all conventional (i.e., non-cyclonic) vacuum cleaners share this basic product architecture, which remained the “dominant design” for nearly 70 years. Nevertheless, a number of incremental innovations have been introduced during the last few years. For example, suction power has increased thanks to improved motor efficiency, ducts and seals. An electronics circuit board has been added, plastic materials have replaced aluminium in the casing, and filters have been incorporated on more expensive models.

⁸⁰ The manufacturers participating in this study did not provide detailed information about the product architecture of their models. For this reason, Figure 5.2 may not correspond exactly to how appliances companies decompose the product structure.

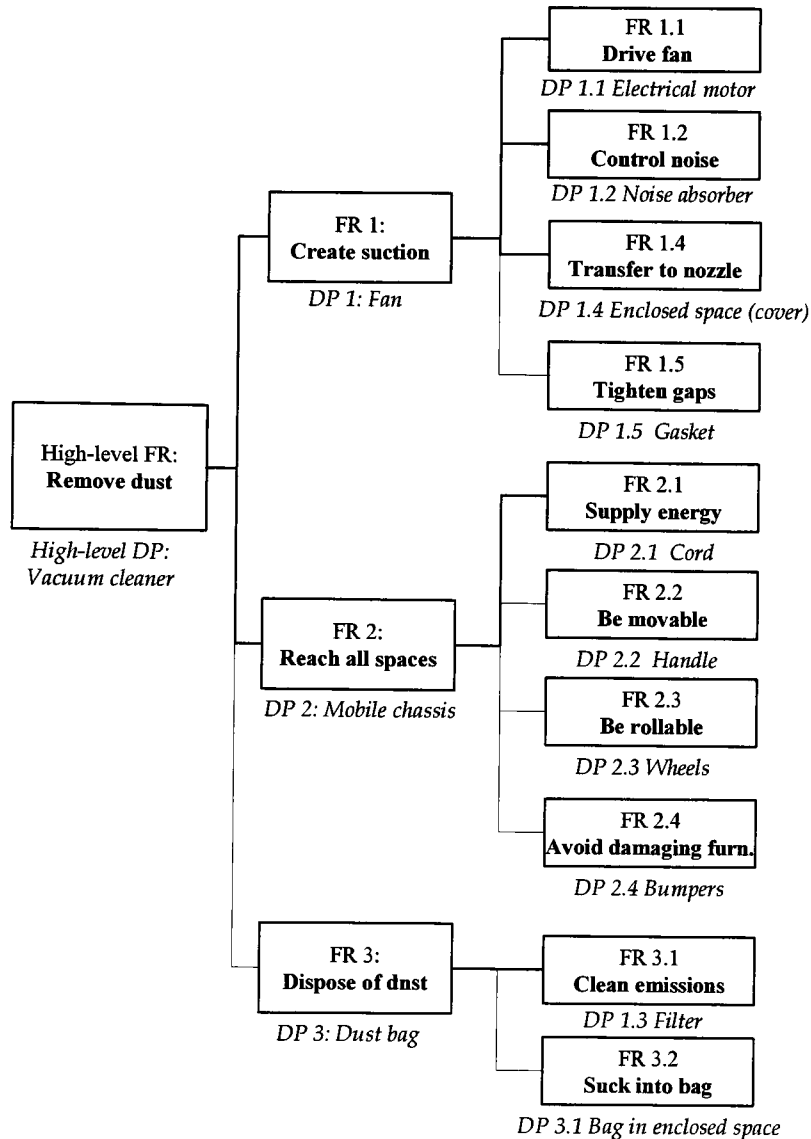


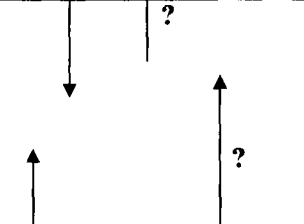
Figure 4.2. Product architecture of a conventional vacuum cleaner. The figure is a modification based on Erixon, Erlandsson, von Yxkull, & Östgren (1994).

Just as a product architecture represents the decomposition of a product from a technical perspective, a product can also be decomposed into its various attributes from a marketing perspective. Although single products compete in a market, customers usually perceive products as a bundle of different features or attributes (Bogner & Thomas, 1996). Sanchez (1998) distinguished between four types of attributes: *Threshold attributes* are those features that

customers *require* the product to contain, but that are not valued beyond a certain threshold point. For example, the ability of a vacuum cleaner to start every time it is turned on (i.e., reliability) is a threshold attribute. *Central attributes* are key to the product concept, such as the suction power of a vacuum cleaner. Increasing the performance of central attributes will normally increase the perceived value of the product for most customers, and should therefore be the focus of continuous performance improvements, which may lead to a competitive advantage⁸¹. Finally, *variety-enhancing attributes* are provided by modules that create variations in products, such as casing colours, while *plus-only attributes* are attributes that are not central to the product concept but “delight” the customer if they are present. In Table 5-1 I have attempted to classify some of the key attributes provided by the main modules of a vacuum cleaner, and suggest likely directions of customer perceptions of value. As pointed out in Sanchez (1998), new attributes that elicit positive reactions among customers might eventually evolve into attributes that are expected of all products in the category, so that a “plus-only attribute” may evolve into being a central or threshold attribute. Similarly, as central attributes are being improved, they may evolve into threshold attributes. For example, motor noise, which may be a central attribute to many consumers, is now being reduced to such a comfortable level (currently 70 dB for many high-end models) that customers may begin consider it a threshold attribute so that further improvements will not increase the perceived value of the vacuum cleaner overall.

⁸¹ For example, a market research survey conducted by Electrolux among women age 30 to 55 established that suction power was the number one consideration followed by high filtration. During a three-year research effort, Electrolux achieved a fifty percent increase in suction-power capability (to 425 W), due to improved motor efficiency and sealing (Jancsurak, 1998).

Table 4-1. Vacuum cleaner product attributes

Attribute	Explanation	Examples for vacuum cleaners:	Direction of customer preference
Threshold	Features which need to be present but whose performance is not valued beyond a threshold point.	Motor noise (Motor)	
Central	Features that are key to the product concept and for which improved levels of performance are more highly valued	Suction power Filtration Ease of handling	
Variety-enhancing	Features which add to perception of variety	Chassis colours Visual design	
Plus-only	Features which "delight" customers if present but which are not missed when they are not present	<i>Examples:</i> Light that signals that floor is clean Signal that indicates that bag is full Remote control on hose	

4.1.2 Industry dynamics in home appliances

The home appliances industry is often portrayed as a slow moving industry. Many of the basic product concepts (such as for refrigerators, washing machines) have existed for decades, and customer needs appear to be stable and conservative. Yet a closer examination reveals that the industry in fact shares many characteristics associated with dynamic product markets such as computers, software and telecommunications⁸².

⁸² At the same time, one should note one difference that exists between the home appliances industry and "high velocity" high-tech industries: Appliances are usually stand-alone products, whereas products such as computers, mobile telephones and video recorders form part of an open system and therefore need to be compatible with other parts in order to work properly. Technical standards ensure that computers can transfer data to each other (e.g., ICP protocols), that mobile telephone networks can link up with each other

Many segments of the home appliances industry have recently been characterised by over-capacity and falling margins, which has triggered cost-cutting and consolidation. It is clear that the managers that I interviewed perceived their industry to be fiercely competitive. As the president Electrolux Home Appliances put it:

....the home appliances industry right now is a fight for life or death...our company is undergoing major restructuring...the main "change driver" is increased capacity, which leads to stiffened price competition....what drives the whole process is cost. It must be done cheaper and cheaper. In addition, there's the technical evolution of new solutions which must be incorporated. And we must watch what competitors are doing...

Considering product models as the level of analysis, we observe that the pattern of product evolution in home appliances conforms to the "dynamic" pattern identified by Sanderson & Uzumeri (1997). That is, manufacturers offer a *high variety* of models (usually hundreds or thousands of different models) and frequently introduce *new variants* that gradually replace the existing models. Although current data are not available, a decade ago Baden-Fuller & Stopford (1991) found that the number of washing machine models sold in European stores increased from 52 to 201 between 1976 and 1987. The number of models per brand increased from 2.4 to 5.6. Managers that I interviewed confirmed that these trends were still visible. They also estimated that the time from conceptual design to production had been halved during the last 10-15 years, due to pressures for introducing improved models more rapidly.

Managing product families, and in particular, model variety, is a key issue in the home appliances industry. The need to manage variety is rooted in the geographical and local customer

(e.g., GSM), and that video recorders can be connected to TV's (e.g., VHS). In such markets, compatibility and industry standards are major sources of competitive advantage as customers want to connect products to each other or transfer data between them (e.g., to use palmtops in concert with PC's) and want to get access to supplementary products such as software. In contrast, home appliances are closed systems in that they are bought as a separate entities. Until now, nobody has been concerned about whether the vacuum cleaner in the house is compatible with the washing machine or not. In the long term this situation is bound to change as appliances are connected to each other and with the internet. For example, at recent industry

preferences that still prevail, the different electrical standards around the world, and the many customer segments that exist. One key difference is between the low-end “opening price point” segment, and the high-end segment, where innovation and high product performance is more important than price. A low-end vacuum cleaner costs around £60-70, whereas a high-end model might cost £200 or more. Although I was unable to obtain financial data about the development costs and revenues for products aimed at different market segments, my informants confirmed that there were significant margin differences between low-end and high-end models; one manager estimated the difference to be 15%. Manufacturers in the low and medium segment thus have incentives for moving to the high end group. In fact, when I conducted this study, Panasonic was in the process of launching a high specification model to compete with the top end models from Miele, Electrolux, Hoover, Nilfisk, and Dyson Appliances⁸³. Customer preferences also vary between countries: An extreme example is Japan, where customers prefer very small models that are packed with new technology. For example, many models for the Japanese market contain fuzzy logic technology for regulating suction power. Consequently, prices are much higher with the cheapest models starting at around £150, that is, more than double of the cheapest models in Europe. There are also big differences within Europe: In the United Kingdom, customers prefer the upright type, whereas the “canister” model is standard on the continent. As I will describe in more detail below, British consumers have long shown a dislike for dustbags, leading to Dyson Appliances’ attempt to produce a bagless vacuum cleaner. Preferences for size also differ, with the smallest models being very popular in the Mediterranean countries.

In addition to the need for model variety, there is an equally strong need for frequent improvements and model upgrades. In most western countries there are between 10 and 15 vacuum cleaner manufacturers that compete in overlapping market segments. The companies

conventions, manufacturers have displayed prototype appliances that self-diagnose for faults and send requests to the nearest service centre if a technician is needed.

⁸³ These are the manufacturers’ names; brand names for vacuum cleaners vary between countries.

follow their competitors closely and frequently imitate new features that are introduced. All of the three firms that I studied had “reverse engineering” facilities where they took apart competitor models, examined their product architecture, and even calculated the estimated cost of every major component.

As in other industries, the vast majority of model upgrades is based on incremental improvements to different components. But we have recently seen the introduction of more radical innovations in this segment. Looking at the evolution of new product features of vacuum cleaners, there are five important design milestones that have occurred during the last few years⁸⁴: the introduction of high specification models with advanced filters, the dust sensor, the mini or compact models, the Dyson bagless vacuum cleaner, and the robotic vacuum cleaner. Although I do not have access to detailed technical or economic data, these innovations provide examples of the type of rivalry in the home appliances industry.

⁸⁴ In this section I consider *new product innovations* only; rivalry based on *cost competition* is another important competitive arena for home appliances companies. Having the ability to configure design and manufacturing processes to achieve low cost is an important strategic capability. For example, Ulrich & Pearson (1998) studied the design of coffee makers and estimated that the most efficient design would reduce manufacturing cost by 40% in that it required fewer parts and simplified assembly process.

Table 4-2. Recent design milestones for vacuum cleaners

	Company that introduced innovation	Type of innovation	Response of competitors
(1) Advanced HEPA filters	Unknown	Modular/ incremental	Incorporated by all of the global manufacturers plus a number of local / regional companies
(2) Dust sensor	Panasonic /Miele	Incremental	Imitated by Philips (1993) and Electrolux (1999)
(3) Compact models	Rowenta (1995/1996)	Architectural	Imitated by Electrolux, Panasonic, Miele, and others.
(4) Robotic vacuum cleaners	Electrolux (1998 - prototype)	Radical	Most large companies may have on-going development projects. Dyson launched robotic vacuum cleaner in 2000.
(5) Bagless vacuum cleaners	Dyson Appliances, 1991 (first commercially successful model)	Radical	Imitated by Electrolux (around 1996-1997), Hoover (1999), Polti (1999), and Sanyo (1999) ⁸⁵

Advanced filters. Using traditional vacuum cleaners often made the indoor climate worse because accumulations of allergens and dust particles on the floor and on furniture were blown into the air. During the last 10 years most top end models have been fitted with filters that capture these particles before the air is expelled.⁸⁶ Filters were also used before the advent of the HEPA standard (High-Efficiency Particulate Filters) but the HEPA filters delivered dramatically better performance. In order to achieve a HEPA rating, a filter must remove 99.97 per cent of particles

⁸⁶ In the process of designing a vacuum cleaner that captures allergens and small particles, it is reported that the US firm Kirby invented nearly airtight seals that have been patented. However, other manufacturer have been able to achieve the same effect with other technologies so this innovation of a key component technology did not establish any real competitive advantage (see McGrath, 1997 and her discussion of “matching”).

as small as 0.3 microns (Leimbeck, 1997)⁸⁷. Because there has been an increasing concern for the quality of the indoor climate, this innovation clearly conferred temporary competitive advantage to the first manufacturers who incorporated the feature; however, it was also easily imitated and is now part of the standard package of attributes for a high-end vacuum cleaner. At least in the high end segment, HEPA filters have become a “threshold attribute”, in that it is an expected attribute for which even higher performance would not be valued for the majority of customers (cf. Bogner & Thomas, 1996; Sanchez, 1998).

The dust sensor. The dust sensor indicates with a green light when the floor is clean. To incorporate a dust sensor, relatively minor design changes are required to the floor tool (where the sensor and light are located) and to the electronic circuit board. I would thus characterise this as an incremental innovation. The optical dust sensor was first introduced by Panasonic but has subsequently been copied by Miele and Electrolux.

Compact models. A key trend in the low-price market segments has been the move toward small, compact models (sometimes called “super compacts”). Rowenta, a French firm, introduced the first compact model around 1996. The only distinguishing feature is size: the functionality is the same as in low cost canister models. Most of the other large manufacturers have now imitated this concept. Compact models are particularly popular in the Mediterranean countries where they account for almost 50% of total sales. I assume the compact model to be an architectural innovation, in that it restructures the relationships between the components while keeping the components more or less intact, although I also assume that it involved some degree of component level miniaturisation of existing components.

⁸⁷ It is clear that filters may affect other modules in that they reduce airflow and thus may require, among other things, more powerful motors. The general concern for the quality of the air expelled from the vacuum cleaner may also necessitate improvements in ducts and seals as there might be air leaks before or after the filter systems if previous designs are not adjusted appropriately (*Machine Design*, 1996). Nevertheless, the development of advanced filters can best be characterised as an *incremental* innovation using the framework presented in Henderson & Clark (1990). To my knowledge, the adjustments in other

Robotic vacuum cleaners. These robots, which are used mainly in hotels and airports, first create an internal representation of the room and then move between obstacles that have been located. However, there are both functional and economic factors that hinder the commercialisation of the robot vacuum cleaner for home use. With present day technology each robot would cost about £30,000 (Babyak, 1992). The robotic prototypes only vacuum floors, whereas current vacuum cleaners are used for other purposes as well, such as cleaning furniture. Engineers that I spoke to envisaged that even with the commercialisation of the robot, there would still be a need for smaller hand held vacuum cleaners based on traditional technology.

The Dyson Bagless Cyclonic vacuum cleaner. The development of the so-called dual cyclone technology is one of the most well-known radical innovations in the vacuum cleaner industry. It was introduced by Dyson Appliances, a U.K. based company founded around 1992 by industrial designer Jim Dyson. In the cyclone⁸⁸, the dusty air enters a cylinder, which accelerates the speed of each particle to 924 m. p. h. by centrifugal force. By applying this force the mass is increased several thousand times, and the particles are forced round and round into the bottom of the cyclone where they are collected. The air, which has no mass, exits through holes in a chimney in the centre of the cyclone. In the conventional vacuum cleaner, the air current passes through the dust bag and exhales through the back of the casing (on more recent models, it exits through the front above the suction head).

4.1.2.1 Summary

This overview of industry dynamics provides a backdrop for the description of the case studies to follow. It is appropriate to portray home appliances in general and the vacuum cleaner segment as

modules have been relatively minor and manufacturers have relied on their already established core competencies in design and testing to carry out this effort

⁸⁸ This description is based on chapter 7 in Jim Dyson's autobiography (Dyson, 1997).

a dynamic market. Companies (at least the global companies) must manage a great deal of complexity due to the heterogeneity in customer needs in different countries and regions. They must also cope with a fairly high rate of product innovation. Competitive advantage is usually temporary and limited to the time it takes for a competitor to imitate a new feature. A possible exception to this picture is Dyson's cyclonic vacuum cleaner, which, although imitated, seems to have led to a more sustainable advantage in that it remains a leader within the high-end segment.

4.1.3 Methodology and participants

The case studies were conducted in three leading vacuum manufacturers, two established players (Electrolux and Panasonic) and one small/medium-sized entrepreneurial firm (Dyson Appliances). I conducted semi-structured interviews with engineering managers and toured the main plant in each of three companies. Most of the interviews lasted for approximately one hour. In two of the companies (Electrolux and Panasonic) feedback meetings were also arranged where the informants had the chance to comment upon the findings and correct any factual errors.

Table 4-3. Case study sites

	Electrolux	Panasonic	Dyson Appliances
Description	Global market leader with appr. 8,000 employees	Spanish subsidiary of the home appliances division of the Japanese electronics company	New entrant (founded 1990)
Product models	Models in all segments (9 different brand names)	Traditionally strongest end and medium segments; were introducing high end model at the time of the study	Only high end models priced at above £200
Global organisation and sales	Globally Plants in nine countries Subsidiaries with high local autonomy	Headquarters in Asian country Plants in four countries (three outside Asia) Subsidiaries with relatively low autonomy	Based in one country Licences technology to one other company Some exports to other countries.
Core competency⁸⁹	Product quality Manufacturing capability	Efficiency in production Manufacturing capability	Product design Marketing
Strategic and financial status at time of study	Consolidation - had recently announced major job cuts (10% of staff) and closed down one plant.	Market share in key markets had fallen during last 5 years	Strong growth in terms of sales and employees
Participants in this study	Eight managers and executives including president	Four managers including head of engineering department	Five managers and engineers including founder

4.2 KEY FINDINGS

4.2.1 Product development process

Electrolux and Panasonic both relied on a fairly conventional product development process. At Electrolux, there existed a stage-gate-framework (called check point system) that delineated the new product development process into distinct phases, such as market analysis, concept development, detail design, production, etc. The average time for developing a new product was estimated to 18 months. In addition, there was a less structured process (carried out at company

headquarters in Stockholm) for “primary development”, i.e., more basic research-oriented, radical innovations. These two development processes were characterised as loosely coupled and poorly integrated with each other. A similar structure existed in Panasonic. Incremental improvements and cosmetic changes were carried out in engineering departments adjacent to the four main plants. Basic research was carried out at the headquarters in Osaka, Japan, where there is a design centre that includes a research group for vacuum cleaners. Unlike Electrolux, however, Panasonic has a dual organisation consisting of relatively autonomous manufacturing and commercial companies (the latter responsible for marketing and sales). The product development process starts in the commercial company with a documentation of customer needs. Then the design centre in Japan becomes involved, and also decides who will carry out the design of the proposed model. In three cases, Panasonic had chosen to contract out the chassis design (styling) to external design firms (in the UK, France, and Spain).

Being a small and entrepreneurial company, Dyson Appliance’s product development process was carried out by a set of teams working on the same premises in Malmsbury, UK. At the time of the study, Dyson Appliances had 3 teams that focused on improving existing products, 3 teams that focused on new types of vacuum cleaners (e.g., robotic), and 3 teams that focused on other types of products (e.g., washing machines). Each team had 10-12 members and was led jointly by one development manager (with project management responsibility) and one design engineering manager, whose job it was to ensure that the original vision for product actually was implemented.

⁸⁹ Managers’ own characterisation.

4.2.2 Use of modular platforms

In Electrolux and Panasonic, engineering managers stated that modularity had been important for creating high variety in product models while reducing costs through component commonality. The introduction of platforms with standard components had enabled re-use between product generations and sharing between different models. At Electrolux and Panasonic, some components were common to all models within a product family, and in some cases models across different product families: these included the cord, wand (hose), the motor or parts of the motor (such as the fan), cord reels, multidirectional reel, paper bags, the telescopic tube, and various accessories such as extra floor tools. At Panasonic, the electronic circuit board had previously been common across the platform but was now unique to each model. Whereas these components were described as static, others - such as filters - were the focus for continuous improvement for each new product generation (these can therefore be considered “bottleneck” components (Langlois & Robertson, 1993) or “central modules” (Sanchez, 1998)). Electrolux and Panasonic both mentioned examples of new models upgrades that had taken place by introducing an improved module (such as a more powerful motor to increase suction power) without changing the remaining modules. Customers might also to some extent upgrade the product themselves: Electrolux has 3 different floor tools that are available in home appliances stores including an electric “turbo” floor tool. It also supplies 3 different filters for its top model. Panasonic similarly provides two different dust bags, one with a closing system (to avoid dust from escaping while discarding the bag) and a cheaper model without the closing system.

In contrast, in Dyson Appliances, managers reported a low level of component re-use and transfer between models at the time of my study. This was partly based on a certain scepticism regarding the concept itself, and partly explained as a result of their new technology platform. However, engineering managers also said that modularity would become a much more important issue in the future in order to reduce costs as the number of models was expected to grow.

...we're developing the [third model] as a successor to the [model 1 and 2]. There won't be much commonality between them because we're trying to incorporate new features. However, this will change, cost is one important driver.

...sometimes it is good not to re-use components because it is difficult to find a solutions that's optimal for different products - you have to compromise instead of optimise. However, multi-product use of standard components will grow in Dyson Appliances. But right now it is too early because we are still developing the initial platform.

Despite its limited modularity-in-design (Baldwin & Clark, 1994), Dyson Appliances appeared to have a high degree of modularity-in-production. Observing the assembly process I noted a minimal use of automated tools – most of the components were received from different suppliers ready to be literally snapped together by hand.

The engineering managers in the firms I studied seemed to think mainly about geometrical or spatial interfaces when talking about modular designs. Two engineering managers described the product architecture in the following way:

...the interfaces are mainly between the components and vacuum cleaner body...except between electronics and the motor

...an interface can be for example the way you mount the motor inside the body by using a type of rubber bands...

A number of challenges were mentioned in terms of managing component interfaces. For example, in Electrolux, examples were mentioned where existing architectures were abandoned to accommodate new modules:

...the problem is that new models sometimes make use of new vacuum cleaner casings. Then one often cannot apply this [the pre-existing modules] and has to come up with something new [define

new modules /interfaces]...that can be a problem, that one has to develop new modules for each new model...

...it is true that if you have modules, you can improve them without changing everything else, but we can't really make this work...we have a problem...it is desirable but new components appear and they have a tendency to get smaller or cheaper, and then we change other things to incorporate them and the interfaces have to change too...

In other words, it appeared that this engineering manager had difficulty maintaining sufficient discipline among designers in terms of using the established platform. It is also possible that the product architecture was too inflexible to begin with and thus made it impossible to leverage the existing platform instead of designing new components.

4.2.3 Modularisation process

For both Electrolux and Panasonic, the starting point for their modularisation attempts was not a clean slate but an already existing product portfolio consisting of a wide range of products, each designed and manufactured according to particularistic criteria. This was especially evident in Electrolux, which had acquired a number of other companies during the last 5-10 years, each with its own product lines, standards, and supplier networks.

...[before] the system was decentralised, things were devolved to local units. What started then was a kind of de-standardisation, things that were common became particularistic to the different units. Since then many new companies have been acquired, and a new product "flora" has been introduced.

The modularisation process in both Electrolux and Panasonic is one that centres around the co-ordination of multiple and conflicting component standards and development processes. A few years ago, Electrolux started implementing a plan aimed at greater co-ordination between

projects, plants and subsidiaries⁹⁰. Duplication of effort was reduced by dividing the responsibility for specific modules among different development teams at the various plants around the world. Some engineers (such as one of my informants) were given an explicit mandate to work on component co-ordination and reduce duplication and overlaps. The different development groups co-ordinate their work in quarterly “product council” meetings, where plant and marketing managers also take part. However, the efforts at increasing co-ordination only made slow progress. Managers at Electrolux did not believe that they could follow a purely technical rationale in their efforts at co-ordinating the different project teams and subsidiaries:

...they [the German subsidiary] have other models, and it's not easy to standardise, because they have different specifications and requirements, and deliver mainly to the German market.

...the Germans work in a different way...it would have been desirable if modules were developed in the same way [as here].

...the module centres have their own will and their own history...for example, [our German subsidiary] buys its motors externally [rather than use ours]...they have to be convinced that our motor is as good as the one they can buy externally...one needs to build confidence among the participants, such as the engineers and procurement managers...but yes, from a purely technical point of view one could perhaps work [as specified by the modular approach].

Electrolux (and, to a lesser extent, Panasonic) had defined “module centres”, that is, development groups responsible for specific modules. However, the general work process seemed to be one of relative interdependence and subsequent iteration to come up with satisfactory designs:

⁹⁰ In order to facilitate inter-project co-ordination it is probably necessary to re-structure roles and organisational units. Toyota, a leader in applying the platform concept, have redefined their previous matrix structure by introducing a “centre organisation”: Projects with similar technological focus are part

...we have module meetings every quarter where we set "design rules"...(however) we have a lot of communications between module owners...something here influences something there...especially between those responsible for development of motor, electronics, and floor tool. Things are interconnected.

Historically, the development of the Panasonic global organisation followed a different path from Electrolux, in that it grew by establishing foreign subsidiaries rather than acquiring existing companies. However, engineers at Panasonic mentioned many of the same challenges in terms of achieving co-ordination across organisational boundaries. The Panasonic subsidiary that I studied defined its main role as that of translating headquarter designs to local specifications. If other subsidiaries were doing the same, one would perhaps expect a high degree of co-ordination, but my impression was that there was little sharing among the subsidiaries of either components or design concepts:

...The [platform] concept is very difficult to implement. Even though we produce the same components in different plants, the specifications are different and the components are therefore not interchangeable across plants.

4.2.4 Component sourcing

Electrolux and Panasonic manufacture all the main components in the vacuum cleaner - motors, casings, hoses, reels, aluminium parts such as wands, etc. Yet there is also an increasing use of suppliers and third parties in research and development of advanced components such as filters and electronic circuit boards, and the smaller home appliances companies tend to outsource large parts of the assembly process. As a recent start-up, Dyson Appliances did not inherit a

of the same "centre"; they also have one group that provides common components to all centres

manufacturing operation and is therefore able to outsource between 70 and 80% of production. Dyson Appliances buys its motors from subcontractors in Japan and Italy, whereas molded plastic parts such as the casing are manufactured by small UK companies. Unlike Electrolux and Panasonic, Dyson Appliances has the option of switching to alternative suppliers of components if the current suppliers are unable to keep costs down, an option they already had exercised a couple of times, according to the operations director.

...we will look at alternative suppliers if they can't keep the costs down. We have saved 200.000 pounds in belts this way.

As pointed out by Lorenzoni & Lipparini (1999), firms will tend to rely on external contributions when a specific supplier is recognised for having a distinctive capability. In the case of vacuum cleaners, the high end models contain filters that conform to the industry standard HEPA. It is of interest to note that most if not all of the manufacturers (including the three firms in my study) rely on external suppliers to provide this technology. In some cases even the differentiating features are sourced from external suppliers. For example, at Panasonic, the engineering manager considered the dust sensor in the high end models as his company's most important differentiating feature. This technology is licensed from Kurz, a German electronics device company, which holds a patent on the technology. This feature is thus available to other firms as well, and in fact, Kurz already supplies the same technology to Miele, a major competitor.

4.2.5 Innovation management

Being established, global companies, Electrolux and Panasonic faced similar challenges in responding to product innovations introduced by competitors. Marketing managers in both

(Cusumano & Nobeoka, 1998).

companies characterised their organisational structure as complex and slow. One example is the introduction of compact models was an important event for the southern European markets. It took Panasonic over two years to imitate the concept and introduce a compact model, which the product manager admitted did not have competitive pricing or features. Panasonics' marketing managers (who routinely monitor sales statistics from market research firms such as GFK) discovered the popularity of the Rowenta model, and then asked manufacturing managers to design a super compact. The European plant did not have capacity to design or manufacture the compact model, and they therefore decided to import a model from their Malaysian plant while working on developing a model targeted specifically at the European market and increasing the plant capacity. In other words, it appeared that the failure to respond was due to organisational inertia rather than difficulties in designing or manufacturing the product. In any case, this delay in responding with a competitive model gave other manufacturers a chance to gain a lead position.

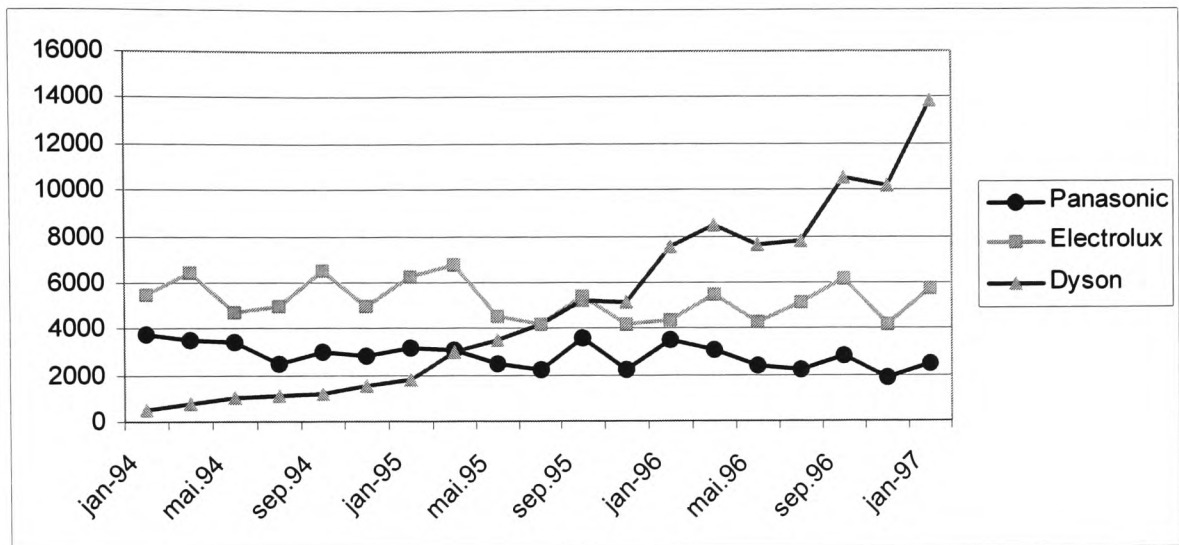


Figure 4.3. Value of units sold in the UK (£ 000's) between January 1994 and January 1997). Source GFR, reproduced in Dyson (1997).

The Dual Cyclone vacuum cleaner was introduced on the British market in 1991 and soon became a market leader. This was a particularly impressive achievement given that it was priced at around £ 220, more than double the price of the low end models available at the time. In 1998, *the Times* estimated Jim Dyson's shares in the company to be worth £400m. The engineering managers that I spoke to acknowledged the success of the Dyson but argued that the success was mainly due to good marketing, and that their products were in fact technically superior. The latter point has some merit if one looks at consumer tests that compare dust uptake, noise, and filtration of different models. Utterback (1993) has pointed out that when an "invading technology" first appears, the established technology generally offers better performance or cost than the challenger, which is still unperfected. The independent consumer tests have concluded that both suction power and filtration are better in some of the top-end models offered by the large established players compared to the Dyson models (e.g., *Which?*, 1995). Since vacuum cleaners based on established technologies are also being continuously improved, it is difficult to say when or if the cyclonic technology will match the performance of products based on

established technology, or whether it will eventually replace the conventional technology as the dominant design for vacuum cleaners. Engineer managers at Electrolux were indeed uncertain about the future of this technology:

...I personally don't think that the cyclone is going to dominate the market for vacuum cleaners, but who knows, it is hard to say...

Whereas Panasonic had decided not to develop cyclonic vacuum cleaners, Electrolux decided to copy the Dyson concept by introducing a vacuum cleaner in an upright range that provided a choice between a paper dustbag or a cyclone. Since these alternatives can be incorporated in the same cleaner, it would suggest that the cyclone is a modular innovation. However, engineering managers in Electrolux and Panasonic admitted that optimal performance of a cyclone required many changes in other modules including the floor tool and the motor, and that theirs lagged the Dyson on performance parameters such as suction power and dust uptake⁹¹.

The Dyson is now the most successful model in the UK market and other manufacturers are attempting to imitate the concept (most recently, Hoover introduced a very similar bagless cleaner)⁹². It is therefore ironic that none of the established players took the opportunity when, during the late 1980's Jim Dyson travelled around to demonstrate his product and offered them a licence to manufacture the design. At the time, Dyson did not have the resources to start manufacturing himself, and needed a partner to bring his invention to market. All the major firms declined to collaborate or licence the product.

⁹¹ Consequently, the dual cyclone principle represents a radical, rather than an incremental or modular innovation (cf. Henderson & Clark, 1990).

⁹² Dyson's dominating market position is so far only achieved in the United Kingdom. Dyson Appliances only recently established sales subsidiaries in other countries such as Australia, Germany, Spain, and France.

The most recent focus for competition has been robotic vacuum cleaners. Both Electrolux and Panasonic have manufactured robotic vacuum cleaners for industrial purposes for some time. But Electrolux recently developed a small series of prototypes of a robotic vacuum cleaner intended for domestic use. The development of these prototypes took part in an alliance between Electrolux, the engineering department of a European university and a US laboratory dedicated to the design of service robots. In this case Dyson Appliances is the follower – in 2000 it launched a small robotic model (with a cyclone) targeted to the domestic market.

4.3 DISCUSSION

In Panasonic and Electrolux there was a relatively strong emphasis on using standard components as part of their approach for managing product families. Engineering managers stated that modularity had contributed to lowering cost and more rapid introduction of improved components. The case studies reported here thus confirm some of the benefits of modularity that have been proposed in the academic literature and recently documented in the study in this industry (chapter 5, this thesis). At the same time, the product platforms of these companies can at best be described as hybrids between integral and modular architectures (Table 5.3), if we employ the definition of these concepts in the academic literature (see chapter 2). In the following I discuss this finding in more detail.

Table 4-4. Summary of key findings

	Electrolux	Panasonic	Dyson Appliances
Main advantages derived from modularity	• Scale economies (increased volume for components) • Cost reduction through simplified assembly • Faster component upgrades	• Cost reduction through simplified assembly • Faster component upgrades	• Currently few • Expected future cost saving from component sharing
Key barriers / problems noted	• Difficulties in platform definition and management • Organisational complexity – difficult to achieve required degree of coordination	• Difficulties in platform definition and management • Organisational complexity – difficult to achieve required degree of coordination • Sourcing strategy unclear or missing	• Technology still in development, too early to freeze interface specifications • May compromise rather than optimise designs

4.3.1 Product platforms

Although engineering managers could easily describe the components that had been standardised and the benefits from component sharing and re-use, closer prodding revealed that we were not dealing with modular systems in the manner defined by Sanchez (1995) or Baldwin & Clark (2000)⁹³. In the academic literature, modularity is seen as a strategy for increasing a firm's *strategic flexibility* (Sanchez, 1995) and is also predicted to have important benefits for the firm's

⁹³ The formal definition of modularity is a design that minimises the interdependencies between different modules. This in turn requires advanced understanding of existing component interferences, including geometrical aspects, such as attachment interfaces (how one component is physically connected to another) and the spatial location and volume a component may occupy, transfer interfaces (how power is to be transferred between components), control and communications interfaces (how signals will be exchanged), and the various ways in which functioning of one component may generate heat, noise, magnetic fields, or other effects that must be accommodated by other components (Sanchez, 1996). Moreover, a modular product architecture should allow for upgradability in that sufficient “degrees of freedom” exist to incorporate new modules with improved performance. This requires some knowledge about “potential” interferences that might occur if design parameters for one module are changed. Finally, deriving

co-ordination abilities, marketing, and organisational learning processes (Sanchez & Mahoney, 1996; Garud & Kumaraswamy, 1995). My impression was that few of the managers interviewed shared this broader, strategic view. During the interviews, managers mainly considered physical interfaces when describing the product platform and seemed to view modularity chiefly as a principle for achieving cost savings in production (through simplification of assembly, reduction in number of parts, etc.). These manufacturers (at least Electrolux and Panasonic) also increased product variety and decreased time-to-market as side effects, but these benefits did not appear to be part of the initial rationale for introducing more modular product designs.

There was also some uncertainty about the appropriateness of using the product platform concept in this industry. As mentioned, the engineers I spoke to had a tendency to think about the physical casing as the “platform”. The casing is similar from a production point of view to car platforms in that other components are mounted “onto” the casing in the assembly process. The president of one of the firms noted some differences when comparing their platforms with those in the auto industry:

...the physical platform for cars is the most costly part, whereas some of the components are more costly in home appliances, so it's not directly analogous.

However, my interviews with engineers indicated that this difference may not have been properly communicated or understood. The key idea behind the modular platform concept is to identify commonalities among different products and standardise components that perform similar functional requirements. However, the cost savings are of course smaller if the parts that are standardised are the less costly ones. One engineer in Electrolux stated that they had not derived cost savings from producing variants based on the same platform, and that the development time

“economics of substitution” (Garud & Kamuraswamy, 1995) requires that interfaces then are frozen for a

was similar too. I interpreted this statement as an indication that that the platform had been defined (or at least interpreted) based on considerations of assembly process and assembly cost, rather than total development time and cost. I was also uncertain about whether there was a shared recognition of how different platform definitions might affect flexibility (i.e., the number of product options that the platform may confer). Several authors have pointed out that platform definition needs to be done by simultaneously considering component cost from a manufacturing perspective and product functionality and differentiation from a marketing perspective (Robertson & Ulrich, 1999; Cusumano & Nobeoka, 1998). One should try to isolate functional requirements that undergo frequent changes (due to changes in technology or customer preferences) from other functional requirements (Thomke & Reinertsen, 1998; Robertson & Ulrich, 1998). For example, Panasonic designed their casings with separate coloured panels so that the exterior styling can be changed, without affecting other parts. In Electrolux, however, the casing and styling were coupled / integrated (at least for some of the models that I saw), making cosmetic changes more costly.

Identifying the *process* used to develop new product models is another way of assessing the degree of modularity. The general principle is that the product architecture should provide design rules that substitute for on-going co-ordination between the teams developing the different modules (Baldwin & Clark, 2000). Clearly, the work processes that I observed did not conform to the criteria for modular processes described by Sanchez & Mahoney (1996) and Baldwin & Clark (2000). Moreover, from what I was able to ascertain, none of the companies utilised modern measurement systems aimed at facilitating the leveraging of resources across product families (see Kogut & Kulatilaka, 1994; Meyer, Tertzakian, & Utterback, 1997). The managers I interviewed may therefore have had few formal criteria to guide the processes of platform definition and renewal. One of the engineering managers at Electrolux remarked:

certain period while components are “mixed and matched” to produce model variations and upgrades.

...We measure time, project cost, and product cost, and against specifications - and partly how many concept specifications we have satisfied. It's not very good. How things should be measured, that's something we have discussed...

Given the lack of platform measurement systems, it is doubtful that the incentives in these companies supported module sharing across different plants.

4.3.2 Component sourcing

In their study of the European home appliances industry, Baden-Fuller & Stopford (1991) concluded that the non-integrated firms suffered “no significant disadvantage when buying components from the integrated firms or from one of the many specialists” (p. 497). This is something of an understatement. Dyson Appliances probably achieves important cost and flexibility benefits relative to Electrolux and Panasonic from outsourcing component production to suppliers.

Although it is clear that manufacturers can draw advantages from relying on the specialist capability of suppliers, it is potentially problematical for assemblers if most of the “central features” of vacuum cleaners, such as filtration (or Panasonic’s dust sensor), in fact rely on technologies that are externally sourced rather than developed in-house. Somewhat paradoxically, Electrolux and Panasonic had seemingly relevant expertise in other organisational units. For example, Electrolux has a separate division focusing on filters, and Panasonic were already using a proprietary dust sensor in its models aimed at the Asian market. For reasons that I do not know, however, the firms chose to source these components externally.

There may be a trade-off between achieving flexibility through modularisation and maintaining product differentiation through unique features from proprietary technology. Anecdotal evidence from other industries suggests that some firms have experienced that their

products have lost uniqueness as a result of modularisation (e.g., car manufacturers sharing the same product platform; PC manufacturers relying on industry-wide standards). However, one should note that some firms have been able to maintain a high degree of differentiation by combining standard “below-the-skin” components with uniqueness in terms of a highly visible styling and brand name of the product (e.g., Swatch watches) (Sawhney, 1998). Combining the benefits of standardisation and differentiation probably requires a well developed sourcing strategy based on thorough analysis of customer preferences, cost structure, and internal capabilities.

4.3.3 Organisational barriers

In the prescriptive technology management literature, modularisation often starts from a clean slate - such as a set of functional requirements that are to be satisfied by producing a design with uncoupled design parameters (e.g., Suh, 1996). Technical interfaces are often treated as objective and stable properties of technologies. However, my findings lend support to Staudenmayer’s (1997) point that interdependencies are subjectively perceived and often ambiguous. The modularisation process can be seen as a process of “sense-making” in that it is not confined to defining purely technical/objective interfaces but also requires the establishment of consensus around interdependencies that have hitherto been either unrecognised or unmanaged. An anecdote from the modularisation process at one of Electrolux’s other divisions may serve to illustrate this. An internal consultant told me that the first step in the process was to bring the relevant development engineers together and literally put all the different components of a product on the table. He would then ask the engineers to indicate which of the components each considered to be part of “his” module. He added that this process usually ended up with a number of components on the table that nobody thought to be theirs.

The fact that there are significant organisational barriers to implementation of modular systems suggests that there is a need to couple the strategic flexibility approach (Sanchez, 1995) to an implementation theory that addresses how to implement modularity in complex multinational corporations. Such an implementation theory would need to consider the modularisation process in both a social and political context. Social factors include the impact of differing cultural norms and existing social networks (as with suppliers) that may complicate the implementation of corporate-wide standards. One should also consider the existence of incentives that favour sub-optimisation as local units may have incentives that favour using particularistic standards even though these might be counterproductive for the company as a whole. Since standard-setting is an example of a conflict between individual rationality (local unit) and collective rationality (the firm), it might be helpful to use a game theoretical perspectives to understand how the negotiation process evolves (e.g., Genschel, 1997).

4.3.4 Modularity and dynamic capabilities

Above I described some of the recent design milestones for vacuum cleaners. A natural question is whether modularity facilitated the introduction or imitation of the product innovations. The cases studies suggest that modularity facilitated a number of incremental innovations, such as upgraded motors and filters. For the radical innovations there is more uncertainty. Unfortunately, the cases cannot provide definite answers. Detailed and objective product-level data is lacking and it is also hard to draw firm conclusions because none of the companies that participated employed fully modular architectures.

The success of the Dyson vacuum cleaner lends support to the idea that companies should try to create new market space by *shifting customer buying criteria* (Kim & Mauborgne, 1999), in this case, moving the vacuum cleaner to a higher price segment by appealing to ergonomic and aesthetic customer needs rather than purely functional ones. The Dyson vacuum cleaner has a

high tech look and appeals to customers who want a design object, not only a machine that picks up dust. The design turns the conventions “inside-out” in that the user is able to see the dust spinning around and piling up inside the cyclone, which is made of transparent plastic (another feature which since has been copied by several large firms). One journalist compared this feature with the Pompidou centre in Paris, where the air-conditioning and escalators are visible on the outside rather than hidden inside (Dyson, 1997). This is not to say that the vacuum cleaner doesn’t have some distinct functional advantages (ergonomics, bagless, etc.), however, its overall technical performance does not exceed that of products from the established companies based on conventional technologies.

There are probably both cognitive and structural /technological reasons for why the Dyson has remained successful, despite some attempts at imitation. As pointed out by Langlois (1998), opportunities for innovation are often missed because of misperception and subsequent misclassification of events. The established companies did not see the market opportunity offered by a new product concept when it was offered to them, and probably still experience problems in orienting their cultures to emerging customer preferences that may involve unfamiliar types of needs (ergonomic, aesthetic, fashion, etc.). And even if the needs are correctly perceived, established companies still have to re-structure their development activities to fit the new customer value proposition. The Dyson involved a radical product structure change that redefined the previously existing relationship between the vacuum cleaner bag, fan, motor, sealing, casing, and other components. This is reflected in the company’s design process, which integrates visual styling and technology development (see Dyson, 1997). In contrast, the visual design of products at established companies (including Electrolux and Panasonic in the study) is often decoupled from technology development both in time and organisationally (styling was done by a separate department, or in the case of some Panasonic models, sometimes outsourced to product design

firms). Hence established organisational structures may be an impediment to successful imitation of the Dyson product concept.

The Dyson case demonstrates the competitive advantage that can be gained from architectural innovation, even in a “mature” industry like home appliances. This may suggest some qualifications of the strategic flexibility approach for adapting to dynamic markets (Sanchez, 1995). The approach may be mostly relevant for explaining leveraging of already existing platforms, and it is uncertain how platforms contribute to more radical forms of innovation. The approach may be very effective if combined with processes dedicated to continuous upgrading of platforms and architectures (see Sanchez & Mahoney, 1996), but still seems poorly suited to explain how some companies (particularly small, entrepreneurial firms) sometimes succeed in shifting customer buying criteria and thereby open up new market space (Kim & Mauborgne, 1999).

This argument does not necessarily diminish the importance of modular platforms to large and established companies. Haanes & Fjeldstad (1998) argued that a firm that competes mainly based on capabilities that support incremental innovation should refrain from attempting to introduce wholly new technologies. It is quite possible that large firms do not possess the right capabilities to compete with the smaller, more agile and more creative firms. Re-organising their firms and acquiring the capabilities needed to introduce radical innovations might be prohibitively expensive and risky. One observation I made during this study shows how large and mature firms may build on their existing capabilities to move into new market segments. I contacted Electrolux a year after I visited to evaluate whether any major changes had occurred. The engineering manager that I spoke to stated that Electrolux had basically maintained its product philosophy for vacuum cleaners and refrained from converting their main product lines to the cyclonic technology. Instead, they recently decided to move into a new field with higher margins, namely small air filtration units. Although the degree of component sharing is minimal,

the product is closely related technologically, in that it contains the same types of modules (e.g., motor, fan, filter, casing). He mentioned that the development was done by the same development engineers (and the same organisation) at the plant for vacuum cleaners that I visited during my case study.

4.3.5 Limitations

The case studies reported here were conducted in three different countries – the UK, Sweden, and Spain (the latter in a Japanese company). On the one hand, this allowed me to discover some cross-border consistencies that I hadn't expected – for example, I observed a striking similarity between the manufacturing facilities in Electrolux and Panasonic, despite the differences in company history and national culture. On the other hand, cultural differences may have been an impediment in terms of achieving consistency across cases. For example, it appeared that the Electrolux managers were more self-critical and willing to openly acknowledge internal problems than the Panasonic managers were. Adding to this was a somewhat uneven degree of access in the three companies. I believe I was able to gain a satisfactory degree of access to Electrolux, at least using the criterion proposed by Eisenhardt (1989), which is to stop adding observations when theoretical saturation is reached. But in Panasonic and Dyson Appliances it would have been desirable to include more managers within each company.

The cases studies reported on here were conducted as the first, largely inductive, phase of a study that also involved a more deductive phase based on a survey study (chapter 5). The case studies were successful in terms of “anchoring” the research in a concrete industry setting, generating more specific hypotheses, and suggesting some key causal links between important concepts relating to modularity and dynamic capabilities. However, the data are not of sufficient size or quality to allow verification of propositions or more detailed comparisons between the three manufacturers. As with most case study research (Eisenhardt, 1989), the main contribution

of this study is not hypothesis confirmation but hypothesis generation – the framing of questions for further research.

4.4 CONCLUSION

This paper discussed the relevance of the modular platform concept in home appliances and reported the results from case studies of three vacuum cleaner manufacturers. Two of these companies had standardised key components and were working on further component co-ordination between their plants. Nevertheless, my interpretation was that the product architectures and product development processes of these companies retained some of the character of traditional integrated design. I also observed several aspects that slowed down or even precluded the effective utilisation of product platforms, including uncertainty regarding the definition of the concept and problems overcoming organisational complexity and sub-unit differences. These findings are similar to previous studies of innovation in mature manufacturing companies (e.g., Dougherty & Cohen, 1995). A key implication is that companies need a more holistic change philosophy to implement modular principle. Successful implementation of a platform strategy may require interventions at multiple levels, including culture, structure and work processes, information systems, and incentives (e.g., Nadler, 1988).

I also discussed the strategic importance of modularity. As for incremental innovation, managers indicated that modular principles had been a key factor in supporting rapid model upgrades and increasing variety, which is consistent with quantitative research in the same industry (chapter 5, this thesis). The platform approach may be more relevant to mature than to entrepreneurial companies. I used the cyclonic technology commercialised by Dyson Appliances as an example of a highly successful architectural innovation in the industry. Entrepreneurial companies are often better able to target the market with radical or architectural, rather than

modular or incremental, innovations (Christensen, Suarez, & Utterback, 1998; Henderson & Clark, 1990; Utterback, 1993). This doesn't imply that modularity is irrelevant to entrepreneurial companies. The Dyson technology may potentially be the beginning of a new modular platform. However, the case study indicates that *relative importance* of modularity for Dyson Appliance's competitive advantage has been limited so far.

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5 MODULARITY, STRATEGIC FLEXIBILITY AND FIRM PERFORMANCE: A STUDY OF THE HOME APPLIANCES INDUSTRY

ABSTRACT

Recent theorising has proposed that modular product and process architectures are key enablers of strategic flexibility. I formulated an integrative conceptual model encompassing antecedents, contributing factors, and outcomes of modularity. I then tested this model on data from managers in US and UK home appliance companies using structural equations modelling. The results indicate a positive relationship between modular product architectures and performance, with product model variety as a mediating variable. The results also highlight linkages between perceptions of market context and the use of modular products architectures, and between complementary organisational capabilities and firm performance.

5.1 INTRODUCTION

Modular product and process architectures are considered prerequisites for efficient mass customisation and cycle time reduction, and thus potential sources of increased strategic flexibility for firms facing dynamic market environments (Sanchez, 1995; Pine, 1993; Meyer & Lehnerd, 1997). *Modular product architectures (or platforms)* are created by decomposing a product design into relatively independent components and by specifying standard interfaces that define the inputs and outputs that flow between interacting components (Sanchez, 1998; Shirley, 1992; Suh, 1996). Similarly, *modular process architectures* are de-compositions of the company's key activities into specific routines and interfaces that allow frequent re-configuration of processes, in the same way as for modular components in physical products (Sanchez & Mahoney, 1995).

Sanchez (1995; 1998) predicted three “first-order” effects of modular product designs. Through new combinations of standard modules, modularity should enable a high number of product variations (or “product options”). At the same time, the re-use of standard modules should reduce the time of switching between options (compared to integrated designs), as well as the cost of switching. Home appliances companies create different models of vacuum cleaners, washing machines, freezers and refrigerators by mixing and matching key components in different combinations. For example, General Electric leverages several models of dishwashers by installing different doors and controls on common assemblies of enclosures, motors, and wiring harnesses (Sanchez, 1998). Electrolux recently tested a concept of mass customising refrigerators by letting consumers chose between 15,000 combinations of colours and materials, such as between stainless steel or wooden shelves. This concept also offers customers the ability to upgrade parts of their refrigerators (such as the colour of the body or the handles) to fit the new style of kitchens that are renovated or refurbished (Rayner, 1999).

Sanchez (1995; 1998) and Garud & Kumaraswamy (1995) have also described some important “second-order” effects. Modularity should allow parallel and distributed business processes, increase incremental innovation by separating component-level and architectural learning processes, and enable interactive and real-time market research based on analysing customer perceptions to new product variations. Because the strategic use of modularity is still a recent phenomenon in home appliances, these second order effects are perhaps less evident. However, some of the global home appliances firms have made local development centres responsible for specific modules (for a vacuum cleaner, these modules may be the motor, the electronic circuit board, or the accessories). Because task interdependencies have been reduced by establishing standard interfaces, these centres are allowed to carry out their development efforts in a relatively autonomous fashion (chapter 5, this thesis). Incremental innovation is fostered because home appliances companies have identified modules that undergo frequent technological change (e.g., filters in vacuum cleaners) and often outsource the development of these to suppliers with distinctive capabilities. In the future, some appliances firms are also likely to imitate the strategies of electronics firms such as Sony that carry out real time market research on small lots of trial models leveraged from modular architectures. For example, Electrolux recently established an “excitement centre” in Paris to test customer reactions to experimental concepts for future home appliances.

A number of case studies have described the use of modular systems in industries such as software (Cusumano, 1991; Post, 1997; Meyer & Seliger, 1998), computers (Baldwin & Clark, 1997), consumer electronics (Sanderson & Uzumeri, 1995), and car manufacturing (Cusumano & Noebeka, 1997). However, whereas these cases represent “best practice” of applying modular platforms, the key proposition is that *all* companies would benefit from implementing modular systems if they face dynamic market conditions (Sanchez, 1995). Although it is clear that some firms have derived benefits from introducing modular systems, we know little about the effects

for populations of firms within industries. Some authors have argued that establishing modular systems incurs significant co-ordination costs and point to case studies of failed attempts at introducing global platforms in the car industry (Tagliabue, 1996; Fisher, Jain, & MacDuffie, 1995). Successfully introducing modular systems does require fundamental technological and organisational re-orientation and it is little surprise to find that many traditional manufacturing firms struggle to implement these principles (Marsh, 1997).

In this research, I sought to contribute to the extant literature in the following ways. I was interested in looking systematically at a sample of “average” firms, with varying degrees of modularity in their products and processes⁹⁵. Noebaka & Cusumano (1997) previously conducted a study of modular platforms in the car industry, and Meyer & Roberts (1986) in small technology-based firms. This study adds to the existing knowledge base by focusing on the home appliances industry, which so far has received little attention⁹⁶. This industry is also relevant to study because there might be more variance between firms with regard to product architectures than in more high-technology (or network based) industries, where industry-wide standards often dictate product architectures. In home appliances, product platforms are usually proprietary to every firm and there have so far been few incentives for creating industry-wide standards.

In addition to technology management theories, my propositions were also informed by organisational and strategic management theories that address the role of *complementary resources*. The role of complementary resources can be viewed from two perspectives. The first concerns the *process* of adopting new product creation frameworks. This process is often initiated when managers perceive the competitive environment to be changing more rapidly than before and then develop an explicit commitment to increasing flexibility by renewing their firms’ products and processes. Implementing new principles for product design and development may in

⁹⁵ Modularity is not a dichotomous variable (Ulrich & Eppinger, 1995) in that most systems can be classified along a continuum from highly modular to highly integrated.

⁹⁶ Recent exceptions are John & Harrison (1999), Sobrero (1995), and Sobrero & Roberts (1996).

turn lead to (or depend on) changes in culture or work patterns. In other words, it seems reasonable to assume that the causal links between product modularity and strategic flexibility are *mediated* by other factors, such as managerial perceptions of the market context, the firm's strategic intent, and organisational climate and structure. I thus follow the recommendations of Sanchez & Heene (1996) in explicitly incorporating cognitive elements in a systems view of how managers respond to dynamic environments.

Secondly, resource based theory (Teece, 1987; Barney 1991) suggests that it is important to consider complex sets of organisational resources in understanding how strategic flexibility may result in *competitive advantage*. For example, the strategic value of product modularity may be linked to the presence of other organisational resources such as flexible structures, processes, or culture. It has already been demonstrated that investments in technological resources such as information technology require the existence of complementary resources to confer competitive advantage (Powell & Dent-Micallef, 1997). Again, I assumed that a holistic model would be necessary to capture the antecedents, contributing factors, and strategic outcomes of modularity. The propositions link the different dimensions of the conceptual model that appears in Figure 1. The particular methodology I apply is structural equations modelling, which allows me to consider simultaneously the relationships between single variables (as in correlational techniques) as well as the fit of a more complex overall model with reinforcing and counteracting causal links.

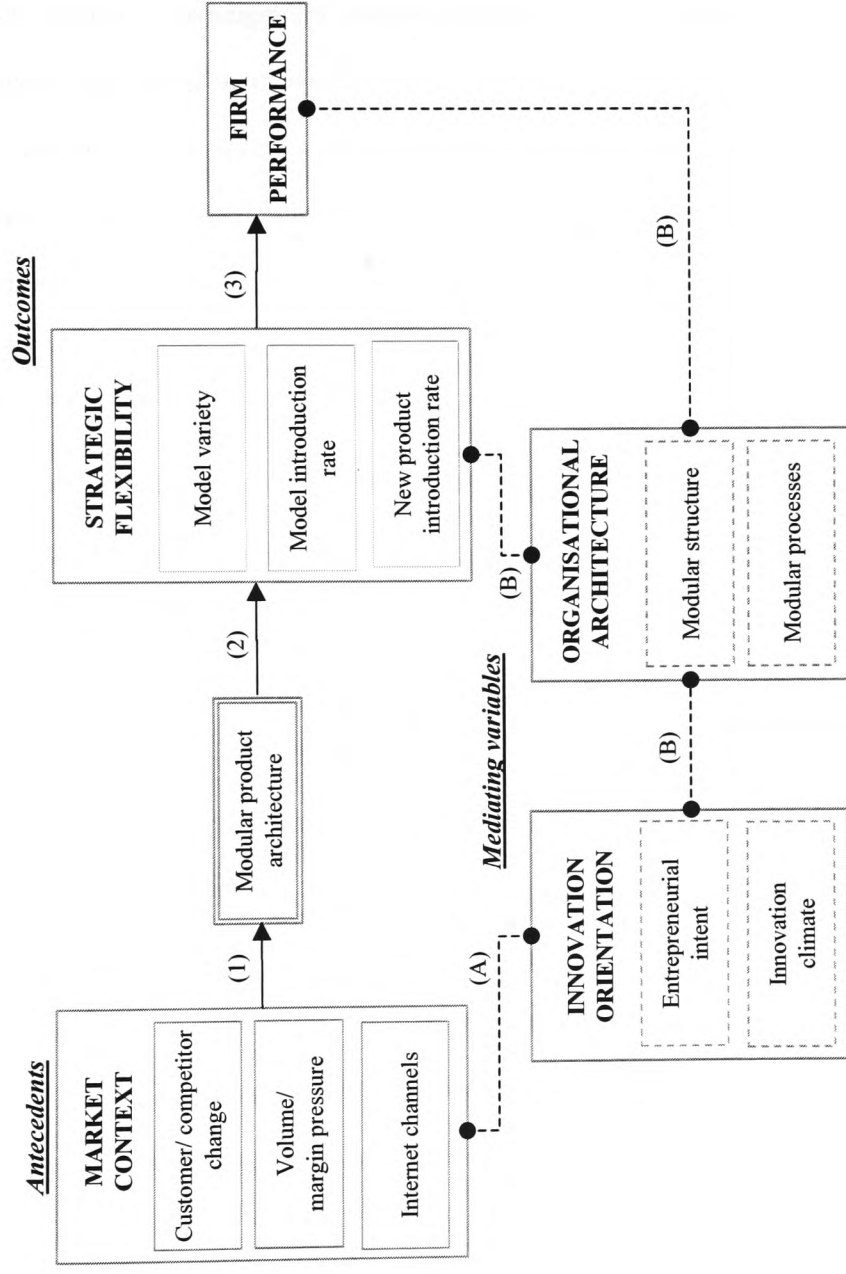


Figure 5.1. The hypothesised conceptual model of the relationship between market context, innovation orientation, organisational architecture, modularity, strategic flexibility, and performance.

5.2 PROPOSITIONS AND RESEARCH QUESTIONS

The traditional paradigm for product competition and manufacturing relied on *minimising variety and change* to achieve economies of scale, low cost, and quality. This paradigm grew in response to the need for techniques for managing firms in product markets with mostly stable technologies and market preferences. More variety (or more frequent model changes) was associated with higher unit costs (due to a correspondingly lower volume for each item in a product line) and to higher complexity of the manufacturing operations (leading to higher requirements for co-ordination and control of inventory, scheduling, defects, etc.). The low rate of change meant that conventional principles for product design defined product architectures as the *output* of the development process. These *integrated* designs contained many interrelated components that made the overall design time-consuming and costly to change, since change in one component required compensating changes in other components (Sanchez, 1995).

New strategic principles have emerged for managing firms in products markets characterised by changing technologies, by customer preferences that are shifting, uncertain or heterogeneous, and by the threat of being outmaneuvered during frequent competitive interactions with competitors. In dynamic product markets, there are no specific tangible resources that can provide “sustainable competitive advantage”. However, a superior ability to leverage existing competencies to take advantage of emerging customer needs may lead to temporary advantage. The concept of strategic flexibility broadly denotes such firm abilities to respond to rapidly changing markets (Sanchez, 1995)⁹⁷. In the context of product

⁹⁷The concept of strategic flexibility (Sanchez, 1995) primarily addresses the technological and product design dimensions of an organisation’s flexibility in competing in product markets. It is similar but not identical to the following concepts, most of which also include other dimensions such as culture and structure: Transformative capability (Garud & Nayyar, 1994), dynamic capabilities (Teece, Pisano & Shuen, 1997), adaptive capacity (Ashley & Brahm, 1989), strategic response capability (Bettis & Hitt, 1995), organisational flexibility (Volberda, 1996), self-designing organizations (Hedberg, Nystrom &

competition it can be operationalised as *the number of product variations* offered, *the frequency of new model introductions*, as well as *the number of entirely new products* introduced. It has been suggested for some time that manipulating product variety and change are vital aspects of competitive strategy (Hofer & Schendel, 1978; Lancaster, 1990; Kekre & Srinivasan, 1990). The contribution of the strategic flexibility approach is to highlight the enabling role of *modular product architectures*. This approach highlights how strategic flexibility can be increased through the re-combination of modules, while costs and complexity are contained by re-using the same, standard modules across models (component sharing) or model generations (component carry-over). For example, after acquiring Philips' home appliances business in 1991, Whirlpool modularised the products to ensure that many models could be built on the same basic platforms (Maruca, 1994). Whereas competitors typically had one motor for each vacuum cleaner model or product family, Whirlpool introduced one standard motor for all models.

Formally speaking, a modular architecture is one that minimises interdependencies between modules performing different functions⁹⁸. This principle is applicable to any complex system, including work processes, organisational structures, or knowledge systems, which can be decomposed into relatively autonomous entities that are co-ordinated by means of standard interfaces (Sanchez & Mahoney, 1995). For example, Zenger & Hesterly (1997) note that self-managing teams are increasingly replacing hierarchy and considered separate "economic units" that are configured to product and exchange definable outputs, be measured as separate units, and rewarded directly for their performance. Jarvenpaa & Ives (1994) describe the "dynamic network organisation" as one where modular units are mixed and matched according to unique customer needs.

Starbuck, 1977), sustained innovation (Dougherty & Hardy, 1996), and enacting organizations (Daft & Weick, 1984).

⁹⁸ Complex systems may allow many different decompositions, only some of which provide the desired flexibility in a given market context. Decisions about how to define and select modules are based on the particular *functional requirements* for the product or process as well as considerations of the costs and benefits of alternative ways of modularisation (see Erixon, 1996; Robertson & Ulrich, 1998; Thomke & Reinertsen, 1998).

One should note that the modular approach represents a departure from conventional ways of viewing organisational flexibility (Worren & Moore, in review). For example, in previous studies of decision making, flexibility has sometimes been operationalised as recursiveness - the tendency to revisit or change earlier decisions (e.g., Sharfman & Dean, 1987). In contrast, the notion of architecture implies that certain higher-level elements (e.g., interface specifications) need to be “frozen” for a predetermined period of time to allow modular development processes at the component level. In both classic organisation theory (e.g., Morgan, 1990) as well as in more recent theorising on organisational improvisation (e.g., Miner & Moorman, 1998; Barrett, 1998), flexibility is typically equated with informal and ad hoc systems. However, it is impossible to decompose a system that does not have an explicit structure. Modularisation of business processes thus requires a relatively high degree of *formalisation and codification*. As with earlier approaches to process innovation such as Total Quality Management and re-engineering, modularisation begins with an analysis and documentation of existing processes in order to identify and define the units that are to be the reconfigurable building blocks. Codification and partitioning of knowledge and processes then allow the leveraging of resources across organisational boundaries (Zander & Kogut, 1995; Zulanski, 1993). This is analogous to leveraging modular product designs except that the resources that are transferred are process specifications and best practices as opposed to physical components. For example, one home appliances company I studied standardised its product development processes across different product divisions producing stoves, dishwashers and refrigerators. This standardisation defined common approaches, stages, and criteria (e.g. for product concept development and screening). By having all the involved teams and departments follow the same basic process architecture, the company achieved more rapid knowledge transfer and rotation of personnel across organisational boundaries⁹⁹. By de-coupling resources (in this case, knowledge and human capital), flexibility is increased

⁹⁹ Werr et al. (1996) made the interesting point that standard methodologies provide “cognitive interfaces” that improve co-ordination cross organisational boundaries.

because the resources can be applied to a range of alternative work processes instead of being limited to a specific department or division.

In sum, modularity has been proposed as a key principle for firms adapting to dynamic markets. I thus expected that firms in which managers perceive the environment to be more dynamic will be characterised by higher degrees of product modularity; that product modularity will be positively related to strategic flexibility, which in turn should positively influence firm performance. My arguments can be summarised in the following propositions:

Proposition 1: Firms facing a more dynamic market context are more likely to employ modular product architectures.

Proposition 2: Modular product architectures are associated with higher strategic flexibility (model variety and model and product introduction rate).

Proposition 3: Strategic flexibility (product variety and model and product introduction rate) is associated with higher firm performance.

As noted above, I adopted a holistic model to capture some of the intermediate variables that may moderate the relationships between modularity and firm performance (see Figure 6.1). However, these linkages are complex and extant theory did not provide a clear rationale for specifying the direct or indirect links that may exist. For this reason I framed this part of my exploration as two research questions related to factors that influence the process of adopting modular principles and factors that influence the strategic value of modularity.

The strategic flexibility approach prescribes that firms facing increased dynamism first change their overall strategic logic governing product creation and marketing, and then introduce modularity as a means to achieve higher strategic flexibility. However, my initial field work had suggested that the principles governing product architectures were partly disassociated from strategic planning in some firms, and that some manufacturing managers viewed modularity more as a means for reducing cost rather than as a means for increasing strategic flexibility (chapter 5, this thesis). For researchers it is important to remember that the level of modularity in any given firm may reflect both intended strategic adaptation as well as

the heritage of existing, integrated systems, as the process of modularisation may take several years in a large firm. Some firms may also adopt modular principles for product design without revising their fundamental strategic logic¹⁰⁰. Such firms may make incremental adjustments to their product structures (for example, standardise certain components across product lines or product generations) as an isolated effort to reduce cost rather than as a strategically motivated attempt at introducing new product development processes. In the model I therefore included a construct - Entrepreneurial Strategic Intent - to examine whether there is a linkage between product modularity and the firms' articulated strategic intent for developing new products or entering new markets with existing products.

Another important mediating variable is organisational climate, which is defined as the perceptions organisation members share of fundamental elements of their organisation (West, 1998). Organisational climate has been considered a centrally important factor in determining organisational effectiveness (Denison, 1990; Ghoshal & Bartlett, 1994). Although organisational climate is a multidimensional construct encompassing elements such as trust, support, shared values and vision, in the present context I was particularly interested in the effect of one element, the firm's orientation toward innovation, which I label Innovation Climate. It is now well documented that a firm's organisational climate may either facilitate or impede individual creativity and innovation; it is also possible that the organisational climate influences the strategic logic adopted and followed by decision makers (cf. Sanchez & Heene, 1996; Daft & Weick, 1984). A positive innovation climate exists where the development of new ideas is encouraged and rewarded (Amabile et al., 1996) and where there is a strongly shared mission among employees (West, 1992). I included this variable to investigate whether the firms' innovation climate influences the degree of modularity, and also to examine the links between market context, innovation climate, and entrepreneurial intent. In other words, I explored the following research question (A): What is the relationship between market context, Entrepreneurial Intent, and Product Modularity?

¹⁰⁰ See Sanchez & Heene (1996) for an insightful discussion of the consequences of driving adaptive

Although the modularity concept originated in technology management, many authors emphasise that firms need complementary organisational resources and capabilities to exploit the “economics of substitution” afforded by modular product structures (e.g., Cusumano & Noebeka, 1997; Garud & Kumaraswamy, 1995). These capabilities include a systems for continuous improvement of work processes through codification and standardisation; appropriate organisational structures (e.g., platform teams or centres); and an infrastructure to facilitate knowledge sharing and re-use such as electronic networks and databases. Thus it is not enough to merely redefine product architectures in order to increase flexibility: firms also need to simultaneously re-align organisational structures and processes. The nature of the process of alignment is typically complex, tacit, and firm-specific, and it may result in a unique configuration of organisational capabilities that provide significant impediments to competitive imitation. At the same time, research indicates that such alignment is difficult to achieve, and my fieldwork had also suggested a relatively low level of alignment in the typical home appliances company. For this reason I was interested in exploring how the organisational variables in my model (Figure 6.1) relate to each other and how they influence strategic flexibility and firm performance. Apart from Innovation Climate and Entrepreneurial Intent (described above) I defined two other complementary resources: Modular Organisational Structures, and Modular Work Processes. Hence this reasoning led me to formulate my second research question (B): How do complementary organisational resources influence the relationship between product modularity, strategic flexibility, and firm performance?

5.3 RESEARCH METHODOLOGY

change from the “bottom up” versus “top down” through fundamental re-orientation of strategic logic.

5.3.1 Instrument

I developed Likert-type measurement scales for the variables described above related to market context, organisational resources, modularity, and firm performance. Wherever possible, I re-used items or the general question format from existing scales. However, I was unable to use existing scales in their entirety. A key priority was to keep the total questionnaire relatively short in order to increase response rate (cf. Dillman, 1978). This concern precluded the incorporation of existing scales measuring constructs such as innovation climate (e.g., Amabile et al., 1996) or environmental uncertainty (e.g., Miles & Snow, 1978; Milliken, 1990), which would have doubled the length of the total questionnaire.

I developed new items tapping the dimensions of modularity related to product architecture and process and structure as I was unaware of any previous attempts to measure these constructs. The development of these items was informed by my field studies (chapter 5, this thesis), which included semi-structured interviews with around 20 managers and executives in three leading home appliances companies. These interviews helped me refine the definition of key variables and identify the appropriate wording in this particular industry. Two leading experts on modular systems (one academic and one consultant) then provided feedback on a pilot version of the questionnaire¹⁰¹.

My field work had indicated that there were some specific events that led companies to re-examine their product design philosophies and consider increased modularisation. These included falling margins or sales volume; the appearance of new competitors with products utilising new technologies; and the emergence of new internet-based supplier and distribution channels¹⁰². Consequently, I wrote 7 items to assess market context; for each item the

¹⁰¹ A group of managers attending an executive course also provided feedback on a slightly modified version of the questionnaire which was intended for another industry.

¹⁰² There are different and partly conflicting conceptions of environmental dynamism and uncertainty in the literature (e.g., Miles & Snow, 1978; Dess & Beard, 1984; Milliken, 1987, Slater & Narver, 1994; Jaworski & Kohli, 1993). Sutcliffe & Zaheer (1998) defined three different categories of environmental uncertainty, but also noted that they may be parts of a continuum. These categories were: *Primary uncertainty* (arising from exogenous sources such as changing customer preferences

respondents were asked to indicate the future probability of the event mentioned. In contrast to scales that tap global attributes of the environment I thus followed the approach used by Milliken (1990) who focused on perceptions and interpretations of specific changes in the industry environment.

To capture the firms' entrepreneurial intent, I included three items that asked respondents to indicate whether they had formulated plans to improve their product development processes, to use existing or new technology to develop new products, or to enter new markets with existing products. Although some authors have conceptualised entrepreneurship in broad terms such as "the process of pursuing opportunities", I took the narrower approach suggested by Lumpkin & Dess (1996), who defined entrepreneurship as new entry, which can be accomplished by entering new or established markets with new or existing goods or services. As a contrast I also included one item that asked respondents to rate their firm's commitment to cost reduction.

Modularity in processes and structure were measured by 9 and 3 items, respectively. I developed items based on the recent theorising reviewed above (in particular, Sanchez & Mahoney, 1996; and Worren & Moore, in review). In capturing modular structure I included items about the existence of small, autonomous units and rotation of personnel between different product areas. As indicators of modular process I used several items focusing on codification, standardisation and re-engineering of work processes, as well items asking about knowledge management systems and knowledge transfer. Innovation climate was assessed by items adopted from Amabile et al. (1996) and Powell & Dent-Micallef (1997), asking respondents to assess the degree of shared vision and the encouragement of creativity in their firms.

In line with the conceptual frameworks proposed by Sanchez (1995), Sanderson & Uzumeri (1997), and Nayyar & Bantel (1994) I operationalised strategic flexibility as: 1) the

and new technologies), *competitive uncertainty* (arising from the actions of potential or actual competitors), and *supplier uncertainty* (caused by opportunism by upstream or downstream exchange

total number of models/ variants offered by the firm¹⁰³, 2) the total number of new models/ variants introduced during 1998, and 3) the number of entirely new products introduced during 1998¹⁰⁴. My interviews had indicated that manufacturing and marketing managers easily could identify such figures for their company or division.

Perceived performance was measured using three items developed by Powell & Dent-Mitcallef (1997). Subjective measures of performance have been widely used and most studies find high convergent validity with objective measures such as publicly available accounting data (e.g., Powell & Dent-Mitcallef, 1997; Hart & Banbury, 1994; Dess & Robinson, 1984; Venkatraman & Ramanujam, 1987).

I included some questions that collected background information and two control variables, firm size and age. Respondents were asked to indicate the number of employees in their division, and the date the company and their division were established. As with the other constructs these were measured using Likert scales. To reduce autocorrelation effects, questions pertaining to key constructs were placed in separate sections of the questionnaires.

5.3.2 Sample

As described above I focused on firms in the home appliances industry to test my model. Administration of the survey followed guidelines prescribed in Dillman (1978). I identified home appliances firms through lists provided by a UK industry association (Association of Manufacturers of Domestic and Electrical Appliances - AMDEA) and a US industry magazine (*Appliance*). I called up every firm on the lists to verify names and to confirm that it was a manufacturer of branded consumer appliances. After excluding firms that did not

partners). Conceptually, my scales relate mainly to the first two categories, although the last sub-scale on internet-based supplier and distribution channels overlap with the construct of supplier uncertainty.

¹⁰³ As a control I also asked respondents to indicate the number of variants within their main product family, but because this variable correlated strongly with the total number of variants, I used the latter in my analyses because it had fewer missing cases.

¹⁰⁴ The authors cited all emphasise the dual objectives of variety and speed. However, as in the conceptual model proposed by Sanderson & Uzumeri (1997) my measures focus on the product level

satisfy this criterion, I sent out questionnaires to manufacturing and marketing managers in the remaining 500 firms (50 in United Kingdom and 450 in the United States). Follow-up letters and faxes were sent to managers who did not respond to the initial mailing. In the larger, multidivisional firms I sent the questionnaire to managers at the divisional level, and they were asked to respond based on the products and characteristics of their division. I chose this approach as my field work had indicated that the divisions for the global firms were largely independent business entities with responsibility for separate product lines (washing machines, vacuum cleaners, stoves, etc.).

Of the 500 questionnaires mailed, 103 were returned for a response rate of 20%. Although I sent questionnaires to multiple respondents within each firm or division, I only received multiple responses from 7 firms. As a control respondents were asked to indicate the category of products they manufactured, and one firm was excluded because it was not in my target group as defined above. Firms differing in size, age and geographical scope were represented in the sample. In terms of size, mean employees¹⁰⁵ was 1050, while the median was 750 and the standard deviation 580. The majority of the companies (62%) indicated that they manufactured for global markets, while 32% served local and 5% regional markets. Most of the companies in the study were fairly old - 70% of the mother companies were incorporated more than 30 years ago and only 15% were incorporated during the last 20 years. However, some of the divisions or business units of these managers were more recent, with 30% having been established after 1980. To control for non-response bias I compared early with late respondents (Armstrong & Overton, 1977). The first 75% of the returned questionnaires were defined as early responses and the remaining 25% as late responses and thus deemed representative of firms that ultimately did not respond to the survey. First I compared the means of four background variables (geographical scope, firm size, firm age, division age), and no significant differences were found. I then compared the means of 13

only. Thus benefits of modular architectures relating to processes (such as decreased throughput time and speed to market) were not directly assessed in this study.

¹⁰⁵ Respondents indicated the size of their division or business unit on a Likert scale.

explanatory variables, 12 of these were non-significant, with one variable showing a significant difference. Nevertheless, I attributed this finding to chance because of the lack of significant differences among the other 16 variables that were compared.

5.3.3 Construct validation and scale purification

I followed the usual steps in exploratory factor analysis to validate the constructs and create indices summarising the items. In general, the factor analysis confirmed the structure of the constructs as defined above, with two or three exceptions. For the seven environment items the analysis suggested a three-factor solution. This result is consistent with other studies that have found that environmental uncertainty and dynamism are multidimensional constructs (e.g., Milliken, 1990; Sutcliffe & Zaheer, 1998). It was relatively easy to interpret the pattern suggested by the factor loadings. I consequently created three variables, labelled “customer/competitor changes”, “margin/volume pressure”, and “Internet channels”, respectively. The subsequent analysis confirmed that these three dimensions of the environment had distinct effects on other key variables. For the product modularity items, the factor analysis produced a two-factor solution. Four “core” items were combined into the main variable for modularity, in addition, two items were combined to form an “advanced modularity” variable. Only the analysis for the core items are reported in the remainder of this paper. Two items correlated poorly with either variable and were subsequently dropped. For the process modularity construct, 7 items loaded on the same factor. These were combined to form an index whereas two items that had poor item-to-factor correlations were dropped from the scale.

The reliability (Cronbach alpha) of all variables is reported in Table 1. Alphas ranged from 0.56 for Modular Structure to 0.84 for Firm Performance. Although some of the alphas are under 0.70, customary used as cut-off point, I am of the opinion that the inclusion of these variables is warranted. Methodologists have demonstrated that the routine use of a 0.70 cut-

off is inappropriate unless other types of information are taken into account (Schmitt, 1996; Cortina, 1993). Classic test theory essentially holds that reliability places a bound on the upper limit on validity (the relationship between a predictor and a criterion variable). The upper bound of validity is the square root of the reliability of the criterion or outcome variable. This means that relatively large differences in alpha have relatively small effects on validity: With an alpha of 0.70 the upper limit is 0.84, whereas with an Alpha of 0.49, the upper limit is still as high as 0.70. Schmitt (1996) argues that even relatively low (e.g., 0.50) alphas are acceptable if the measures have other desirable characteristics, such as meaningful content coverage and reasonable unidimensionality. I ascertained that the measures have satisfactory unidimensionality by first performing factor analysis, which showed that items belonging to each variable load on the same factor (items with poor loadings were abandoned). Note also that lower than ideal reliabilities actually mean that I provide conservative tests of the hypothesis (i.e., that the true correlations between variables are underestimated).

I investigated the distributional properties of the data using residuals scatterplots and normal probability plots. I found clear departures from the assumption of equal variance for the three strategic flexibility indicators. Consequently I used a log transformation to correct these indicators. I also examined outliers and influential observations using indicators such as Cook's distance (Norusis, 1990). I corrected the data for one influential outlier that strongly affected the parameter estimates¹⁰⁶.

¹⁰⁶ I called up the respondent submitting this data, who said that he had misunderstood some of the questions in that he had considered e.g., component sharing *between* product lines rather than *within* product lines when filling out the questionnaire. Based on my telephone interview I subsequently corrected this company's score on one variable (product modularity).

Table 5-1. Factor analysis outcome for key variables¹⁰⁷

Variable name and items ¹⁰⁸	Factor loading
<i>Customer/competitor change</i> ($\alpha = .58$)	
• Competitors will introduce products with superior performance compared to ours	.70
• Customer preferences for product functions and features will change significantly	.79
• Competitors will increase their product variety	.76
<i>Margin/volume pressure</i> ($\alpha = .62$)	
• Margins on our key products will fall by more than 10%	.82
• Sales volume for our key products will fall by more than 5%	.85
<i>Internet channels</i> ($\alpha = .74$)	
• New entrants in our industry will use the internet as their main channel to customers and suppliers	.91
• Customers will use the internet to configure products themselves rather than choosing from a standard assortments	.85
<i>Entrepreneurial intent</i> ($\alpha = .70$)	
• We have a business plan to use existing technology to enter new market segments	.82
• We have business plan to develop new technologies for new kinds of products	.77
• We have an overall business plan to redesign our product development process	.70
<i>Innovation climate</i> ($\alpha = .80$)	
• People here are encouraged to solve problems creatively	.76
• In general, our people accept change readily	.88
• People here share a view of where the company should be in the future	.84
<i>Modular structure</i> ($\alpha = .56$)	
• We try to create small, autonomous units to encourage innovation and flexibility	.65
• We frequently rotate people between different product areas	.82
<i>Modular processes</i> ($\alpha = .80$)	
• Improving work processes has become a key part of our business plan	.55
• We have documented the steps involved in our key work processes	.69
• We have defined business processes that cut across functional boundaries	.66
• We have standardised work processes across departments and business units	.62
• In the concept development stage, we use a formal procedure to analyse customer needs and define product specifications (e.g., Quality Function Deployment)	.74
• Our product development engineers have electronic databases listing standard components and their interface specifications	.65
• We have procedures and systems for transferring knowledge across projects and business units	.70
<i>Modular products</i> ($\alpha = .64$)	
• Our products have been decomposed into separate modules	.51
• For our main product(s), we can make changes in key components without redesigning others	.39
• The extent of re-use of components (Likert scale from 0-20% to 80-100%)	.82
• The degree of component carry-over (Likert scale from 0-20% to 80-100%)	.74
<i>Performance</i> ($\alpha = .84$)	
• Over the past 3 years, our financial performance has been outstanding	.88
• Over the past 3 years, our financial performance has exceeded our competitors'	.90
• Over the past 3 years, our sales growth has exceeded our competitors'	.82

¹⁰⁷ The strategic flexibility indicators (model variety, model introductions, new products) were not included in the factor analysis but used directly after a log transformation as explained in the text.

Following the recommendations of Kendall (1975, p. 25) indices were constructed by applying the weights for each item obtained by the principal components analysis then summing the weighted items¹⁰⁹. These indices were used in the subsequent analyses.

5.3.4 Analysis

The model presented in Figure 6.1 was tested with structural equations analysis using the software package EQS Version 5 (Bentler & Wu, 1995). EQS is similar to the more frequently used LISREL (Jöreskog & Sörbom, 1993). There were missing data on one variable (Strategic Flexibility) for 14 firms. Given the difficulty of using pair-wise deletion with covariance matrices, I chose to delete missing cases from the analysis, which was carried out with the remaining 73 firms. Although this sample size is small, it is above the minimum sample size required for estimation of covariance matrices (Jöreskog & Sörbom, 1993, p. 26)¹¹⁰. On the other hand, the sample size restricted the number of variables that I could examine simultaneously as the required sample size depends on the number of variables included in the model being tested¹¹¹.

Statistical packages provide different indices of fit to determine whether the overall model fits the data well. During the analysis I assessed the goodness of fit using the Comparative Fit Index (CFI), an index that reflects fit relatively well at all sample sizes. Values of CFI range from zero to 1.00. A value of CFI greater than .90 has been proposed as an acceptable fit to the data, indicating that 90% of the covariation in the data can be

¹⁰⁸ Some of the items have been slightly abbreviated. See appendix for the complete questionnaire.

¹⁰⁹ This approach is similar to using factor scores in regression analyses except that it allowed us to eliminate items with reliability alphas or low item-factor loadings or high cross-factor loadings (we used 0.4 as a cut-off point).

¹¹⁰ As a control I also ran regression analyses of pairs of variables in the structural model (e.g., modular products and model variety, controlling for firm size). Taken together the regressions produced the same general pattern of relationships as in the structural model. There was one exception, however: In the regression analysis, Modular products correlated with New product introduction rate, when corrected for firm size ($R = 0.22$; $F \text{ prob.} = 0.6$).

¹¹¹ The questionnaire included three control variables: Firm size, firm age and division age. Because of the restriction on the number of variables I included only firm size as a moderator (with paths to model

reproduced by the model (Bentler, 1990). As alternatives I also provide the Chi square and the values of the root mean squared error of approximation (RMSEA), a recently developed index. The chi-square should not be significant if there is good fit. I included the Chi-square value because it is a common test statistic, but one should note that many researches believe the chi-square to be misleading in some circumstances, such as when ideal sample size and distributional requirements are violated. Values of RMSEA range from 1.00 to 0.00, with values closer to zero indicating better fit. By convention, there is an adequate fit if RMSEA is less than or equal to 0.08 and there is good fit if RMSEA is less than or equal to 0.05. However, cut-off points are arbitrary and it has been pointed out that what is deemed acceptable depends on the level of fit achieved by prior models of the same phenomenon (Kline, 1998).

As is common in structural equations modelling, my analysis was both confirmatory and exploratory. I started with a model representing several possible cross-paths between the variables, and then used the Lagrange Multiplier and Wald tests to assess which ones should be omitted from or added to the theoretical model. The main post hoc improvements that I made to the model were the interrelationships between the variables measuring innovation orientation and organisational architecture, which I had left unspecified in the hypothesised model presented in Figure 6.1. I also added a path (a correlation) from performance to Strategic Intent. This correlation indicates that the causal direction may be in any direction. In Figure 6.2 the correlation is represented by a two-way arrow whereas the regression coefficients are represented by one-way arrows. As is customary the standardised path coefficients (effect sizes) are displayed above their respective arrows.

variety and modular products in Figure 2) because firm age and division age were uncorrelated with these variables. Firm age and division age were also uncorrelated with firm performance.

Table 5-2. Descriptive statistics and intercorrelations

Variables	N	Items	Means ₁₁₂	S. D.	1	2	3	4	5	6	7	8	9	10	11	12
1. Customer/ competitor changes	87	3	3.24	.73												
2. Margin/volume pressure	87	2	2.43	.80	.131											
3. Internet channels	87	2	2.30	.96	.254*	.034										
4. Entrepreneurial intent	87	3	3.53	.87	-.058	-.303**	.241*									
5. Cost reduction	87	1	4.31	.80	.071	.319**	-.132	-.005								
6. Innovation climate	87	3	3.55	.78	-.045	-.264*	.196	.373**	-.122							
7. Modular structure	87	2	2.81	.91	.032	-.094	.233*	.251*	-.125	.303**						
8. Modular processes	87	7	3.45	.71	.002	.015	.308**	.336**	.152	.433**	.352**					
9. Modular products	87	4	3.20	.75	-.136	-.060	-.004	.231*	-.083	.069	.152	-.170				
10. No. of models/ variants	73	1	988	2327.2	.062	-.184	.163	.231*	-.064	.155	.041	-.054	.156			
11. New model/variant introd.	73	1	130	405.4	.089	-.106	.107	.245*	.063	.134	-.094	-.028	.099	.802**		
12. New product introductions	73	1	7	13.8	.233*	.210	.262*	.183	.009	.212	.075	.035	.215	.346**	.306**	
13. Performance	87	3	3.38	1.11	.089	-.299**	.237*	.115	-.152	.342**	.307**	.260*	-.004	.340**	.115	.112

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

¹¹² In order to facilitate comparison, the means and standard deviations are pre-transformation. The correlations are for the transformed variables.

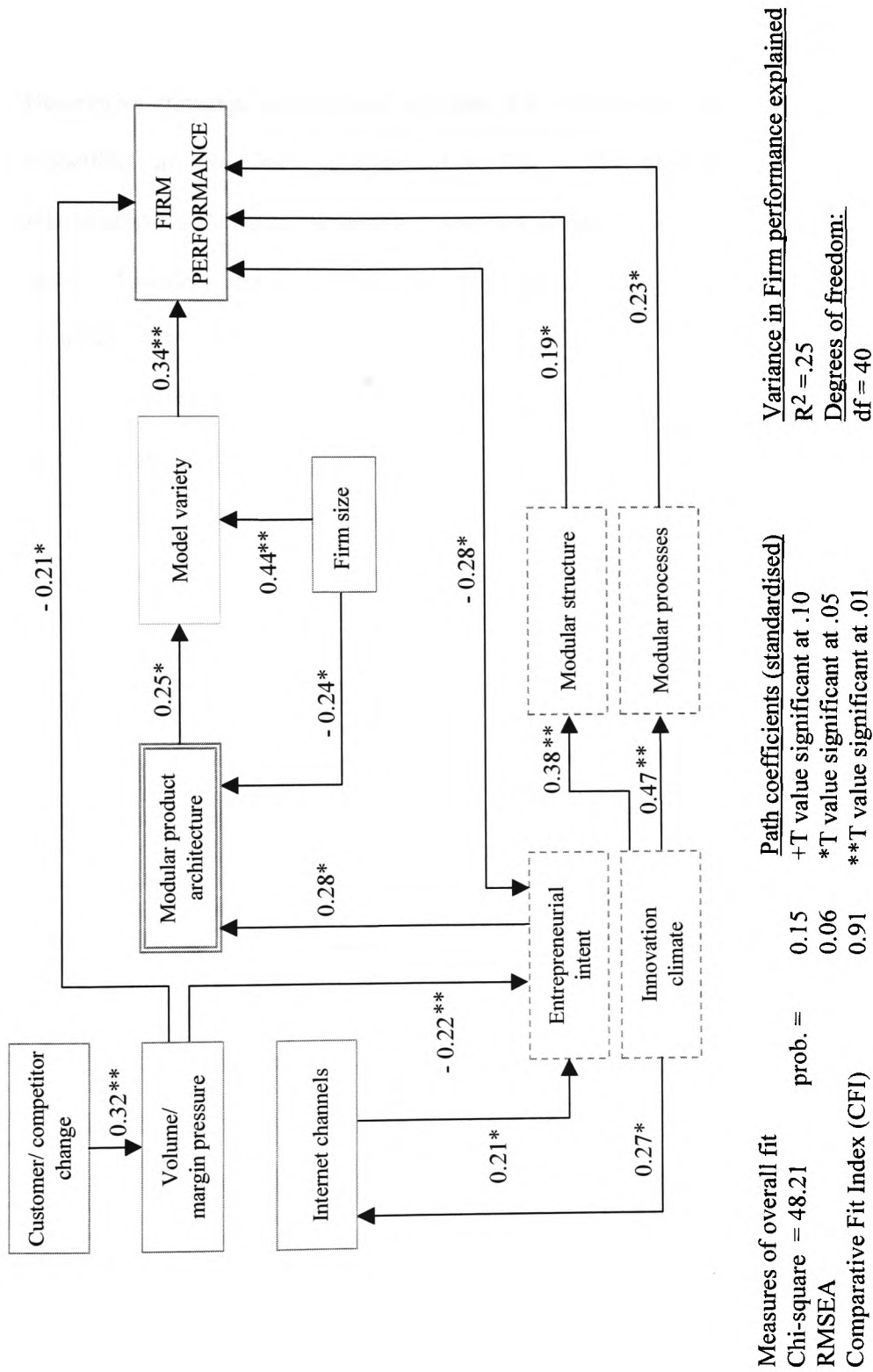


Figure 5.2. Structural equations model of the relationship between market context, organisational variables, modularity, model variety, and performance.

5.4 RESULTS

Descriptive statistics are provided in Table 6-2. The results from the structural equations modelling are presented in Figure 6.2. The results generally support the proposed relationships, with some exceptions. Compared to the conceptual model in Figure 6.1 the structural model suggests a more fine-grained picture of the interrelationships between the variables in the model.

Proposition 1 stated that firms operating in a more dynamic market context should employ higher degrees of product modularity. This proposition was only partially supported. Recall that the operationalisation of the market context variable led to the construction of three sub-scales measuring the perceived market environments. As can be seen in Figure 6.2, these sub-scales have distinct effects on the other variables. Customer/ Competitor Change has a fairly strong positive influence on Internet Channels ($\beta = .32, p = \leq .01$). Firms experiencing more uncertainty with regard to customer preferences and competitors' actions perceive that the internet will be a significant force in the industry. Internet Channels in turn has a positive impact on Entrepreneurial Intent ($\beta = .21, p = \leq .05$). However, the third market context subscale, Volume/ Margin Pressure, *negatively* influences Entrepreneurial Strategic Intent ($\beta = -.22, p = \leq .01$). In other words, I do not find that increased uncertainty and pressure in the environment spur companies to make plans for improving the product development process or enter existing or related markets with existing or new products. The analysis also reveals some other linkages of interest. As would be expected, Volume/ Margin Pressure negatively impacts firm performance ($\beta = -.21, p = \leq .05$), i.e., firms that fear declining margins and sales have already experienced poor performance. I also note the positive influence of Innovation Climate on Internet Channels ($\beta = .27, p = \leq .05$). This linkage suggests that organisational climate has an effect on managers' interpretations of external events such as the emergence of Internet-based distribution channels.

My second proposition stated that modular product architectures should have a positive impact on strategic flexibility. This proposition was also partially supported. I operationalised strategic flexibility as: 1) model variety, 2) number of model introductions during 1998, and 3) number of entirely new products introduced during 1998. Modular product architectures showed a positive influence on Model Variety ($\beta = .25, p = \leq .05$), using Firm Size as a control variable. However, modular product architectures did not have a significant impact on Model Introductions or New Products.

My third proposition stated that Strategic Flexibility impacts Firm Performance. There is a significant relationship for Model Variety ($\beta = .34, p = \leq .05$), but again, there were no significant effects for Model Introductions or New Product Introductions. Consequently, I dropped these variables from the model. Although the latter finding is somewhat counterintuitive, Noebeka & Cusumano (1997) also found that companies that frequently introduced new products did not do very well in the marketplace (unless the products re-used existing platform designs).

I had also formulated two research questions. The first research question concerned the relationship between Innovation Climate and Entrepreneurial Intent and Modular Architectures. As described above, I found that Entrepreneurial Intent mediates the effect of market context on Modular Products. Secondly, note the strong links between Innovation Climate and Modular Process ($\beta = .47, p = \leq .01$) and Modular Structure ($\beta = .38, p = \leq .01$). This finding suggests that firms with organisational climates conducive to innovation are more likely to implement programs to improve the flexibility of structures and work processes. The second research question concerned the relationship between complementary, organisational capabilities and product modularity, strategic flexibility and firm performance. The most notable aspect of this part of the analysis is that I found significantly positive direct linkages between Modular Structure and Process and Firm Performance ($\beta = .23, p = \leq .05$ and $\beta = .19, p = \leq .05$, respectively). In other words, although these results indicate a positive contribution of modular organization on performance, they suggest that this effect is

independent from the effects on performance of product modularity through model variety. Finally, note that the negative correlation between firm performance and Entrepreneurial intent ($\beta = -.28, p = \leq .05$). This correlation indicates that poor firm performance may motivate managers to formulate an entrepreneurial intent; at the same time, it indicates that committing resources to product development may hurt firm performance, at least in the short term.

5.4.1 Limitations

This study is subject to the usual limitations inherent in cross-sectional research designs employing single respondents and subjective measures. Although both type 1 and type 2 error are possible, the risk of type 2 error (failure to detect a true population relationship) is probably greatest given the sample size, research design, and scale reliabilities. Particular care should be exercised when interpreting the causal relationship between modularity and performance. The appropriate way of viewing the study is as a comparison between firms varying in degrees of modularity, conceptualised as relatively stable organisational and product-related characteristics. This is not an unrealistic assumption, given that it takes several years to change product and process architectures (chapter 4, this thesis). However, the cross-sectional nature of the study precludes us from detecting “lag effects”. For example, whereas I failed to find a link between model introduction rate and performance, Noebeka & Cusumano (1997), who looked at a three-year period, did find a positive relationship between model introduction rate (labelled product introduction rate in their paper) and sales growth. Similarly, in considering the relationship between modularity and strategic flexibility, a cross-sectional study like the present one may fail to detect effects for firms that recently introduced modular architectures as it takes time both to implement modular systems and to learn how to manage them effectively. This research thus represents a description of actual antecedents, contributing variables, and outcomes of modularity among home appliances firms at the time of the study, as opposed to a test of the potential, future benefits that firms may gain from introducing modular architectures.

There are also limitations related to the measures that were used. Because I formulated an integrated model with a large set of variables, I was limited in the number of items I could use to assess each variable due to restrictions on the length of the questionnaire. This aspect probably reduced construct validity somewhat compared to more complete scales. The dearth of existing measures also meant that I had to develop new items tapping the modularity construct. The factor analysis indicated satisfactory internal consistency, but the scale obviously needs modification and refinement in future research. The strategic flexibility construct was operationalised simply as the number of model variants. A more sophisticated approach would take into account on which dimensions these models vary, for example, whether the models represent different peripheral options (e.g., colours) or more fundamental re-combinations of key components (cf. Fisher et al., 1995).

5.5 DISCUSSION

The main contribution of this study is the development of an integrative model and specification of links between perceived market context, modular architectures, strategic flexibility, and firm performance. In the following I highlight the key findings from the structural equations analysis.

The results lend support to some of the hypothesised causal links in the strategic flexibility approach (Sanchez, 1995). First, I find that model variety (i.e., the number of product models offered by the firm) is positively related to firm performance. This finding is consistent with a study using a much larger sample drawn from the PIMS database, which showed that firms offering broader product lines have significantly higher market shares and profitability (Kekre & Srinivasan, 1990). Secondly, I find that product modularity is positively related to model variety. My study thus contributes to extant research by emphasising product architecture as a key lever in attaining high levels of product variety. Product variety allows the firm to cater to diverse or unpredictable customer needs, while

modular architectures ensure a low incremental cost of producing new variations. In their study Kekre & Srinivasan (1990) noted the absence of any negative effects of product variety on manufacturing costs. Compared to producing a corresponding number of models based on integrated or unique designs, modular architectures reduce design and development cost by allowing the reuse of existing components, and reduce manufacturing costs by lowering variety of parts moving through the assembly line and by increasing volume for common parts (Fisher, Jain & MacDuffie, 1995).

However, I did not find a significant relationship between product modularity and the two other indicators of strategic flexibility - new model introductions and new product introductions¹¹³. This finding can be interpreted in several ways. The organisational capabilities necessary for creating frequent model and product introductions might differ from those that are required to produce high variety. Normally, it is assumed that modularity should enable increased variety and change simultaneously, but there are also authors (e.g., Sanderson & Uzumeri, 1997, p. 31-41) who argue that there is a trade-off between model variety and rate of change, and that firms need to choose between allocating resources to maintaining variety versus directing resources to reinventing a smaller number of models on a more frequent basis. In home appliances, the relative stability of the core technologies may make variety more important than frequent product introductions. However, my analysis cannot conclusively support or reject this explanation.

The proposed model offers some insight into the role of complementary, organisational capabilities. My operationalisation of the modular process construct meant that I focused on codification and standardisation of work processes as key indicators of modularity. Some scholars have treated codification and standardisation as equivalent to routinization and process stability, and as antithetical to flexibility and innovation. However, I relied on the alternative view that codification and standardisation in fact are necessary

¹¹³ In fact, these indicators of strategic flexibility are not well explained by any of the variables in the model presented in Figure 1. Additional regression analyses indicated that Entrepreneurial Intent

prerequisites for achieving high levels of process flexibility (Adler & Borys, 1996; MacDuffie, 1997). It is therefore interesting to note that my model shows innovation climate to be *positively* correlated with modular processes. This finding is consistent with the study conducted by Damanpour (1991), who found a positive correlation between formalization and innovation in manufacturing firms and for both product and process innovations. However, whereas the strategic flexibility approach emphasises how product architectures shape process architectures (Sanchez & Mahoney, 1995), I find that modular structures and processes have direct effects on performance, independently of product modularity. For this sample, the effects of product and process modularity are additive rather than interactive. This finding may indicate that these firms have failed to closely align product architectures and process architectures in the way prescribed by the theory.

Finally, my model suggests a complex relationship between managerial cognition, market context, and the use of modular architectures. A key mediating variable is Entrepreneurial Intent, defined as the existence of plans for redesigning product development processes and for entering new or existing markets with new or existing technologies. I find a positive link between Entrepreneurial Intent and the use of Modular Product architectures. This suggests, as prescribed by the strategic flexibility approach (Sanchez, 1995), that modular product architectures are employed in a strategic manner to improve product creation processes.

Scholars studying cognition in organisations have demonstrated that the relations between an organisation and its environment are socially constructed or enacted (Daft & Weick, 1984). Research on managerial decision making has also indicated that managers process issues differently depending on whether the issues are categorised as threats versus opportunities (Fredrickson, 1985). This may explain the discrepancies between the effects of different market context variables. I found that managers in firms with innovation-oriented

predicted new model introductions ($R = .36, p \leq .05$), but not new product introductions (controlling for firm size).

climates are more likely to rate the Internet as a future channel to customers and suppliers. This finding indicates that managers' perceptions are extensions of their firms' corporate organisational culture and climate. Moreover, I found that high pressures on margins and sales volumes make firms less likely to formulate an entrepreneurial intent, whereas perceptions of new Internet Channels make firms more likely to formulate an entrepreneurial intent. In other words, some home appliances firms may have more market-oriented or proactive cultures that lead managers to interpret external events - in this case, the emergence of new internet-based channels - as implying new opportunities. In contrast, the negative linkage between Volume / Margin Pressure and Entrepreneurial Intent may indicate, as predicted by the threat-rigidity hypothesis (Staw et al., 1981), that declining firms fail to fundamentally change their strategies, even when external threats (i.e., probable decline in margins or sales) are cognitively recognised. These firms may focus on cost reduction efforts as opposed to new product creation systems¹¹⁴. Also note the negative correlation between Firm Performance and Entrepreneurial Intent. Poor firm performance may motivate firms to formulate Entrepreneurial Intent. At the same time, formulating an entrepreneurial intent - which implies committing significant resources to renewing product creation processes - may also hurt firm performance in the short term.

This study contributes to the growing interest in achieving strategic flexibility through leveraging architectural knowledge, which, according to some authors, represents a new mode of competing that may supplant previous craft and mass production paradigms (Victor & Boynton, 1998; Cusumano, 1992). Future research, using enhanced methodologies, may replicate and extend these results in several ways. Research designs that control for lag effects (e.g., longitudinal) may be preferred to test the hypothesised linkages between modular systems and firm performance. Beyond the issues studied here, there are many other issues that remain to be addressed. One critical process is the definition of product

¹¹⁴ This interpretation is supported by the positive correlation (see Table 1) between Margine/Volume Pressure and an item tapping commitment to cost reduction. This item was not included in the structural model due to the limitation on variables caused by the low sample size.

architectures and platforms. Particularly where there are few industry-wide standards, product structures allow different decompositions, and companies may make different choices with regard to how they define key modules (e.g., Ulrich & Pearson, 1998). Another critical process is planning of future platforms. As pointed out by Meyer et al. (1997), it is often difficult to reconcile the desire to leverage current platform investments with the risk of becoming obsolete if the platform is not continuously renewed. Companies continuously need to balance leveraging current resources with building future capabilities. Important insights may thus be gained by studying how different companies define their product architectures and how managers integrate market and technological knowledge to make decision about future architectures.

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6 THE MODULAR FIRM: ORGANISING FOR STRATEGIC FLEXIBILITY

The organisation of the future will be (...) like a Calder mobile, with a thin wire of control, and with modules hanging down of various shapes and colors, each of which is capable of twisting in the wind as the wind changes. And each of which is also capable of being decoupled and disposed of and replaced by some other unit.

- Alvin Toffler

ABSTRACT

With the advent of dynamic and hypercompetitive markets, it is no longer sufficient to *periodically* adjust organisational structures to external changes: It is necessary to build in a high degree of flexibility to enable the firm to adapt to change on a *continuous* basis. Within technology management, modularity has for some time been recognised as a key strategy for increasing the ability to respond flexibly to dynamic product markets. In this chapter I summarise key principles underlying modular *product* architectures and propose analogical concepts for *organisational* architectures. I pay particular attention to criteria for decomposing organisational systems and for defining modules. A hypothetical example is provided of how a home appliance company might apply these principles to create a process platform consisting of reconfigurable building blocks.

To further advance the concept of *the modular firm* I discuss two possible extensions of current frameworks. The logic of modularity not only applies to incremental change but also to strategic initiatives within the firm aimed at building or extending the firm's capabilities. However, rather than the traditional concept of top-down "decomposition" of systems, it is more appropriate to view strategic initiatives as a bottom-up processes of "aggregation" – the completion of a series of small modules that evolve gradually into a complex system. Secondly, the notion of standard interface – key to achieving modularity – is usually conceptualised as consisting of explicit and well codified design rules for handling interdependencies. In the organisational context, I propose a broader definition of interface that includes accountability for outcomes as a design parameter.

6.1 INTRODUCTION

Modular product designs have for some time been recognised as a key principle for reducing complexity while increasing speed and flexibility of product development processes, thereby contributing to building a firm's dynamic capabilities for responding to uncertain product markets. Although modularity is often associated with product development and technology management, it is a generic systems concept that can be applied in different domains (Schilling, 2000). In this paper I attempt to synthesise and extend current research that sheds light on how modular principles can be exploited to enhance organisational flexibility (e.g., Sanchez & Mahoney, 1996, Victor & Boynton, 1998; Hoogeweegen et al., 1999).

6.2 THE CONCEPT OF ORGANISATIONAL ARCHITECTURE

A basic premise of this paper is that one can view both products and organisations as complex systems that consist of many interrelated parts. Some of the principles for structuring organisations may therefore be the same, or at least analogous, to principles for structuring products.

One of the most fundamental concepts in product design is the notion of a *product architecture* (Shirley, 1992; Suh, 1996). The product architecture specifies both the functions that are required and the physical components that are needed to perform the functions. It contains, in design terminology, a mapping between *functional requirements* (FRs) and *design parameters* (DPs). As a result of specifying how different functions relate to different components, one thus defines the structure of the product as well as the interactions among components. From a more strategic point of view, one can say that the architecture selects ways of matching technological

possibilities (feasible components that can be used/developed) with market needs for a single product or group of products (expressed in the functional requirements).

One can generalise the definition just provided by stating that an *organisational* architecture should show how an the entire firm (or a major unit of the firm) is to satisfy customer needs (i.e., functional requirements) by employing a set of processes (i.e., components) that transform available technologies into product or service offerings. In the same manner as a product architecture defines technical interfaces, an organisational architecture should specify information dependencies (i.e., organisational units that depend on other units for information) and other types of interdependencies that exist between the organisational units, such as interlocking accountabilities, resources, or decision rights.

The different elements of architectures will be discussed in more detail below. The key purpose at this stage is simply to point out that there is potentially a close analogy between the notion of architecture in the technical and in the organisational domain¹¹⁵. It also serves similar purposes. By documenting organisational components and their interactions, architectures provide a shared map for communication and co-ordination among different individuals and functions within the firm. By defining the basic building blocks of business processes and units, organisational architectures serve as platforms for generating processes that combine the more basic elements into new and more complex configurations. Organizational architectures distil and structure tacit and individually held knowledge about “how we do things around here” (Haeckel & Nolan, 1993).

¹¹⁵Architecture is related to modes of governance as defined in the organizational and industrial economics literature, in that architectures might encompass specifications of formal structures, roles, decisions rights, etc. Yet although architectures specify many elements of how the firm is to be governed, conventional governance frameworks are not necessarily “architectural” in the sense used here (cf. discussion of the concept of architecture in chapter 1, this thesis).

6.3 MODULAR ORGANISATIONAL ARCHITECTURES

A *modular* architecture can be characterised by means of five key principles: 1) Strategic decomposition; 2) Separation between modular and architectural system levels; 3) A low number of functions per module; 4) A minimum number of component interdependencies; and 5) Sharing of DPs among sub-systems with related functionality.

Principle #1: Strategic decomposition. By decomposing (i.e., partitioning) a system, one defines its architecture and the criteria for choosing modules. Both experience and systematic research indicate that this is a critical step in system design. For product designers, there exist rules of thumb as well as more formal tools that may help to define a product architecture (Martin & Ishii, 2000; Suh, 1996; Robertson & Ulrich, 1998)¹¹⁶.

In axiomatic methods for product design (e.g., Suh, 1996), problems are formulated by first specifying functional requirements (FRs), which are single phrases that describe the outputs or effects of the product (Hintersteiner & Friedman, 1999). FRs should be formulated in a solution-neutral manner to allow for flexibility in the way the task is addressed¹¹⁷. The process of designing the product then proceeds by defining design parameters (DPs) that express solutions to each of the FRs (in the case of products, DPs are physical components).

Organisational designers may follow an analogous approach, although formal tools are less developed. The primary source of functional requirements lies in the external environment of customers and stakeholders. The challenge is to interpret and structure the requirements that will

¹¹⁶ As in product and software design, it may be useful to distinguish between two different levels of organisational decomposition. Principle #1 relates to strategic, high-level decomposition whereas principle #3 and #4 below are relevant for lower-level, detail design. This is similar to other organisation design methodologies; for example, Nadler & Tushman (1997) distinguished between Enterprise level and Operational level organisation design.

¹¹⁷ The separation of DPs from FRs means that the modular approach differs from other business process and quality improvement methodologies. The modular approach seeks to design organisations around outcomes (i.e., functional requirements). Traditional process improvement approaches (including “re-

call for organizational functionality, and then map the requirements onto different elements of the organization. Broadly speaking, functionality in the organizational domain may be interpreted as the desired outputs that the organisation must deliver. For example, key functional requirements for a logistics process may be defined as the fulfilment and delivery of a customer order. The corresponding design parameters follow from the structure and content of the functional requirements as illustrated in Table 4-1.

Table 6-1. Functional requirements and organisation design parameters (illustrative example)

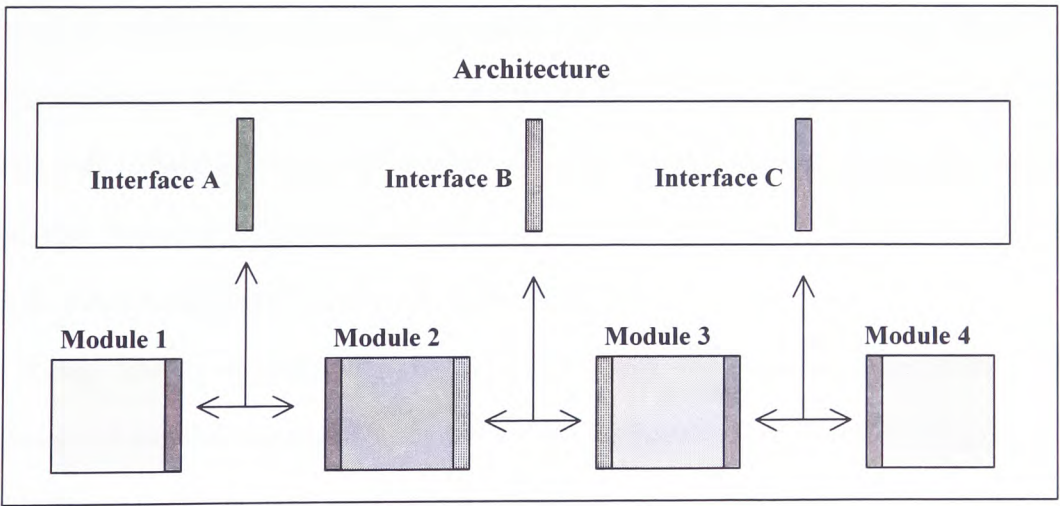
<i>Functional requirements</i>	<i>Organisation Design Parameters</i>		
	Activity	Group or unit	Accountability
Invoice customers	Process module “Fulfil orders”	Customer Service	Sales managers for respective customer groups
Identify new business opportunities	Process module “Business development”	Strategic planning	VP Business development
Manage investor relations	Process module “Investor relations”	Corporate staff	VP Corporate affairs
Manage Human Resources	Process module “HR”	Human Resources	VP Human Resources
Monitor existing alliance relationships	Process module “Alliancing”	Alliance office	Alliance manager

Depending on its strategic intent and value configuration (Stabell & Fjeldstad, 1998), a firm is likely to make different architectural choices for the organisation. One firm may choose to partition its organisation according to market segments whereas another firm may chose to partition the organisation according to technologies. The criteria for choosing modules usually

engineering”) focus on the codification and improvement of procedures and activities (i.e., design

follow from this decision: For the first, a module may be defined as an organisational unit responsible for serving a given market segment (e.g., businesses, households, etc.). For the second, a module may be defined as an organisational unit responsible for a certain product (e.g., software, hardware).

Principle #2: Separation between modular and architectural system levels. A modular product design is an explicit decomposition of a product structure into *components within an overall architecture* (Figure 4.1). The architecture reflects the core technology and contains all interface specifications. The components are parts of the overall product that perform specific functions. By keeping interfaces constant for a given period (i.e., the duration of the product platform), components (modules) are allowed to change, as long as this change does not exceed the range of variation allowed by the interface specification. In other words, modular architectures represent a “decoupling” of architectural level processes from component-level processes, resulting in two main layers - one that is relatively stable and one that undergoes frequent change as modules are continuously improved or replaced with better-performing modules.



parameters).

Figure 6.1. System separated into components within overall architecture

Several authors have commented upon the possibility of applying similar principles to organisation design. If one considers the overall structure of the firm, one may think of the stable part as the functions and competency groups of the organisation. People and resources from these functions and groups are configured into temporary project modules – which make up the changeable part (Galbraith, 1999). In discussing product development processes, Sanchez & Mahoney (1996) similarly distinguished between organisational units dedicated to component development and units devoted to learning about longer-term opportunities and more radical changes in products and markets.

Architectural level learning processes should improve as a result of being (temporarily) separated from component level learning processes. However, Sanchez & Mahoney (1996) also noted that this decoupling of component and architectural-level learning needs to be combined with co-ordinating mechanisms for linking the two processes. One mechanism is predictable *time intervals* between platform changes (e.g., every 24 months in a fast changing industry), when modular and architectural processes are reconnected and co-ordinated. Another co-ordinating mechanism is well-defined *transition procedures* that support teams in moving from one architectural platform to the next (cf. Brown & Eisenhardt, 1997). By including routines for how to upgrade both individual components and the overall system, the organisational architecture not only describes “how we do things around here” but also contains a model for “how we *change* how we do things around here” (Haeckel & Nolan, 1993, p. 123).

A key goal is to make modules independent and self-contained. Nevertheless, the components of a modular organization are not completely autonomous. To ensure on-going co-ordination between units and maintain system coherence, module size, function and interfaces to other modules may need to be controlled centrally. The same holds true for any changes to the organisational architecture itself. Case studies suggest that if architectural decisions are delegated

to divisions or other local units, significant problems ensue when attempting to implement system-wide changes (see Argyres, 1995). To introduce and change organisational architectures, sufficient authority needs to be maintained centrally to overcome the inevitable co-ordination problems and goal conflicts that arise from differences between local units. In this manner, the modular perspective departs from those approaches to enhancing responsiveness and innovation that prescribe complete decentralisation of decisions or “empowerment” of local managers (e.g., introduction of autonomous profit centres).

Principle #3: A low number of functions per module. This principle (related to principle #4) states that most modules should be concerned with the performance of a low number of functional requirements - and ideally, only *one* functional requirement. To implement this principle one defines key organisational functions and then identifies current organisational parameters that it relates to. It is useful to list FRs in a table (a tree diagram can also be used to highlight the hierarchical structure of the system). Table 4-2a shows three functional requirements for a hypothetical firm and the three main modules (i.e., design parameters). (Table 4-2b contains a more detailed view of sub-FRs.) An X is used to signify that a relationship exists between a DP and a FR. If this analysis shows that a DP relates to more than one FR, a redesign of one or more of the design parameters is warranted (provided that the function itself is well defined). One may reassign accountability for a given process so that it belongs to only one module, or redefine a module so that it relates more closely to only one of the specified functional requirements.

Table 6-2a. Functional requirements (FRs) and corresponding modules

	Module 1	Module 2	Module 3
FR 1: Generate demand	x		
FR 2: Fulfill demand		x	
FR 2: Serve customers			x

Table 6-2b. Sub-FRs and corresponding Sub-modules

	Module 1.1	Module 1.2	Module 2.1	Module 2.2	Module 3.1	Module 3.2
FR 1: Generate demand						
FR 1.1 Manage customer relationships	x					
FR 1.2 Create market		x				
FR 2: Fulfil demand						
FR 2.1 Manage supply sourcing			x			
FR 2.2 Fulfil orders				x		
FR 3: Serve customers						
FR 3.1 Manage service contracts					x	
FR 3.2 Provide service & support						x

Principle #4: Minimisation of component interdependencies. In order to modularise a product, designers seek to decompose the design into a set of independent blocks of components. This can be illustrated using a method to document inter-module interdependencies called the Design Structure Matrix (DSM) (Steward, 1981). The DSM shows the tasks performed by different individuals or teams, and illustrates whose decisions different actors need to know in order to complete their work. In the matrix, an “x” appears in the column of the initiating person (or parameter) and the row of the affected person (or parameter). Figure 4.2a shows six high-level activities in a product development process. The interdependencies create an iterative and sequential task structure in that “upstream” tasks need to wait for “downstream” tasks to be completed. In Figure 4.2b, a resequencing of the tasks has placed more of the x’s below the diagonal and two activity blocks appear. These blocks are independent, with the exception of the

interdependency between C and B – the *Analyse technical feasibility* task (C) requires information from the *Refine product concept* task (A).

A standard interface is created by *freezing* interface specification for a predetermined period of time (in the terminology employed here, this time period corresponds to the life cycle of the architecture or platform). In other words, standard interfaces are not allowed to change unless the firm decides to renew the overall architecture of the product. In practice, the standard interface becomes a “design rule” (Baldwin & Clark, 2000), which means that managers can make changes (within a band of tolerance) to a module without consulting with those responsible for other modules. For the example illustrated in Figure 4.2b, the interdependency can be removed by introducing design rules for manufacturability of design, e.g., a rule stating that the normal development process must make use of known components or, alternatively, that product designers must develop new components to agreed standards for manufacturability. Removing the interdependency creates two modules – two independent blocks of activities (Figure 4.2c).

One should note that this principle of interdependency minimisation applies *within the chosen dimension* for decomposing the firm. For example, consider a firm that has traditionally been structured along geographical lines (e.g., with one unit per region). If this firm chooses to redesign its organisation according to platform technology, it will instead minimise interactions between organisational units working on different technologies but may simultaneously increase interdependencies among other elements that are now collapsed into one module (i.e., the old geographical units). The challenge in the strategic decomposition phase (cf. principle #1) is to manage the trade-off between the costs and benefits of alternative ways of partitioning the firm. I return to a more detailed discussion of this issue below.

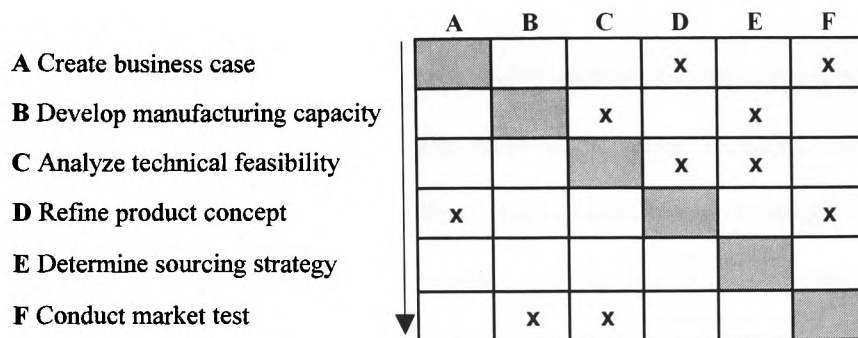


Figure 6.2a. Map of original work process

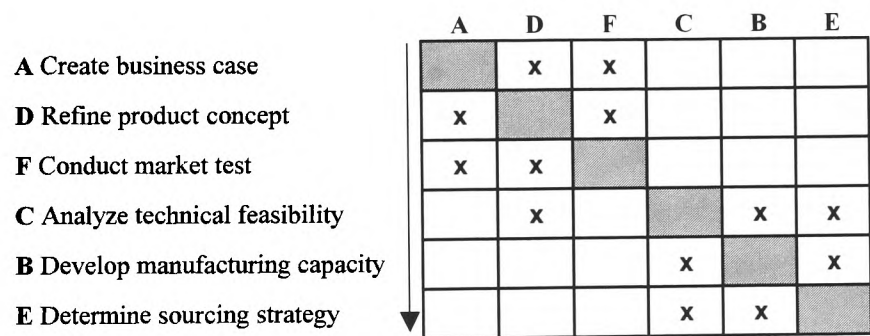


Figure 6.2b. Work process after resequencing tasks

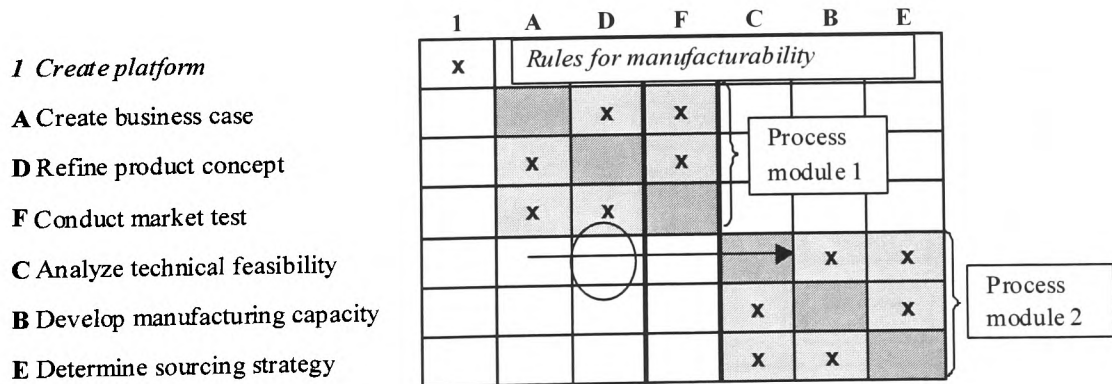


Figure 6.2c. Work process after modularisation

Principle #5: Sharing of DPs where there is related functionality. If some functions are similar across several sub-systems, it becomes possible to transfer and re-use design parameters addressing these FRs instead of developing new and unique solutions from scratch. In manufacturing firms, modular platforms allow sharing standard components among several models in a product line (component commonality), and re-use of components as new product models are introduced (component carry-over). In organisation design, an application of the same principle is found in shared services. Many departments and business units within a large firm perform transaction-oriented activities (invoicing, procurement, payroll, etc.). Introducing shared services means consolidating these activities from local units to a shared, company-wide function (Figure 4.3). In some cases the functional requirements may be similar across individual companies, enabling the creation of generic process models for different industries and processes (Malone et al., 1999). Many consulting firms have developed generic process models for processes such as logistics, marketing, and manufacturing. These process models are stored in repositories (e.g., a database accessible via the internet) that contain basic building blocks that can be combined to create more complex structures.

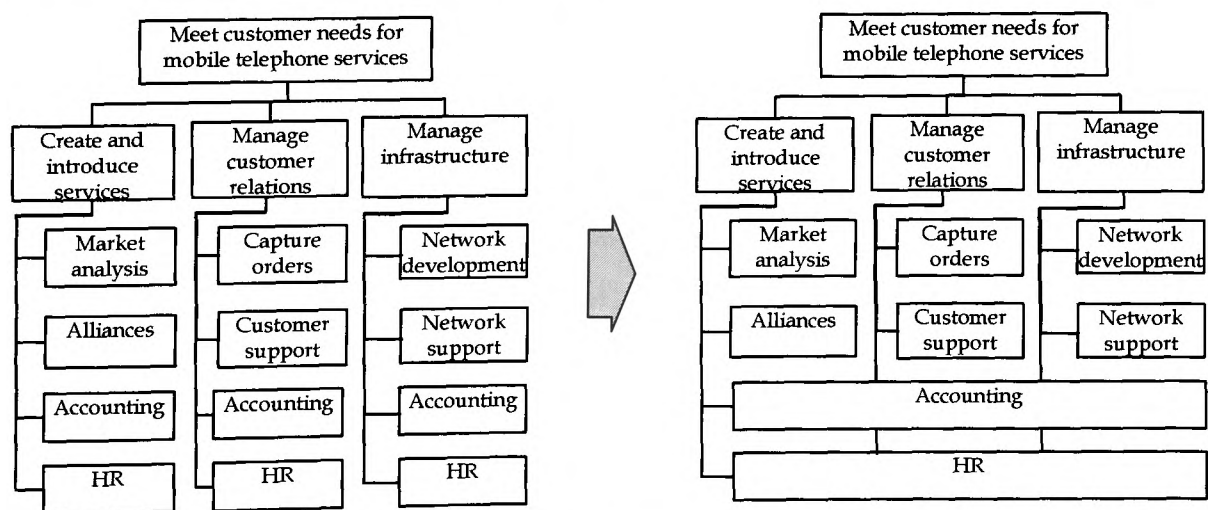


Figure 6.3. Combining individual functions into shared services

Summary. Together, these principles lay the basis for reconfigurable architectures. Principle #1 (strategic decomposition) ensures that the overall architecture is attuned to the firm's strategic goals. Modules can be highly specialised in terms of their function as each module is only supposed to satisfy one functional requirement (Principle #3). Moreover, principle #3 allows any given design parameter to be adjusted (e.g., upgraded/improved) to satisfy its corresponding functional requirement without affecting other functional requirements. In this manner, modular decompositions “contain” technological change and product variety in specific components (Sanchez, 1995; 1996). Together with minimisation of interdependencies (Principle #4) this allows for *substitutability*. That is, several component options can be used to implement a given functional element of the design. For organisation architectures this means that new process modules (e.g., alternative suppliers) can be connected to the configuration (and dis-connected) quickly and at low cost. Principle #5 (sharing of DPs) enables the creation of economies of scope through process module sharing and re-use. In other words, although modules are specific in terms of their function they are highly general in terms of their locus of application. The separation of modules from the overall architecture (Principle #2) also implies a reduction in complexity. The module interface represents an abstraction of certain characteristics of the module (those that interact with other modules), which hides the inner complexity of the module that does not interact with other modules. Employees belonging to one organisational module are thus relieved from having to know all the details about the functioning of other modules to perform their own tasks.

6.3.1 Alternative criteria for decomposition

It is not uncommon to speak of “modularity” as if it represented a given, objective property of products and organisations. However, complex systems allow many alternative decompositions. To choose an appropriate decomposition, different architectural alternatives need to be considered

in light of the organisation’ strategic intent, as implied by the notion of strategic decomposition described above (Principle #1). I have included a list of common criteria for decomposing organisations in Table 4-3.

Table 6-3. Criteria for strategic decomposition of organisational architectures		
Criterion	Strategic intent	Example
(1) Technological commonality	Enable technology sharing among related products	Toyota divided entire engineering staff into three development centres, based on platform similarity: rear-wheel drive vehicles, front-wheel vehicles, and vans. (Cusumano & Noebeka, 1998)
(2) Market	Focusing efforts on one market segment	Dell Computer consists of separate units focusing on commercial, government, and non-profits accounts. Each unit is in turn subdivided into smaller segments (e.g., federal, state, local) (Eisenhardt & Brown, 1999).
(3) Size	Keeping units small enough for agility	ABB has 1,500 business units, each of an average size of 50 employees (Nicholson, 1998).
(4) Critical mass	Making units large enough for efficiency	British Petroleum outsourced accounting services (which were dispersed among divisions) to PriceWaterhouseCoopers, which consolidated them in a single shared services unit (Quinn, 1999).
(5) Value configuration	Avoiding diseconomies of having conflicting value creation logics within same organisation (Stabell & Fjeldstad, 1998).	AT&T split into three entities: Lucent (value shop), NCR (value chain) and regional Bell operating companies (value networks).
(6) Culture	Separating incompatible sub-cultures	Dutch software company Baan deliberately separates unit responsible for long-term research from development and implementation groups (Post, 1997).

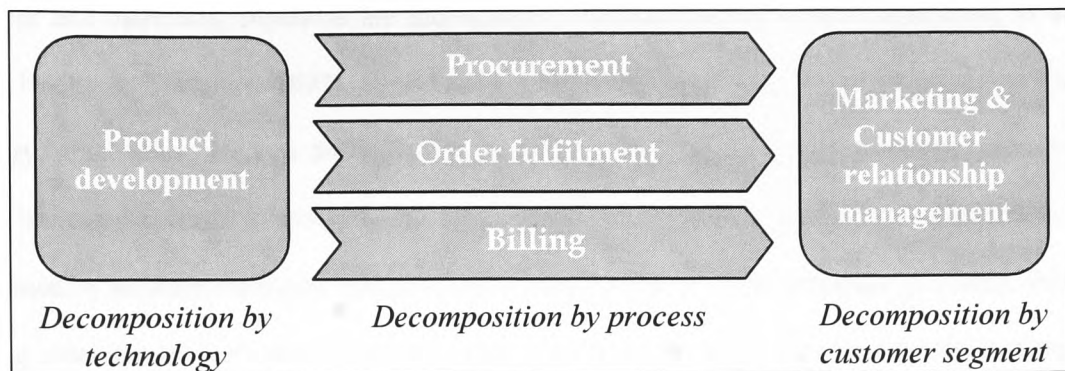


Figure 6.4. Criteria for decomposing different parts of a firm's organisation.

Seeking a decomposition that is congruent with the firm's strategic intent does not imply that one needs to employ one criterion for the entire organisation. It is fairly common for business units to be decomposed in different ways, reflecting their particular role in the overall value configuration (see Figure 4.4).

- The functions between technologies and markets are usually decomposed by *process* (order acquisition, order fulfilment, planning, logistics, production, etc.). During the 1990's, many companies changed from a vertical to a "horizontal" process orientation¹¹⁸. Process redesign allowed companies to simplify internal operations, eliminate non-value added activities, and improve cycle time. It also involved the creation of new organisational structures built around end-to-end processes crossing functional departments. A process owner, a key new role, was made responsible for the performance of each process. Despite this trend, few organisations erased the old functional boundaries completely. In most cases, processes exist side by side with

¹¹⁸ A business process is defined as a sequence of activities that add value for the customer (Davenport, 1993).

more traditional units and groupings. At the same time, the criteria for forming other units and groups have also been changing.

- Sales and marketing functions are increasingly organised around *markets* (Homburg et al., 2000; Nadler & Tushman, 1997). Specifically, companies use groups of customers (related by industry, application, etc.) as the basis for partitioning and grouping organisational units. For firms serving industrial customers, the key role in the sales and marketing organisation is performed by account managers who are responsible for one or a small number of clients; firms serving consumer markets similarly have customer segment managers. This decomposition allows the firm to differentiate their customer relationship management to fit the characteristics of different customer segments. It also represents a shared interface for internal functions toward the customer. It thus allows pooling of resources as account managers usually sell the entire range of offerings produced by the firm.
- Technology development units are increasingly organized around *products*. A recent case study of the introduction of a “centre organisation” at Toyota (Cusumano & Noebeka, 1998) illustrates this principle (Figure 4.5). Before the reorganisation Toyota had 16 functional engineering divisions, each subdivided into different departments. The 7,000 engineers from these departments used to be assigned to up to 15 concurrent projects. It had become difficult to manage the complexity of this matrix because new car models were added to the product line and more staff were hired, gradually increasing the size and number of departments to co-ordinate during a project as well as the number of projects running at any time. Narrow functional specialisation meant that engineers often moved between unrelated projects solving highly specialised problems, which made it difficult to develop and share “systems knowledge”. It was also observed that project managers often attempted to optimise performance or cost of their project in isolation or even at the expense of other projects.

To reorganise this structure, Toyota analysed the functional relationships between components and subsystems used in different projects, and then allocated all staff to one of three centres, based on platform similarity. For example, all projects dealing with rear-wheel vehicles were grouped into one centre. In other words, one third of the staff in each functional department was moved to each centre. Instead of having to co-ordinate 15 projects, some of which were unrelated, functional managers now only had to deal with 5 projects, all related (i.e., based on the same technical platform). By decomposing the organisation based on platform similarity rather than alternative criteria (e.g., market segments such as luxury and sports cars), Toyota maximised the chances for intra-platform co-ordination and technology sharing. A fourth centre was also established to develop components common to *all* platforms. For example, this centre develops ABS brakes that are used in all models.

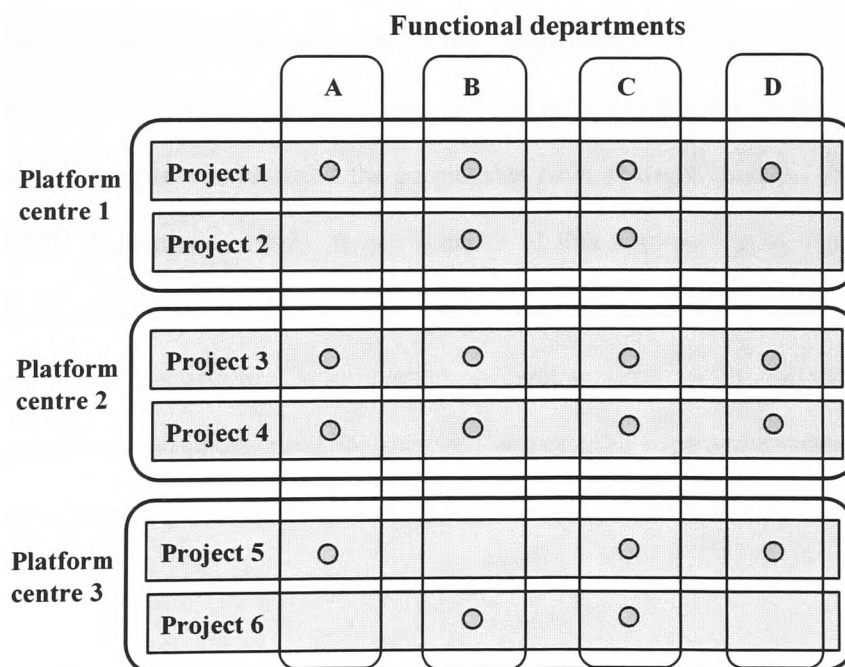


Figure 6.5. The structure of Toyota's product development organisation after it was redesigned
Adapted from Cusumano & Noebeka (1998, p. 53).

In sum, by defining the overall architecture of the firm, the strategic decomposition establishes the key criteria by which to group units and processes at a more detailed level (process, market, and technology). A module in the marketing function is an organizational unit that minimizes interactions across all units interfacing with clients, enabling each client or segment team to target offerings more precisely. A process module is one that minimises task interactions with other processes, allowing concurrency and reconfigurability. A platform team is one that maximizes interactions among engineers working on components that are closely related, minimising communication costs and facilitating transfer and re-use of technical knowledge.

6.3.2 The design of modules

When a firm decides to adopt modular principles for designing its organisational architecture, questions are likely to be raised concerning the design of the organisational modules, in particular, their size, number, composition and internal hierarchy.

There appears to be three approaches in the literature for determining the optimal size of modules. The first approach is to derive the correct size from strategic concerns (e.g., Eisenhardt & Brown, 1999; Christensen, 1997). A key premise of this approach is to match the size of modules with the size of the market: A small module may not possess the technical or financial resources required to compete in a large market. A large module, on the other hand, will have difficulty targeting niche opportunities for growth. For example, large and integrated firms often have difficulties justifying investments in emerging technologies because they initially represent only a small fraction of the firm's potential revenues¹¹⁹.

¹¹⁹ On other hand, the notion of modularity implies that the traditional trade-off curve for efficiency versus flexibility may need to be reconsidered. By allowing for process commonality and the sharing of resources among smaller modules, it suggests that small size may be achieved without significant loss of scale economies. For example, small and medium sized firms traditionally faced major problems in competing with larger firms. The existence of application service providers (ASPs) now makes it possible for small and medium-sized firms to access state-of-the-art software for many business functions including customer

Other authors (e.g., Jarvenpaa & Ives, 1994) have suggested that the size of a module is determined by the degree of decomposability of the system, i.e., one decomposes the organisation into the smallest possible replicable units. A more analytical version of this approach (and consistent with the framework presented above) would be to determine size based on task interdependencies using the Design Structure Matrix. It is possible to propose a rule stating that the size of modules should be as small as possible while at the same time minimising the number of interactions with units belonging to other modules. Within a modular framework it is relatively easy to satisfy both of these objectives because one has the freedom to: 1) change the overall criteria for decomposition, 2) alter boundaries between modules, and 3) eliminate interactions by reassigning functions or redesigning interfaces (creating “design rules”). Intuitive methods can be used for systems consisting of a small number of elements. For more complex processes, there now exist software packages¹²⁰ that can assist in identifying modules (and thereby their size and number) in a task structure.

A third approach is used by some authors that believe that there are psychological and biological laws governing the efficient size of social sub-systems. This approach is usually based on considerations of cognitive or social psychological constraints to working in large and complex systems. Nicholson (1997; 1998) suggested that there are evolutionary reasons for why human beings prefer to be parts of “herds” of no more than 15-20 people within larger “clans”. For much of human evolution, individuals lived their lives within a clan system and would rarely if ever encounter a stranger, i.e., someone from outside the kinship network of the clan. Our psychology is as a consequence geared to a known and finite social universe and the social information processing capacity may therefore correspond to what we encounter in a typical clan. The ABB case is frequently cited. ABB is a federation of approximately 1,500 business units,

relationship management, enterprise resource planning, accounting, and human resource management (Aldrich & Fortune, 2000).

¹²⁰ For an example of software packages, see www.problematics.com

each of which consists of only 150 people¹²¹. Eisenhardt & Brown (1999) similarly noted that Microsoft tries to keep its applications businesses at or below 200 people.

Complex systems consist of interrelated units that in turn have their own subunits. Some modular design theories explain approaches for the nesting of sub-modules within larger modules, for example, defining software objects as part of sub-classes that in turn belong to higher level classes (an object usually *inherits* the characteristics of the class of which it is a member). Similarly, in an organisation one might consider individuals, teams, units, divisions, etc. as modules at different levels of the architecture.

Within software design, there has been an active debate for some time around several issues related to composition and internal hierarchy of modular objects. One issue that is discussed is whether objects should have only one superclass, or whether it can have more than one superclass (multiple inheritance). Multiple inheritance is useful for objects that play more than one role, but it leads to higher degrees of complexity and potential confusion whenever object “roles” contain conflicting responses to the same request. In the organisational literature this debate resembles discussions around the matrix organisations, where each unit is defined along two or more dimensions.

A related discussion revolves around the number of levels of the system: Many organisations seek to reduce the number of middle managers and create “flatter” organisations. On the other hand, removing middle managers also creates a greater span of control for each of the remaining managers and increases the size of organisational units. There is nothing in the modular approach itself that would suggest a limit to the number of hierarchical levels. However, this notion of hierarchy does not correspond to how authority relations are structured within an organisation. A modular firm is not a hierarchy of authority but a hierarchy of functionality (Haeckel, 1999). In fact, extensive functional decomposition of an organisation using modular

¹²¹ This is the average size of business units according to ABB employees that I have spoken with.

principles allows the creation of semi-autonomous organisational units that require less rather than more exercise of managerial authority compared to a poorly decomposed, integrated organisation (cf. Sanchez & Mahoney, 1996).

Despite the importance of early architectural decisions that establish the structure of modules, there is a dearth of practical tools or decisions aids available. Nevertheless, the principles just described suggest some general guidelines that one can rely on when determining the optimal size and number of modules. It may also be possible to develop a more precise metric of modularity. The basic goal of modularisation is to create organisational units that are powerfully connected among themselves and relatively weakly connected to elements in other units. One approach is therefore to compare the number of interconnections (or “spillovers”) *between* the defined modules, relative to the size of each module (i.e., the number of elements in each module). Each element of the DSM can be assigned a congruence score (as proposed in Post & Johnson, 1999), and the average can then be summed for the system as a whole¹²². This is illustrated in Figure 4.6. Note that one can obtain a higher score (indicating a higher degree of modularity) either by redefining boundaries between existing activity blocks (i.e., strategic decomposition) or by removing interdependencies (i.e., creating modules /standard interfaces).

¹²² A similar idea was proposed by Martin & Ishii (2000) who described a “coupling index” that shows the degree of coupling between components in a product.

	A	B	C	D	E	F	Congruence (pr. element)	Module metric	System metric
A		x	x	x			0,66	0,33	0,61
B	x		x	x	x	x	0,00		
C	x	x		x	x		0,33		
D	x				x	x	0,66	0,89	
E				x		x	1,00		
F					x		1,00		

Figure 6.6. Proposed metric for assessing degree of modularity (example).

6.4 THE MODULAR HOME APPLIANCES COMPANY - AN EXAMPLE

I here describe a hypothetical firm, called Electrosonic, which employs a modular organisational architecture. This section can be considered a “Gedankenexperiment” in that it attempts to exemplify the key principles reviewed above by portraying an imaginary firm. But it is also intended to capture some current trends in how real companies are designing their organisations to adapt to dynamic markets.

Electrosonic is a global home appliances firm engaged in all the major markets around the world. Historically, it has been organised as a vertically integrated, multidivisional firm (as have other major appliance manufacturers). Its span of activities encompasses not only assembly but also manufacturing of all the major components of its appliances (including plastics, steel parts, and electronics). Its divisions are organised by product category, such as dishwashers, vacuum cleaners, refrigerators, and dryers. During the last decade, a number of new demands have emerged that have made Electrosonic’s managers rethink this organisational structure and consider alternative organisational designs. The new demands facing Electrosonic come in

addition to the already familiar challenges to home appliances firms, such as introducing frequent improvement in technical features, driving down costs production and distribution, and providing the required level of product variety to compete in multiple market segments.

Home appliances are incorporating increasingly advanced technology, including electronics and software, which are outside the traditional focus of Electrosonic's own research and development. The sentiment among senior managers is that Electrosonic doesn't have unique knowledge anymore – only a manufacturing capability. The unique knowledge is residing in many small, specialist firms in the industry. For example, in Italy, Britain, and the US there are product design firms with innovative concepts that in many are cases superior to those of Electrosonic's internal design department. As for research & development, there is relevant work being carried out in a number of independent labs, as well as in some technical universities. On the manufacturing side, a number of highly focused suppliers have started offering components that in many cases are competitive with Electrosonic's internally produced parts on both price and quality, one example being motors for washing machines. Finally, the Internet has brought with it widespread experimentation with new business models. Competitor firms are taking a fresh look at their basic revenue model, and a Swedish appliances firm has even tested a new concept – called the “Appliance Service Provider” model because it relieves the customer from having to buy the appliance: it would be rented rather than bought, and pricing would be partly based on the level of consumption (which the customer can track on a the appliance makers' internet site that collects the information via a telephone line).

It is clear that many of the small specialist firms offer promising technologies that could be incorporated in the products that Electrosonic is planning. Electrosonic already has some experience with alliances, for example, an R&D alliance with an external research lab to develop a new concept for a dishwasher. Yet there is uncertainty about the demand for the different technologies and about competing standards, making closer integration with any one supplier

unattractive. Electrosonic is searching for a new logic that would create a network of external partners that could provide a number of options that could be exercised depending on emerging market developments. Internally, it is looking for the same level of flexibility combined with the ability to leverage its resources (knowledge and people) more effectively across the traditional product divisions of its old structure.

The strategy chosen by Electrosonic is both to compete and to collaborate. With a basis in its manufacturing capability, worldwide brand and extensive distribution network, Electrosonic decides to take on the role of an *industry architect*. To fill this role, Electrosonic managers focus on two key areas. The first is building the strategic sourcing and network coordination capabilities required of industry architects. These capabilities may well be the foundation of Electrosonic's competitive advantage in the future. As stated by Fine (1998, p. 12):

...the greatest rewards go to the companies that can anticipate, time after time, which capabilities are worth investing in and which should be outsourced; which should be cultivated and which should be discarded, which shall be the levers of the value chain control and which will be controlled by others.

The second area of focus is Electrosonic's organisational architecture. Its current, vertically integrated organisation has proved to be slow and inflexible in responding to changes. To enable Electrosonic to carry out the role as an industry architect, managers agree that an organisational transformation will be required. This transformation is planned as two major phases, each estimated to last about 2 years. The first phase is *decomposition* – a restructuring of the firm into a set of smaller building blocks. The second phase is *disaggregation* – the shedding off of non-core activities. Managers at Electrosonic have discussed the definition of a core versus non-core capabilities. Some maintain that the only core capability would be product offering development and sourcing. Electrosonic currently has 10,000 employees. According to one of the alternatives

proposed, the future Electrosonic organisation would require only 3 people (Figure 4. 7): A managing director, an offering development manager, and a sourcing manager. Everything else can be outsourced.

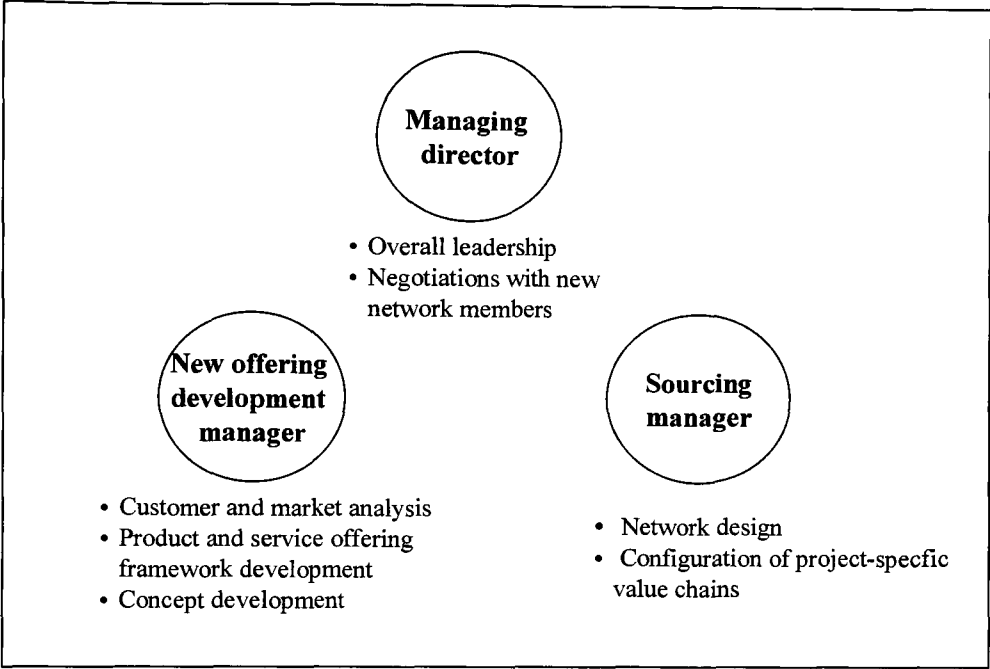


Figure 6.7. Key roles in Electrosonic’s future organisation.

Regardless of the eventual size of the organisation, the key strategy at this point is to create an internal network (supplemented with some external suppliers) capable of *continuous reconfiguration* to meet new customer demands. To operationalise the capabilities that Electrosonic must possess to compete in the future, managers analyse the value chain of the home appliances industry and then identify the functional requirements that Electrosonic must be able to perform. They define seven generic functions¹²³:

- 1) Creating market and customer understanding
- 2) Developing new offerings
- 3) Manufacturing products

- 4) Fulfilling demand
- 5) Servicing products
- 6) Performing support services (e.g., human resources, accounting, etc.)
- 7) Managing network coordination and sourcing

The first five functions are the main customer-driven functions focused on developing and producing offerings, whereas the last two are “enabling” functions related to infrastructure and organisation. Based on the functions, Electrosonic then defines the main organisational design parameters – that is, the main modules of its value configuration (see Figure 4. 8 and 4.9).

Having identified the future functions, managers turn to an analysis of *current* functions to determine the gap between the current and the desired architecture. Senior managers of Electrosonic find that this exercise requires a new level of knowledge about their internal processes. In fact, when the issues were first considered, managers were uncertain about even the basic functions of many sub-units and departments. For example, senior managers were unable to articulate what activities the research & development department were engaged in, or how much time its product development engineers were spending on the different product lines. An internal survey was administered where all managers were asked to estimate the time spent by their employees on various activities (broken down by product category, market, etc.). A chart was then developed to summarise the current functions of all departments and units.

With the input of its employees (gathered by using the DSM and similar tools), Electrosonic documents the interactions between each of the process components that have been identified. An important consideration was to enable each functional requirement to be performed by an external contractor or suppliers. Technical product documentation is therefore developed and made available to subcontractors via a web site. The standard interface also includes

¹²³ Each of these have sub-FRs but I only include the top level FRs.

provisions for how to handle external suppliers consistently in terms of the procurement or award of contracts, staffing, pricing/fee structure, billing, etc.

In some cases the new modules may appear identical the old organisational units. For example, Module C (1) is Electrosonic's main European plant, and the manufacturing operation itself will not undergo significant changes. However, even in this case, the new architecture implies a number of changes:

- Organisational units become more specialised. For example, the plant now focuses on manufacturing only and the responsibility for the small product development office that was part of the plant has now been handed over to the product development process module (B2).
- Organisational units are also more specialised because support services are pulled out and consolidated in a separate unit. This means that the plant no longer has its own HR and accounting offices, but instead buy these services from Electrosonic's shared services unit.
- The old organisation had a divisional structure with one division for each category (dishwashers, refrigerators, vacuum cleaners, etc.). In the new architecture, engineers are grouped based on platform similarity (across specific products). The main organisational sub-units within Technology Development now mirror the three technical "layers" of home appliances products:
 - motor and electromechanical parts
 - electronics and software
 - chassis and external features
- All major units (modules as well as the sub-modules within them) are now defined as independent organisational units. For example, the plant used to be a cost centre, but now has profit-and-loss responsibility.
- The standard interfaces that have been established ensure that the units can exchange autonomously with other internal and external units. Up until now a proprietary CAD/CAM

system was used to transfer product specifications from designers to manufacturing engineers.

Now this system has been replaced with a web-based system adhering to industry standards that enables product specifications to be received from external firms as well.

Table 4-4 summarises the key features of Electrosonic’s new organisational architecture with reference to the five principles reviewed above.

Table 6-4. Key features of Electrosonic’s new organisational architecture

Strategic decomposition (cf. Principle #1)	The overall structure was determined based on an analysis of functional requirements for the organisation and considerations of the types of flexibility required in the home appliances market. The chosen partitioning of the organisation will allow Electrosonic to mix and match different modules to adapt to a wide range of market changes.
Modular vs. architectural level (cf. Principle #2)	The modules are the processes illustrated in Figure 4.9. They are separated from the organisational architecture by means of standard organisational interfaces, i.e., explicit agreements about expected inputs and outputs, performance levels, and costs of each process.
Number of functions per module (cf. Principle #3)	In the architectural model each module performs only one function (Figure 4.9).
Interdependencies between modules (cf. Principle #4)	Incidental interdependencies have been minimized by analysing interactions between organisational units using the DSM and similar tools and by reallocating responsibility for tasks that are unrelated to the core function performed by each module.
Sharing of design parameters (cf. Principle #5)	Previously dedicated development teams now work on several different product models that are related by technological platform. Support functions are consolidated in a separate unit, which will serve the entire Electrosonic organisation.

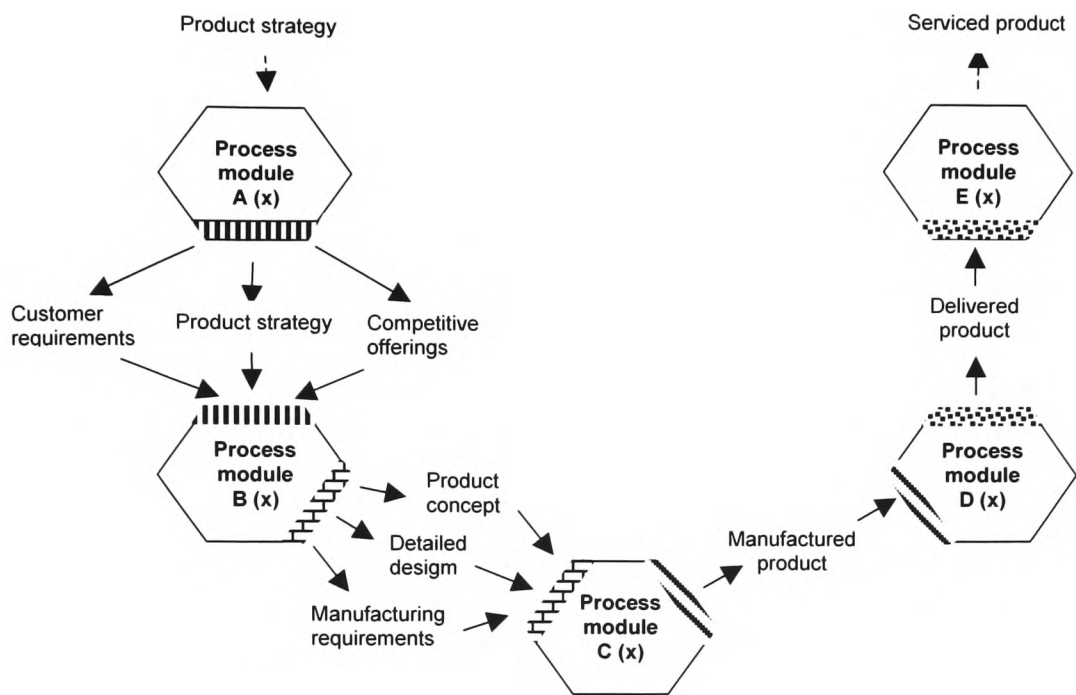


Figure 6.8. Electrosonic's organisational modules and their key interfaces.

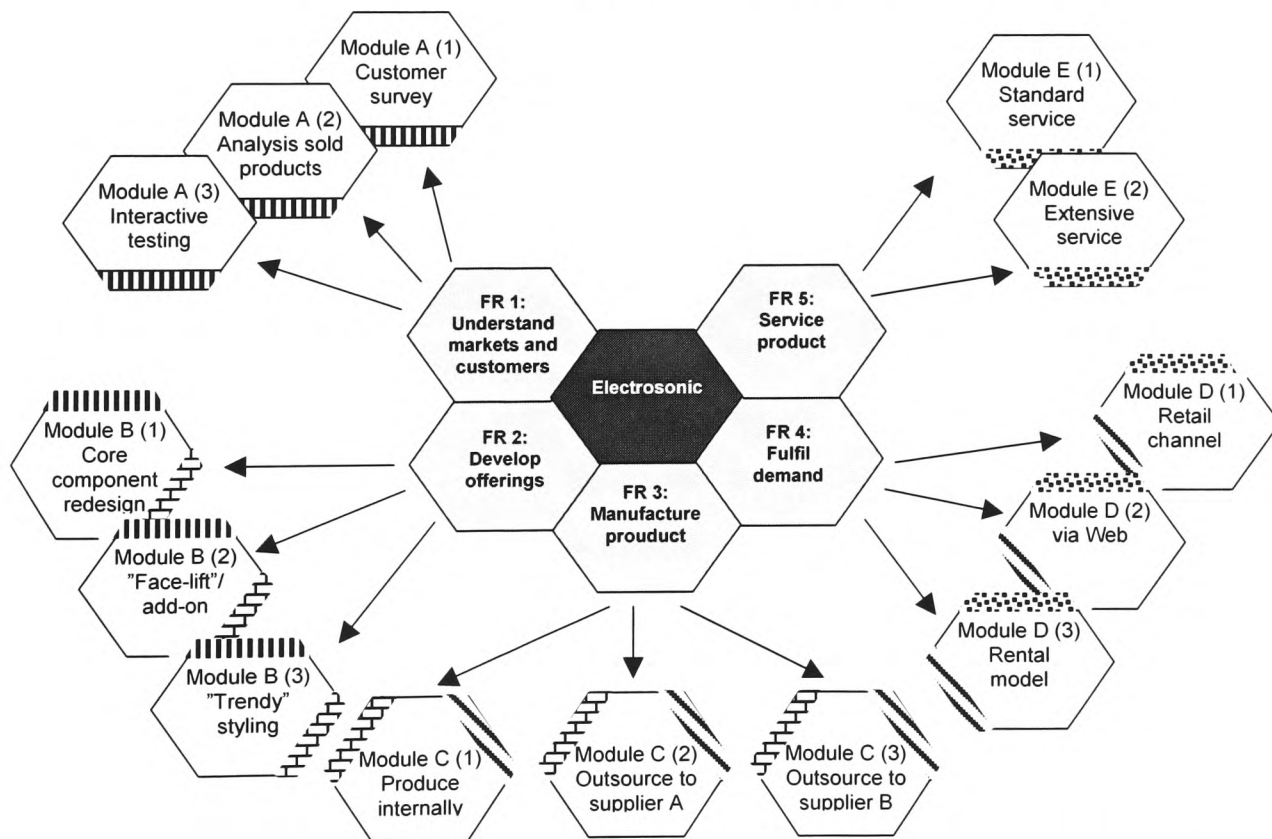


Figure 6.9. High-level view of Electrosonic's organisational architecture (only core functions included).

There are several possible benefits of implementing this organisational architecture (illustrated in Figure 4.9¹²⁴). The most important is the ability for Electrosonic to “mix and match” modules to develop value configurations tailored to specific market needs. As examples, consider the following three scenarios.

Scenario #1. A working group was appointed to look at the future market for appliances that are connected to the internet. The working group recommended to the board that Electrosonic should start by developing an internet refrigerator, the product category that is judged to have the greatest potential in the short term. Based on the organisational architecture outlined above, Electrosonic senior management decides to initiate a project to develop, manufacture and market such a product. The first functional requirement of the architecture is *Understand Markets and Customers*. This can be done in three principal ways. The internal marketing department can conduct traditional market research (using surveys, focus groups etc.) aimed at analysing preferred product attributes (Module A (1)). The second option is using an external research firm to perform statistical analysis of already sold product configurations (A (2)). However, since the product in this case does not yet exist; Electrosonic uses a third option, which is gathering customer reactions to a prototype product (A (3)). This module contains two sub-options. For example, the existing “customer experience centre” in London may be utilised for the study, or a new pilot test may be conducted elsewhere. Electrosonic goes for the latter option, and contracts with an external firm to place prototype versions of the internet fridge in the homes of 20 residents in a small German town outside Frankfurt. The residents will be able to use the fridge and will be interviewed by market researchers once a week to assess their usage patterns and personal reactions.

¹²⁴ A real application would have to combine this architectural perspective with a strategic analysis of the attractiveness of being present in various parts of the value configuration, which is a result of (among other factors) the firm’s internal capabilities relative to its competitors.

For the second function, *Develop Offering*, three process modules exist: Core component redesign (B (1)), face-lift or add-on (B (2)), and “trendy” external (re)styling (B (3)) (in the latter case an external design studio is responsible for performing the work). The project is classified a component add-on /redesign, because the core components of the refrigerator may remain unaltered. (Only the door will be required significant alterations to make room for the internet terminal.). For the third function, *Manufacture Product*, Electrosonic may either manufacture the product in one of its own plants (C (1)) or outsource production to a supplier (in either case many of the components are in turn manufactured by suppliers). In this case, Electrosonic decides to produce the first generation of the product at its own plants. The next function is *Fulfilling demand*. Products may be sold via retailers (D (1)) or directly to customers via a new web site that Electrosonic has set up (D (2)). To avoid conflicts with retailers, these choices are exclusive so that each product line is only available in one of the two channels. The third possibility is based on a new revenue model – rental – and involves fulfilling demand by providing the appliance for free and charging of its use (D (3)). In this case Electrosonic opts for the latter option. The actual rental operation is managed by an external firm that specialises in rental business, and this company also bills customers. The last function is *Service Product*. There are two options, a standard service contract (E (1), handled by an internal department, and an extensive service contract (E (2), performed by an external contractor. In this case the latter option is chosen. It means that customers that experience problems or defects will be directed to the external contractor (who will use the Electrosonic brand), who will also perform any repairs that may be necessary.

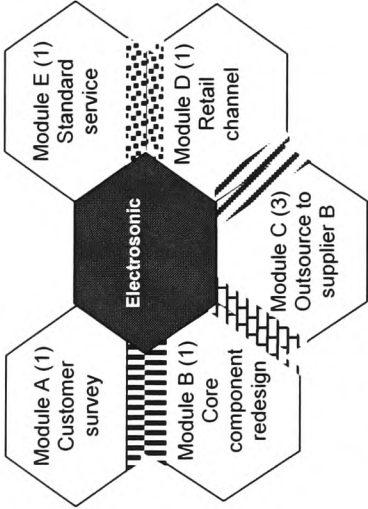
Scenario #2. Despite the development of products incorporating new innovations, the key buying criterion in the largest- volume segments is price. Electrosonic therefore needs to combine its focus on developing high-end products with a determination to produce simple and low cost products aimed at the largest market segments. For the washing machine market, a strategic

initiative concludes that it should be possible to develop a small washing machine with a sales price tag of around £150. The target market would be young people living in small flats and only requiring a limited washing capacity. To determine the product specifications, a traditional market survey is conducted (Module A (1)). Although dimensions need to be smaller, the basic architecture will remain unaltered. To develop the product, the second option is therefore chosen (Module B (2)). It is carried out by an internal group whose main competence is conducting continuous product development of existing product models. The production of the new product is outsourced to supplier A. This supplier has available capacity and turned out to be competitive on cost and quality compared to any of Electrosonic's own plants for this product. As the product is target to the main markets, the traditional retail channel is used (Module D (1)). Finally, the standard service arrangement is also used (E (1)).

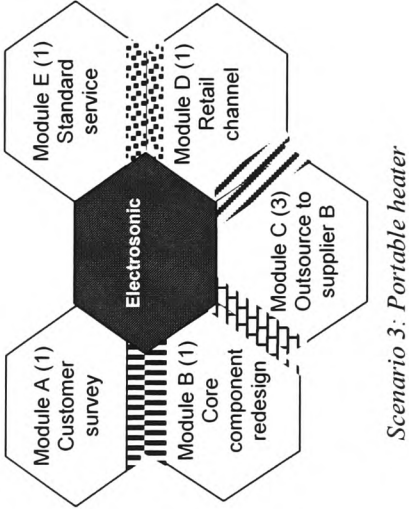
Scenario #3. A concept development team concludes that there exist opportunities for entering related markets in which Electrosonic currently does not have any product offerings. Management decides to start by developing a range of portable heaters and heating elements for home use. To create customer and market understanding (FR1), the process module for traditional market research (A (1)) is chosen. Using conjoint analysis and other statistical techniques, it identifies the bundle of product features most valued by customers (these include a low surface temperature, attractive styling, and easy regulation of temperature by means of a thermostat). Although this is a new product category for Electrosonic, it is deemed sufficiently similar to existing technologies to allow its internal technology development group (B (1)) carry out the concept and detail design of the product. On the other hand, due to limited capacity the entire production is outsourced to a supplier (C (3)). Heating elements are usually sold in the same retail outlets as other home appliances, so Electrosonic is able to exploit its existing channels to distribute and sell the product (D (1)). Finally, a standard service arrangement is chosen to service the product (E (1)). The resulting organisational configurations are illustrated in Figure 4.10.



Scenario 1: Internet fridge



Scenario 2: Small washing machine



Scenario 3: Portable heater

Figure 6.10.. Three organisational configurations (out of 162 possible).

6.4.1 Discussion

Some might argue that Electrosonic is no different from other home appliances companies, all of which must adjust their organisation, products and strategies as markets change. For example, during the last decade, many of the large firms were forced to adapt their business models as many home appliances were gradually commoditised, with cheaper brands offering increasingly high value. Some of the established firms adapted by reducing costs, others by renewed focus on introducing new and unique technical features. What is special about Electrosonic is the architectural basis for its on-going adaptations. The traditional way of achieving change in large corporations is through *organic adaptation* (Chandrashekar & Schary, 1999): Preserving the organisation but changing the functions (i.e., shifting its activities). A modular organisational architecture, on the other hand, preserves the functions but replaces and substitutes design parameters – i.e., organisational modules. It confers Electrosonic with the ability to configure organisational units quickly and cost-effectively to meet new market needs¹²⁵ while deriving economies of scope from leveraging specialised capabilities across different products and processes.

Changing a component of a regular organisational architecture (e.g., adding a supplier) used to involve prolonged negotiation and significant investments in specialised infrastructure. The result was often the creation of a new idiosyncratic solution, for example, an EDI system to allow data exchange with a single supplier, with unique numbering and coding systems for materials and products that were difficult to apply elsewhere. In the Electrosonic model, each organisational function can be satisfied by several alternative modules (DPs). These modules – whether internal units or specialised, external firms - represent a latent network that can be called into operation when needed (Chandrashekar & Schary, 1999). Gathering data on the cost, performance, and capacity of all modules is part of

¹²⁵ This starting point here is not individual customer orders as in the Hoogeweegen et al. (1999) model but identified market needs for a particular product or product model.

the architectural role that Electrosonic performs. This means that Electrosonic is able to consider different scenarios for assembling a temporary value chain based on an assessment of cost and lead time for each individual element.

Having standard interfaces also means that the transition process is exactly the same every time a module is activated or retracted by Electrosonic. In economic terms, entry costs are reduced due to protocols for connecting new module makers to the network configuration. Exit costs are reduced because Electrosonic is able to exit from performing many activities (i.e., those that are contracted out) without incurring the costs involved in laying off workers and closing down operations.

Electrosonic has the built-in flexibility to handle predictable changes in the product life cycle (cf. Linder & Cantrell, 2000). As a product matures, the business model and organisation need to change to: In the early stages, it entails offering high value to small design-oriented segment, earning premium margins. As the product matures, cost reduction takes centre stage and marketing focuses on the larger but price-sensitive mass market segments. Electrosonic can handle such shifts deliberately and repeatedly by coordinating the mixing and matching of specialised process modules into value configurations appropriate to the market and stage of the product life cycle.

The key element of a reconfigurable architecture is to enable several modules to fulfil a given function. But, vice versa, it should also enable the identification of existing modules that can be utilised to fulfil functions elsewhere (i.e., in other system configurations). Electrosonic and its competitors are therefore attempting to identify modules that may be leveraged more broadly. As we have seen, Electrosonic combines its manufacturing capability with the product development and distribution capability of other firms. But some firms in the industry even produce appliances designed and branded by their own competitors. Process modules may also be shared with firms outside the home appliances sector. For example, Electrosonic uses its global distribution capacity to offer logistics services to other companies (so-called third party logistics). In the future, it is possible that appliance companies start

leveraging their customer knowledge, for example, by sharing it with other companies targeting the same markets.

6.5 SUGGESTED EXTENSIONS OF CURRENT FRAMEWORKS

Many recent innovations in organisation design imply higher degrees of modularity (Schilling, 1999). Examples include the disaggregation of large firms (into independent profit centers, teams, etc), the emergence of virtual supply chains, and the introduction of shared services. Despite the increasing diffusion of modular organisational forms, modularity is still an emerging field of investigation and practice. In the following I discuss some future directions for research and propose some possible extensions to current frameworks.

6.5.1 Modularity and competence building

Modularity is traditionally viewed as an approach for leveraging existing capabilities to adapt to incremental changes. However, the approach can also be applied for organising strategic initiatives and innovation processes aimed at renewing the firm's capabilities and resources, for example, by identifying a new business opportunity or developing a new product or service. Strategic initiatives may be organised as independent projects (i.e., modules) with their own leadership, resources, and profit-and-loss responsibility. The main potential of modularity probably lies in facilitating a more evolutionary process for innovation (Lovas & Ghoshal, 2000; Staw, 1990). In the terminology of evolutionary theory, the internal environment of the firm provides mechanisms for both *variation and selection*. Variation is provided by the firms' employees, who are the generators of new initiatives. Selection is provided by strategic management processes that are used to review the fit of suggested initiatives with the firm's strategic intent and select among competing initiatives, some of which are retained by the commitment of resources to further development. Once selected, an

initiative may be cancelled at any point: after initial market research, after product development, or after initial market introduction.

Organising innovation processes is one of the key challenges for many firms. Large companies have had a tendency to respond to challenges by making all-or-nothing decisions - either commit substantial funds to a speculative venture where many of the risks are unknown, or forgo the project altogether (Dahlberg & Porter, 2000). The real options logic described by McGrath (1999) suggests a different approach. Instead of having one large innovation programme a firm could create several, smaller projects. For example, instead of having one major software development programme with hundreds of programmers, a firm may use several teams of five to ten programmers developing different experimental products for several potential markets. Strategic initiatives can then be viewed as a portfolio of options that contributes to reducing uncertainty, increasing variety, and expanding the search for opportunities. This approach is consistent with the practices of the more successful firms in the study by Brown & Eisenhardt (1997) in the computer industry. These firms used “low cost probes” (small and temporary projects) rather than elaborate planning systems to learn about new markets and future product improvements. Each “low cost probe” can be considered a hypothesis about the utility of a new concept¹²⁶.

Evolution revolves around a process of trial and error. New concepts are developed and tested, inferior concepts are eliminated, while others are retained. Lovas & Ghoshal (2000) suggested that the internal selection environment of the firm may either hinder or facilitate firm level adaptation. Firstly, there must be sufficient variation (i.e., a sufficient number of suggested initiatives) to provide real choices to management and to match the level of uncertainty in the external environment of the firm. More and better initiatives can be

¹²⁶ Another argument for decomposition of innovation processes is matching the size of the project with the size of the market being targeted (Christensen, 1997). This is particularly important for firms facing potentially disruptive innovations, which tend to appear first in emerging markets. But emerging markets are small - usually too small to be attractive for large companies requiring large revenues and high growth in earnings to defend their share prices. By placing responsibility in smaller units (e.g., in a “spin off”), performance will more meaningfully effect revenues and profit while the market is growing large enough for the mother organisation.

generated by capitalising on multiple perspectives, for example, by including people representing different functional backgrounds. Yet as pointed out by Staw (1990), creating variation is a challenge for many firms as organisational structures are often designed to *reduce* variability. Common norms and frames of reference often become institutionalised over time and control systems such as performance appraisals, promotion and advancement policies, goal setting, as well as socialisation practices and peer pressure may all serve to create homogeneity (Staw, 1990).

On the other hand, just as the internal selection environment may hinder sufficient variation, it may also be the case that it is insufficiently selective. If one is successful at initiating more projects (i.e., creating higher variety) it is likely that some, or even many, of the projects will fail. But a high failure rate can be positive *if the cost of failure is bounded* (McGrath, 1999). The key is therefore to match the evolutionary process of generating variety with a process for selecting winning projects and terminate losing ones. This does not imply avoiding failure altogether but terminating losing projects before losses become too high. In other words, more frequent evaluation of projects is necessary, as is stringent application of rules for judging future upside potential.

Although the use of cross-functional teams and cross-fertilisation of ideas may aid in identifying new opportunities, it is crucial for the strategic initiatives to be *independently* structured. In integrated systems, selection in effect takes place at the level of the whole firm rather than at the project level (Lovas & Ghoshal, 2000). On the other hand, if strategic initiatives are independent, a cancellation of one initiative will avoid selecting against other initiatives (as there are no significant interactions with the other initiatives). Disaggregation of strategic initiatives into independent units thus creates a portfolio of strategic options (cf. chapter 2).

In sum, applying modularity to competence building activities implies:

- *Creating multiple, smaller projects* – partitioning one large innovation programme into several smaller, independent projects. Where possible, investments are staged so that a small initial project can be scaled up once key uncertainties (e.g., market demand) have been reduced.
- *Combining resources from different business areas*. Variety is increased by including people representing different competencies, technologies, and markets.
- *Conducting more frequent evaluations*. Losses are contained by limiting the “cost of failure” to the cost of creating the option (McGrath, 1999). Thus, many projects may need to be discontinued.
- *Creating a culture with high tolerance for failure*. To be able to terminate projects (and sustain entrepreneurial activity in the future) the individual cost of failure must be limited. But even projects that are eventually terminated may provide the firm with valuable knowledge by resolving uncertainties about technology, markets, or its own capabilities.

Although the overall logic is the same, the application of modular principles for organising innovation processes may necessitate certain modifications in the framework presented above for modular organisation design. As mentioned, the conventional notion of decomposition suggests a partitioning and redesign of a large, existing set of processes into smaller components. This is appropriate for *competence leveraging* activities. *Competence building* activities (business and product development, etc) suggest a different perspective. It is not possible to completely predefine the organisational modules of a system that is growing and changing (or that does not yet exist). Instead of designing from the top downward, it may be necessary to design from the centre outward, starting with one or a few modules (e.g., one single organisational unit responsible for one product) and then adding modules as the market grows and as new products are introduced. Although we assume the existence of a predefined architecture, it may be as appropriate to speak of bottom-up “aggregation” as top-down “decomposition” of organisations to describe how modules are formed in the context of

competence building. It is interesting to note that this interpretation of the term modularity corresponds well with the early theorising of Simon (1967). Indeed, Simon's main proposition was that hierarchic systems would evolve much faster than nonhierarchic systems, thanks to the existence of stable "subassemblies" at each level of the hierarchy. In social systems, constructing new architectures by building on a series of small and complete outcomes creates a psychological and political effect termed "small wins" by Weick (1984).

Small wins (...) preserve gains, they cannot unravel, each one requires less coordination to execute, interruptions such as might occur when there is a change in political administration have limited effects, and subparts can be assembled into different configurations (Weick, 1984, p. 44).

Although there are differences in terms of the role that modularity plays for competence leveraging versus competence building, one should note that modular principles may contribute simultaneously to both. By creating standard interfaces, a module is made able to function in more than one system. The most obvious effect is creating economies of scope, as the resources in question can be leveraged across several sub-systems. For example, consider a team of consultants as a module of a consulting firm. Its clients benefit by gaining access to the teams' skills and expertise without having to permanently hire the team. The investment in recruitment, training, etc. for the team is pooled among several clients. Costs are also reduced for each client because it becomes better able to match staffing levels with demand at any given point in time (Matusik & Hill, 1998). At the same time, by working for several different clients, the team is exposed to a broad range of business practices, technologies, and working arrangements. Some of the value that consultants (and other contingent workers) bring to their clients is the ability to "broker knowledge" (Hargadon & Sutton, 1997), that is, transferring and combining pieces of knowledge from a variety of previous client projects (possibly in other industries) to generate a new and innovative solution for the current client.

6.5.2 The nature of organisational interfaces

Above I defined *organisational architecture* as a framework that describes both the required functions and the organisational design parameters (components and their interfaces). Modularity scholars have usually conceived of organisational interfaces as “design rules”, i.e., explicit procedures for handling technical interactions. The emphasis has been on dealing with *information interdependencies*, i.e., how employees go about organising activities where the relevant information for solving their respective tasks is distributed among several people. In generalising the notion of interface from products to organisational processes, however, it may be necessary to adopt a broader perspective to capture the many ways in which members of organisations achieve co-ordination. Information exchange is an important activity occurring between organisational units, but it is not the only one.

One important means of co-ordination is the *conveyance of commitments* among people (Scherr, 1993). The existence of a rule or procedure does not in itself guarantee that a customer actually receives a product that is requested: Somebody has to agree to the request and commit to performing whatever procedures are in place for delivering the requested product. Hence for organisational architectures to be actionable, it may be necessary to include individual roles & responsibilities by specifying the individuals that are accountable for achieving outcomes (i.e., functional requirements)¹²⁷. (Table 4.1 above incorporated this element.)

Commitments between seller and buyer are often formalised (e.g., by means of contracts or orders). Communication between members of an organisation, on the other hand, is often non consequential and sometimes fails to specify accountability for outcomes. In one study conducted in the U.S., fewer than 20% of managers surveyed believed that it was clear who had responsibility for solving key business problems in their organisations (Shaw, 1992). Haeckel (1999) pointed to cases in manufacturing firms where it was uncovered that

employees failed to make even a single commitment regarding volumes, costs or delivery dates - only forecasts, estimates, and targets. However, there now exist methodologies for formalising the requests and agreements made between organisational actors. One example is the “Commitment Protocol” (Scherr, 1993), which essentially standardises the process of requesting, negotiating and agreeing to commitments. The advantage is greater clarity around accountabilities and the possibility for systematic follow-up of whether expectations are met or not. The Commitment Protocol also clarifies interfaces by specifying how commitments are relayed from one person to another across organisational boundaries.

To be complete, then, I propose that organisational architectures encompass three distinct (but related) “layers”:

- A framework that describes the overall structural decomposition of the firm. The units identified in this framework typically contain the firm’s capabilities or resources - knowledge and people (e.g., functions, competency groups, or platform teams). At higher levels these may be pools that supply resources to the regular, operational processes of the firm as well as to ad hoc projects (e.g., special strategic initiatives or improvement programmes).
- A process architecture that describes the decomposition of the processes (also called tasks, activities or production elements) that are necessary to develop, produce, market, deliver and service the firm’s product or service offerings (as defined in the product architecture).
- A map of the accountabilities of the employees involved in carrying out the processes. This map will reflect an agreement among organisational actors about the roles and responsibilities that are required to implement the processes. It may also specify when and how actors are supposed to give commitments to each other and to external parties (e.g., customers)¹²⁸.

¹²⁷ Accountability is defined as a constituency holding a person responsible for performance. It may also include a system of reviews of performance and the existence rewards and punishments that are contingent upon the review. For further discussion see Ferris et al. (1995).

¹²⁸ In accordance with this framework, there may be three main ways of reconfiguring a system: 1) Adding, deleting or transferring sub-units such as business units and departments (i.e., traditional

The institutional process of *establishing* interfaces is another topic that deserves attention. Modular organisational architectures enable considerable decentralisation and “embedded co-ordination” instead of overt exercise of managerial authority (Sanchez & Mahoney, 1996). However, some theory and case evidence indicate that the initial process of establishing modular organisational architectures actually may require a strong centralised authority. Because it involves reaching agreement on standards among multiple parties with conflicting interests, it may represent a classic “common good” problem (Olson, 1971). Even though the system might gain as a whole, a particular unit has incentives for haggling over proposed standards if they conflict with investments that have been made in specific technologies or competencies¹²⁹. As Argyres (1999) noted, some type of hierarchical mechanism may be needed to overcome inherent bargaining problems¹³⁰.

Although the existence of a central authority may be necessary to resolve conflicts between sub-units with conflicting interests over standards, it does not mean that the entire process needs to proceed in a top-down fashion. McKelvey & Kilman (1975) outlined a participatory approach to redefining boundaries between organisational units. They applied the approach during the reorganisation of a business school at a major U.S. university. This business school consisted of only one department, but it wanted to form a number of smaller groups of researchers. The most important task-related interdependency was deemed to be faculty collaboration based on research interests. Each faculty member was sent a survey listing the names of all faculty members. The respondents were asked to indicate who they

restructuring/reorganisation), 2) Creating new processes based on combinations of sub-processes, and 3) Re-assigning accountability for a given process from one actor to another. The platform charter shifts described in Galunic & Eisenhardt (2001) and “activity relieving” described in Normann & Ramirez (1993) are essentially examples of re-assigning accountability for certain activities (to other internal units and to customers, respectively).

¹²⁹ This was also one of the findings in the field work reported in Chapter 4 of this thesis.

¹³⁰ On the other hand, some researchers have found that even highly fragmented systems can be able to reach agreements. For example, Genschel (1997) studied standard setting in international telecommunications. This process is characterised by a multitude of competing standards organisations, yet he concluded that it has been both stable and efficient.

felt could contribute to their own research activities over the next five years. Based on these preferences, a multivariate analysis (factor analysis) was then performed to statistically group researchers into organisational units.

This example shows that although the architectural concept was predefined (even in statistical terms), the *implementation process* was still a participative one. In most cases, it needs to be. Involving employees is obviously important to ensure future commitment and cooperation. But employees are also more likely than top managers to have detailed insight into how work activities inter-relate – which is the key input required in the modularisation process. Nor does one need to assume that individuals remain static within the modules once the interfaces have been established. On the contrary, individuals may have the freedom to “enter” into and “exit” out of modules (e.g., project teams) in order to match their own interests and preferences with the current business needs (Post & Johnson, 1999). Rather than having to allocate resources top-down a modular organisation should thus allow independent and self-optimising behaviour. On the other hand, once an individual commits to performing a defined role within a module, a modular organisational architecture will typically be more specific than conventional organisational designs in terms of defining individual accountabilities and deliverables.

6.6 CONCLUDING REMARKS

The concept of modularity is an important principle for solving organisation design challenges in dynamic environments and also offers a promising theoretical framework for scholars studying new organisational forms.

The key task of modularisation is understanding and managing *interdependencies*. Of course, the concept of interdependency is not new to organisation design. It was central to Thompson’s (1967) classic treatise as well as to later theorising based on the information

processing approach (e.g., Galbraith, 1973; Nadler & Tushman, 1996)¹³¹. The modularity approach re-emphasises the importance of designing organisations around task interdependencies. At the same time, it goes further than previous theorizing within the information processing approach, which largely treated the information processing requirements resulting from task interdependencies as a fixed variable. The modularity approach assumes that task interdependency is a *manipulatable* variable that can be “tuned” to achieve strategic goals such as creating a capability for flexible response (cf. Levinthal & Warglien, 1999).

Although developed independently, the modular approach shares many similarities with emerging research within complexity theory. Like the building blocks (fractals, patches) modelled by complexity theorists, modules within organisational architectures serve to impose regularity and consistency in complex organisations engaged in continuous adaptation to changing market environments (cf. Leonard-Barton, 1995). Kauffman (1995) explicitly transferred simulation techniques for studying biological and physical systems to the context of organisations. The simulation essentially consists of breaking a complex task into a quilt of non-overlapping patches and trying to optimise within each patch, regardless of the effects on surrounding patches. The key finding is that when the system is broken into well-chosen patches, each adapts for its own selfish benefit, yet the joint effect is to achieve a good result for the system as a whole. Even though the results are obtained without central co-ordination (another “invisible hand”, as he calls it), they are dependent on the initial definition of “architecture”. Choosing too small patches lead to chaos, whereas large patches freeze into poor compromises. The intermediate optimum (“the edge of chaos”) is usually very close to a transition between the ordered and the chaotic regime. This work lends further support to the notion that the manipulation of interdependency is a key tool in designing systems to allow emergent, self-organizing processes to take place.

¹³¹ In practice, many organisations have not strategically decomposed their organisations nor exploited the potential to more closely aligned task interdependencies with organisational architectures. For

example, in the companies studied by von Hippel (1990), traditions and tacit knowledge were more important than product structure in determining organisation design:

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7 SUMMARY AND CONCLUSIONS

7.1.1 INTRODUCTION

This thesis focused on the role of modular architectures in creating the capabilities required to compete in uncertain markets – dynamic capabilities. The research questions focused on three issues: The strategic value of modularity in the home appliances industry; the implementation of modular architectures in large firms; and the potential for applying modular principles in organisation design.

The research questions were addressed using different analytical methods and the three main papers (Chapters 4, 5 and 6) considered several aspects of the concept of modularity. For this reason a key objective of this chapter is to integrate the thesis by pointing to similarities and differences across the chapters.

While the first half of this chapter attempts to summarize the thesis, the last half of the chapter is devoted to discussing implications and future research on this topic. Some potential improvements in methodology and extensions to existing theory have already been discussed (e.g., sections 5.4.1 and 6.5). In this chapter I therefore focus on broader research themes that might guide future studies in this area.

I end the chapter with a discussion of how this thesis contributes to an emerging stream of research that advances the concept of *architecture* in strategic management and organisation theory. I explain how this stream of research challenges conventional theory by attempting to re-emphasize planning and structure as key constructs for theorizing in management studies.

7.2 SUMMARY OF APPROACH AND FINDINGS

This research focused on the home appliances industry and the key unit of analysis was organisational architecture. The choice of industry, unit of analysis and overall objectives are discussed in chapter 1.

The second chapter contains a fairly detailed literature review. The first part of the literature review identified the contributions of Simon, Hayek, Weick, Williamson and Weick as historical antecedents to the current frameworks that form the basis of this research. The second part of the literature review examined current approaches in different sub-fields of management research, namely, technology management and product development, software engineering management, finance and accounting, and organisational design and learning.

Drawing on this literature I derived a definition of modular architecture. This definition stated that modularity is the intentional (i.e., planned) decomposition of a system into relatively independent sub-parts with standard interfaces. I further showed that highly modular systems are those that allow reconfigurability based on substitution and change of individual components of the system.

Although I pointed to historical antecedents, I also noted important differences between past and current frameworks. The key contribution of chapter 2 is thus to position modularity as a new and distinct concept in organisation theory.

The remainder of the thesis was divided into three papers, each utilising a different analytical technique. The first and second paper draw on qualitative and quantitative data collected in the home appliances industry. The first paper (chapter 4) reported on case studies carried out in three vacuum cleaner manufacturers. It described the degree and type of dynamism in the external environment facing these firms and the way in which they have responded by altering their product platform strategies. The conclusion from these studies was that the companies had attempted to introduce some principles related to modularisation,

such as standardisation to enhance component sharing and carry-over. But I also noted the challenges of making the co-ordinated changes required to effectively exploit modular platforms, particularly in complex international firms with divisions that employ multiple and even conflicting technologies and organisational practices.

The second paper (chapter 5) reports on a study that collected data from managers in U.S. and U.K. home appliances companies by means of a questionnaire. Using structural equations modelling, the paper examined the linkages between key antecedents (market context), contributing factors (innovation orientation and organisational architecture) and outcomes of modularity (strategic flexibility and firm performance). While controlling for firm size, it found that modular product architecture had a positive influence on model variety (the number of product models offered). It also found a significant relationship between model variety and firm performance. The contribution of this paper is twofold. First, it contributes to methodology by developing a questionnaire for assessing modularity in product and process design. Secondly, it provides one of the first empirical studies of the effects of modularity on strategic flexibility and firm performance.

The third paper (chapter 6) sought to synthesize existing theory on modularity (largely from the field of technology management) and to generalise the principles to the domain of organisation design. It also provided an example of how a large manufacturing firm may adopt modular principles to create a reconfigurable organisational architecture. Although this chapter is theoretical in its focus, it may provide the basis for the development of more specific organisation design methodologies aimed at enhancing organisational flexibility. It outlined a proposed methodology of analysing task interdependencies in order to make decisions with regards to how to structure the formal organisation of a company.

7.2.1 Comparison between chapters

Because this research has employed different analytical methods and considered different aspects of the concept of modularity, it may be useful to point out what the relationship is between the various chapters of the thesis.

Commonalities. Figure 7.1 contains a Design Structure Matrix illustrating the key interconnections between the chapters. The first thing to notice is that the studies share a common platform, which was established in the first chapter. That is, all papers in the thesis have the same purpose, as outlined in chapter 1: To contribute to our understanding of how companies increase their dynamic capabilities by means of modular systems. Moreover, the main papers (chapter 4, 5, and 6) focus on the same unit of analysis and the same industry, also defined in chapter 1 (the box marked a) in Figure 7.1).

The first research question – concerning the implementation and current use of modular systems – was primarily addressed in chapter 4. The second research question – concerning the strategic value of modularity – was pursued in chapter 5. The third research question – concerning implications for organisation theory and design – was dealt with in chapter 6 (the box marked b) in Figure 7.1).

Figure 7.1 shows that the issues of later chapters depend on the definition of constructs or research findings of preceding chapters. For example, chapter 4 and 5 are quite different in terms of research question and methodology. Yet they are strongly related to each in terms of how the research process unfolded: It would have been difficult to perform the survey study reported in chapter 5 without the preceding case research reported in chapter 4. The extant literature on home appliances industry was quite scarce and I found it insufficient as a basis for empirical research on this topic. The case research gave me a basic understanding of key competitive challenges facing home appliances companies, the typical product design of vacuum cleaners, and the way appliance manufacturers were organised. This was essential for the development of the survey questionnaire, where these constructs were operationalised. The field research also made me familiar with the terminology used by

managers in the industry and this helped to increase the face validity of the items in the questionnaire. The additional research questions that were formulated for the survey research reported in chapter 5 also arose from the experience gained during the case research, which sensitised me to organisational and managerial issues surrounding the implementation of modular system.

There are also interconnections between chapter 4 and chapter 6. Chapter 6 discusses implications for organisation theory and design, and likely scenarios following wider adoption of modular process and organisation designs by home appliances companies. This discussion of possible future developments benefited from the review of the current status of the industry reported in chapter 4. Moreover, the hypothetical case study that is outlined in chapter 6 was inspired by conversations I had with industry participants that I met during the case study research. These managers were themselves quite interested in how their companies might look in the future, and the movement toward more flexible organisational forms was a common theme in these discussions.

Figure 7.1 Interdependencies between different chapters of the thesis

		Chapter 1			Chapter 2					Chapter 3				Chapter 4				Chapter 5				Chapter 6			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Issue																									
Chapter 1 (introduction)	1 Overall objectives																								
	2 Unit of analysis																								
	3 Choice of industry																								
Chapter 2 (literature review)	4 Antecedents in org. theory																								
	5 Review of current literature																								
	6 Construct definition																								
	7 Def. of research question 1																								
	8 Def. of research question 2																								
	9 Def. of research question 3																								
Chapter 3 (methodology)	10 Methodological stance																								
	11 Overall research design																								
	12 Boundary conditions																								
	13 Limitations																								
Chapter 4 (cases)	14 Relevance of concept in home a.																								
	15 Extent of application																								
	16 Barriers to implementation																								
Chapter 5 (survey)	17 Proposition 1-3																								
	18 Additional research questions 1-2																								
	19 Conceptual model (Fig 5.1)																								
	20 Methodology, questionnaire dev.																								
	21 Analysis and Results																								
Chapter 6 (org. design)	22 Concept of org. architecture																								
	23 Hypothetical case																								
	24 Suggested extensions																								

e) Interconnections between research questions themselves

b) Relativ emphasis in relation to initial research questions

a) Commonalities across the three main papers

c) Interconnections between chapter 4 and 5

d) Interconnections between chapter 4 and 6

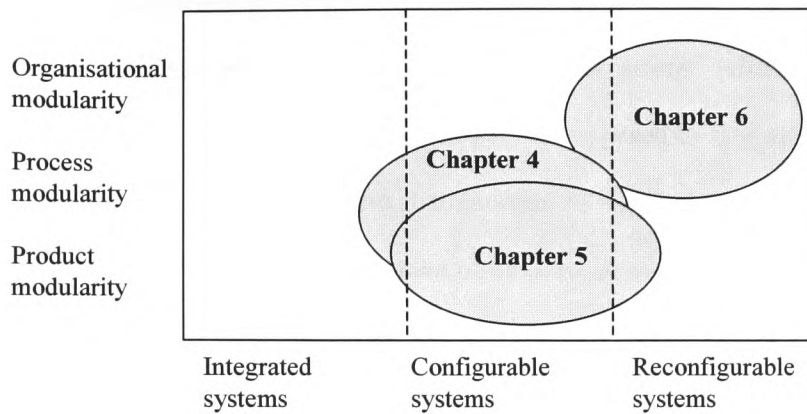


Figure 7.2. Focal point of different chapters of the thesis.

Differences. One difference between the chapters is the *degree of modularity* observed in the empirical phenomena that are observed or in the theoretical models that are described (Figure 7.2). Specifically, the companies described in chapter 4 and 5 are characterised by (at best) a moderate degree of modularity in their products and processes (they have “configurable” architectures), whereas chapter 6 focuses on highly modular systems (with reconfigurable architectures). However, this does *not* imply that different definitions or theoretical frameworks have been applied in the different chapters. As I argued in chapter 2, as a concept modularity should be considered a continuum ranging from integral to (highly) modular. This allows one to apply the same conceptual framework to characterize empirical phenomena and theoretical constructs varying in degree of modularity. Chapter 6 intentionally sought to extend current models by discussing what a highly modular company might look like.

As I just noted, different chapters address different research questions: the implementation of modular systems, the strategic importance of the concept and implications for organisation design. However, I should add that the research questions are not entirely independent. The relationship between the research questions becomes clear if one applies the perspective of resource-based theory within strategic management. Authors like Barney

(2002) would argue that the flexibility achieved through modularity would need to be valuable, rare and inimitable in order to confer sustainable advantage to a firm. The use of modular product architectures is usually associated with greater reliance on articulated knowledge and more extensive use of more general – as opposed to firm-specific – product-level resources (e.g., product architectures that conform to industry standards). As discussed in chapter 2, one may thus expect that adoption of modular principles to be negatively related to sustainable advantage. This argument has merit if one looks at the product level alone: For example, firms are likely to enjoy only a temporary competitive advantage by introducing a product with new features if the features derive from the inclusion of an improved component sourced from an external supplier (competing firms can reverse-engineer the product or may even be able to use the same component supplier).

However, if one looks beyond the product level it becomes clear that modularity is embedded in complementary organisational resources and capabilities that may be difficult to imitate and thus provide a source of competitive advantage. I cover two or three categories of complementary resources in this research. In chapter 4 I described the coordination problems involved in aligning product architectures in a large firms. The necessary organisational resources to overcome such problems may include skilled project managers, a corporate culture of shared values, and interpersonal relations among managers in the relevant sub-units of the firm. These are clearly socially complex resources that may be difficult to develop and consequently hard to imitate. Another important organisational resource may be the ability to read and respond to environmental events. In chapter 5 I noted that the adoption of modularity was dependent upon managers' perceptions of the level of industry dynamism, which in turn are influenced by the corporate culture. In conclusion, individual modular technical components may become less firm-specific due to increased documentation, use of outsourcing and open standards, but the organisational capabilities necessary for implementing modular systems (e.g., managers' cognitive skills and the ability to coordinate product development processes across business units) may indeed represent rare and

inimitable resources. Hence the research question addressing strategic importance and the research question addressing implementation of modularity are related to each other.

7.2.1.1 Comments on some emergent findings

Several authors have pointed out that the research process typically yields both planned and unplanned results (e.g., Eisenhardt, 1989). This was also the case in this research. In particular, I would like to comment on three emergent findings:

The relationship between modularity and firm performance. In the early phases of my research I had expected to find a direct relationship between modularity and firm performance. After discussing the issue with other researchers I gradually changed my mind and developed a conceptual model (Figure 5.1) for the survey study where the hypothesized relationship goes from modularity through strategic flexibility to firm performance. Had I used a conventional statistical methodology (e.g., correlational analysis) I may have concluded that there was no relationship between modularity and firm performance. However, by introducing the intervening variable strategic flexibility (operationalised as the number of product variants offered) and utilising structural equations modelling, we clearly see that an indirect relationship exists between the two variables (see Figure 5.2). One interpretation of this finding is that some of the companies that have modular designs are unable to translate these modular architectures into flexible products; there may for example exist constraints in manufacturing or distribution that hinder them in doing so. The finding is important for future empirical research that looks at the modularity-performance relationship: One needs to include strategic flexibility as variable before one can say something about the performance effects of having modular architectures.

Strategic integration versus module independence. In chapter 4 I described the complex task of implementing modular systems in large organisations consisting of multiple units with conflicting standards. I basically found that one must distinguish between the design of the implementation project and the resulting organisational configuration. As noted in chapter 2 and 4, a modular system (once implemented) should enable “embedded co-

ordination” of independent and geographically dispersed activities. Somewhat paradoxically, however, it requires a high degree of *integration* in the implementation phase. Developing architectures requires a holistic perspective. Managers from different business units need to work jointly in order to document and redesign/remove the interdependencies that exist across business units – only then can organisational modules begin to operate in an independent fashion. The implementation of a modular system can thus be considered a task of *complex strategic integration*. This suggests some links to the recent research by Burgelman & Doz (2001), which on the face of it, would seem to address an issue very different from that of modularity.

The possibility of different “flexibility configurations”. The studies presented here confirm that product modularity is related to firm performance in a variety-intensive industry. The empirical results thus lend support to the theoretical approach outlined in Sanchez (1995). Nevertheless, a question remains regarding the universality of the observed effects. Although it seems logical to assume that modularity is a fundamental prerequisite for product-level flexibility, we cannot exclude that there are other ways (than product level flexibility) of successfully adapting to diverse or quickly changing market environments. A more configurational approach would suggest that there may exist different paths to reach the same end state (Doty, Click, & Huber, 1993). Among the case study companies, the description of Dyson Appliances hints at such a possibility: An innovative company that is leveraging its design and marketing capability but which (at the time of the study) had a low level of modularity in its technical architecture. An example similar to Dyson is that of the Italian design group Alessi, which seems able to create high-margin design objects out of every conceivable household product without doing much to the technical functionality of the products. A third example is BMW. Although many car makers (e.g., Volkswagen) have been very successful at exploiting modular product platforms, BMW has focused more on “electronic platforms”, i.e., the sharing of software and common technical insight among its car models rather than re-using the same physical components (*Economist*, 1999). In terms of

thinking about alternative “flexibility configurations”, one possibility is thus to shift attention from the technical architecture of the product to other variables that influence market success. The technical architecture of the product in these examples is hardly irrelevant, but the existence of such “outliers” may suggest that the exploitation of other “platforms” – related to brand, knowledge management and visual styling - may be as important as the physical product platform in explaining competitive success for at least some companies.

7.2.2 Limitations

As with all research, the methodology employed in this thesis is subject to certain limitations and biases¹³². Some of the limitations are common to all studies utilising similar methodologies, whereas some are related to the specific way in which the studies were carried out for this research.

In interpreting the results it is important to note that the participating companies were all drawn from the same industry – the home appliances industry. Focusing on one industry was a decision that was taken early in the research process. In chapter 3 I noted that although modularity is a generic systems concept and thus applicable to many or maybe all industries, some of the results regarding the effects of modularity may be attributed to the specific conditions in this industry. For example, the home appliances industry is “variety-intensive” and much effort is devoted to containing costs of producing a high number of product models. Had I studied a different industry (e.g., PC manufacturers), it is possible that I would have been able to document stronger effects of modularity on the ability to frequently introduce new products.

The case studies reported in chapter 5 were carried out in three companies in three different countries. The organisational and cultural diversity of the sample is both a strength

¹³² The choice of industry was explained in chapter 1. In chapter 3 I reviewed some of the limitations of the chosen methodology. Specific issues related to the case study and the survey study were discussed in chapter 4 and 5, respectively.

and a weakness. While I was able to discern some common themes, there remains a concern about the comparability of the three cases.

The survey study reported in chapter 5 utilised a fairly conventional survey methodology in order to collect data. Most of the limitations of this study are common to all studies utilising a similar data-collection method. In order to improve the ability to make causal inferences I recommended a time lag sampling procedure for future studies instead of the cross-sectional approach. I also noted that I had to develop a new questionnaire, as there was no pre-existing questionnaire that I could make use of. The subsequent analysis indicated that the questionnaire had satisfactory statistical properties; nevertheless, the validity of the findings would have been even higher if one could make use of a questionnaire with already established item reliabilities.

7.3 FURTHER RESEARCH

There are many opportunities for further investigation of this topic. In this section I cover ten different research themes. In some cases these derive directly from the study reported here; in other cases I identify recent contributions by other scholars that can provide starting points for those who want to extend extant theorising on modular systems and strategic flexibility.

7.3.1 Replication of study

The most obvious extension of the empirical research reported here is to simply repeat the studies in the same industry. As for the survey study, I suggested in chapter 5 that methodologically, a repeat study would be optimal in terms of establishing causal links between the degree of modularity and the effect on firm performance. But the case research could also be repeated. More than 4 years have passed since the case research was carried out. When I planned my research, highly modular organisational designs were only a possibility. In some industries, they are now becoming a reality: A recent article in the *Economist* describes the likely disintegration of today's car manufacturers and the emergence of "vehicle brand owners". The vehicle brand owners only perform the core tasks of designing,

engineering and marketing vehicles, whereas the assembly process may be done by parts suppliers (*Economist*, 2002). Such a model is already in use by Porsche (and by some motorcycle companies). Home appliances companies have often looked to the car companies for new ideas. In other words, if my study was to be repeated today I would expect to find that also white goods companies are moving toward more flexible organisational configurations¹³³. Possible issues to cover in such a study might include:

- The proportion of components in a product offering that has been outsourced
- The emerging industry structure (the degree of subdivision into module makers and system integrators/architects).
- The mechanisms that system integrators use to govern a network of suppliers (how suppliers are selected, how transactions occur, to what extent the system integrator maintain competence in the areas that are outsourced, etc.)
- The existence and nature of flexible internal networks within large firms (e.g., module centres)
- The existence of reconfigurable inter-firm networks (as outlined in chapter 6 of this thesis) – for example, current suppliers that can easily be substituted with alternative suppliers, as opposed to long-term partners.

7.3.2 Strategic flexibility for firms other industries

Another extension would be to study the effects of modularity in other industries, and, more importantly, industries that differ from the one studied here. Stabell & Fjeldstad (1998) argued that the traditional value chain is but one of three distinct value configurations. They developed different value configurations related to Thompson's (1967) categorisations of technologies (long-linked, intensive, and mediating, respectively). Whereas the value chain

¹³³ At the same time, it is also important to point out that recent indications are that car companies (e.g., Volvo) are now insourcing some activities that were previously outsourced. As Schilling (2002) pointed out, modularization of product systems can shift the locus of competition and, in some case, increase bargaining power of component makers (which may be the reason why Volvo reverses some of its earlier outsourcing decisions).

describes a process that transforms inputs to products by using a long-linked technology (manufacturing), the *value shop* describes the process of solving unique client problems using “intensive” technologies (e.g., hospitals, consulting firms), and the *value network* creates value by facilitating exchanges among clients using a mediating technology (e.g., banks, internet portals).

As a general systems concept, modularity is potentially applicable to any firm, regardless of industry. For example, many insurance companies (defined as value networks by Stabell & Fjeldstad) have configured their offerings as modular products in the sense that there is a set of options (usually priced separately) that the customer can choose from and that can be combined into a larger package. The structure of the insurance products may also be reflected in the IT systems, which may be based on e.g., object oriented technology and reusable software modules. Consequently, it is possible to conduct a study similar to the one reported in chapter 5 in the insurance industry, and only minor changes in wording would be required for the items in the survey questionnaire¹³⁴.

However, one might expect to find a different causal relationship between product level modularity and firm performance. Fjeldstad & Stabell (1998) noted that there are different cost and value drivers for each of the three value configurations. The logic of the value chain is transformation of inputs into products and modularity contributes directly to strategic flexibility, and consequently, firm performance, by creating economies of scope (cf. chapter 2), for example, by allowing the leveraging of components within a product platform across a range of product models.

For companies characterised as value networks, the design of the product offering (e.g., the loan products of a bank) may be somewhat less important than the design of the networks that connect different customers to each other (e.g., those who lend money and

¹³⁴In fact, I considered performing such a study as part of this research and I developed an early draft of a questionnaire intended for insurance companies, based on the items listed in table 5.1. However, I abandoned this plan due to budget and time constraints.

those who borrow). According to Stabell & Fjeldstad (1998), size and composition of the customer base are the key drivers of value in the value network. Hypothetically, then, a bank that suffers from an inefficient product structure may still be able to retain a competitive advantage if it is better able than its competitors to attract customer groups that fall within the segments that it targets. On the other hand, it is also possible to imagine situations in which modular product architectures would contribute directly to strategic positioning of value networks. Stabell & Fjeldstad (1998) discussed *vertical and horizontal scope* as key strategic positioning options. Modularity may support the extension of the vertical scope of a value network in that a firm that employs modular architectures more easily will be able to interconnect with other firms that co-produce offerings if they employ common standards. For example, it may allow a bank to link up with a telecom operator to provide electronic payment services. Modularity may contribute to increasing the size/composition of customer networks by allowing a firm to re-use product or infrastructure components in targeting an extended customer base. For example, a bank may find that it can leverage its current IT systems and offer its customers a broader set of financial products.

The key value creation in the value shop does not deliver a physical product but a resolved customer problem. The process is organized to deal with unique cases, for example, the patient who visits a general practitioner or the client of a consulting firm. In studying value shops one may thus have to modify the definition of strategic flexibility. As currently defined the concept centers on product-level flexibility. However, the value creation process in value shops is embedded in social networks and the deliverable may be an intangible product (e.g., a correct diagnosis). Some would argue that this kind of system is more characterized by permeability than by modularity (Kogut & Bowman, 1995). A comprehensive explanation of how value shops achieve flexibility might thus require us to consider social factors such as organisational identity and cooperation across formal boundaries.

However, this does not mean that modularity is irrelevant to the strategic value drivers in value shops. The key is to look at supporting infrastructure and organisational designs that enable the application of knowledge in client-centered problem solving. A modular knowledge architecture may help a consulting firm in re-using and transferring solutions across different clients and thus reduce costs. More importantly, such a knowledge architecture may also spur value creation in that it allows consultants to creatively combine and recombine ideas from previous clients to arrive at a new solution for a current client (see Hargadon & Sutton, 1997 and section 7.3.10 below). A modular organisational architecture may also help a consulting firm decrease the cost of coordinating problem solving efforts among its professionals (and thus enable larger scale operations than would otherwise be possible). An example would be software development projects with geographically dispersed teams coordinated by means of standard interfaces between software modules (see chapter 2).

In sum, including firms with other value configurations may require some modifications of current frameworks for understanding strategic flexibility. But it also offers exciting opportunities for deepening our understanding of how modularity contributes to dynamic capabilities.

7.3.3 Organisational innovations

Apart from studying specific industries, it may also be of interest to study general organisational innovations in order to map the concepts of the modularity approach to new organisational models that are emerging. One example is the introduction of shared services, which has been an important trend during the last few years. Shared services involve the consolidation of administrative functions (e.g., accounting, payroll, or customer service) into one physical or virtual service centre. As I mentioned in chapter 6, some features of shared services appear closely analogous to those of modular product platforms: Shared services usually consist of specialised teams (i.e., modules) with process interfaces that are “standard” in the sense that previously departmental or business unit-specific teams now serve a number

of internal (and sometimes external) clients. One possibility is to systematically study a sample of shared service centres and evaluate how their process interfaces have been defined and how this affects their ability to interact with their customers. So far it appears that most shared services centres focus on relatively routine and transaction-oriented activities, for which client requirements are relatively stable. But it would also be of interest to evaluate to what extent shared services might involve reconfigurable processes. This may be the case in larger firms where internal client have more diverse needs¹³⁵ or in firms in highly dynamic industries where the administrative functions must continuously adapt to changes in the core business functions.

7.3.4 Technological versus organisational modularity

According to Sanchez & Mahoney (1996) and Baldwin & Clark (2000) a modular product architecture should enable a firm to create and maintain a modular organisational architecture. This is an important hypothesis that deserves to be investigated empirically. In this research I touched on the issue in several chapters, for example, in my interviews during the case research I asked managers to explain both the product architecture and product development processes. The survey study I conducted also considered both of these issues. However, it is possible to explore this hypothesis much more rigorously.

The relationship between technological and organisational modularity has recently been the subject of some empirical research. Brusoni, Prencipe & Pavitt (2001) analysed the organisational structure of companies designing and manufacturing aircraft engine control systems. Their aim was to look at the effect of specialisation in knowledge on the boundaries of the firm. They conducted interviews with managers in the three main manufacturers and in four of their suppliers, and analysed patent data from the last 25 years to identify changes in the firms' technological capabilities. A key finding is that companies maintained

¹³⁵ I have participated as a consultant in defining the processes for several shared services centres. In one of these there were divergent needs among internal clients, which led to the development of a flexible "menu" of choices with regard to the configuration of services that were offered by the shared

technological capabilities even in areas where design and manufacturing activities had been outsourced to suppliers. Brusoni, Prencipe & Pavitt (2001) thus argue that specialisation in the activity domain was not accompanied by specialisation in the knowledge domain. They consequently challenge the proposition that there is one-to-one correspondence between product and organisational architecture¹³⁶. The main conclusion I draw from this study is that those firms that take on an architectural role need to maintain a broad knowledge base in order to integrate contributions from specialised suppliers. It also points to the need for including knowledge development as well as more concrete production activities in the equation when one studies the relationship between product and organisational modularity.

When studying this issue at a more micro level one may utilise the methodology developed by Sosa, Eppinger and Rowles (2000). Their approach was to create a Design Structure Matrix (DSM) for the product and a separate DSM for the organisation, and then to measure the degree of correspondence between the two. Their study took place in the product development organisation of a large commercial engine manufacturer. To develop the DSM for the product they interviewed design experts who described the technical architecture of the aircraft engine. To develop the DSM for the organisation they asked members of each of the 60 teams to rate the frequency and criticality of their technical interactions with other teams. The subsequent analysis revealed that in the majority of cases (90%) known design interfaces were matched by team interactions. Sosa, Eppinger and Rowles (2000) outline a number of statistical techniques that can be used to assess the degree of correspondence between product and organisational level data.

services centre. In the future, clients in this firm may have the option of performing an activity themselves, using the shared services centre, or using an external provider.

¹³⁶ Brusoni, Prencipe & Pavitt (2001) argue that their findings contradict modularity theory; however, I would question whether this is really the case. To my knowledge, modularity scholars have not claimed that there is a deterministic one-to-one relationship between product and organisational architecture. What they have said is that a modular product architecture *enables* the creation a modular organisational architecture.

7.3.5 Organisation design methodologies

One goal among some scholars is to contribute to the dissemination of the modularity concept among practitioners. But how can the modularity concept be made “actionable”? According to Argyris (1996) and Meehan (1981), actionable theory must contain specifications for how intended effects are to be created (see Worren, Moore & Elliott (2002) for a discussion). There already exist methodologies and tools to support the design of modular products (e.g., Martin & Ishii, 1997), but there are few practical guidelines for creating modular organisations¹³⁷. In chapter 6 I presented a framework that can be transformed into a prescriptive model or a methodology. I would suggest that such a methodology be divided into different phases that reflect the typical phases in a real-world project, such as identifying (or confirming) strategic goals, documenting customer needs, defining organisational structure, and so on. It would be an advantage to include a description of the specific techniques and tools that could support the organisation design process. For example, one might explain how modules can be defined by means of the Design Structure Matrix or other tools.

7.3.6 Sources of competitive advantage for flexible firms

Part of the motivation for this research was increasing our understanding of the strategic importance of modularity. The source of my interest in this issue was the apparent conflict between the emphasis on standardisation in the literature on modularity and the focus on firm-specific resources in the resource-based strategy literature. Flexibility is necessary for a firm facing high uncertainty. But according to Barney (2002) it will only be a source of *competitive advantage* if it is rare: If several competing firms all implement the same flexibility enhancing options (in the same way), it will only lead to competitive parity for each of the firms. According to the resource-based view there is a trade-off between adopting

¹³⁷ One exception is the high-level approach for “modular network design” developed by Hoogeweegen et al. (1999). This approach is focused on logistics networks; nevertheless, scholars

modular principles that support flexibility (but that may be imitable) and integrated designs that are less flexible (but are more likely to be inimitable).

McEvily & Chakravathy (2002) looked at the persistence of knowledge-based advantage. They empirically assessed the degree of complexity, specificity and tacitness of the technological knowledge of firms in the adhesives industry, and then measured the number of months it took for competitor firms to imitate new products that the firms had introduced. The results confirm that complexity and tacitness help in defending a firm's new products from imitation, however, this effect was only observed for major and not for minor improvements. (The authors suggest that competitors have a number of mechanisms other than imitation to close a performance gap created by a minor improvement.)

As McEvily & Chakravathy (2002) noted, it is difficult to derive prescriptive advice from the results as they do not consider firm performance as an outcome variable. High complexity, specificity and tacitness may deter imitation but also make knowledge harder to transfer internally in the firm and may thus negatively affect profitability. Also note that this study focused on one level of resources only (i.e., technological knowledge) and did not consider bundles of resources (e.g., manufacturing capability, financial resources). As described above (section 7.1.1), a more fruitful conceptual model may be one in which one views the firm as a system consisting of different levels of resources (tangible, intangible, etc.). Standardisation at one level (technology) does not necessarily prevent the development of firm-specific resources at another level (coordination capabilities, strategizing, culture, etc.).

In my opinion, the main value of this study is to demonstrate how one can operationalise and measure such concepts as imitability. It would be possible to include such variables in a new study of the home appliances industry. In the qualitative research reported in chapter 4 I mentioned some key design milestones for vacuum cleaners and also indicated how long time it had taken for the design to be imitated by competitors. It would be

wanting to develop an organisation design methodology may borrow elements from the way in which

interesting to pursue this further¹³⁸ by assessing the degree of modularity of vacuum cleaner designs (for example by using the “product archaeology” methodology of Ulrich & Pearson, 1998). If it is difficult to reverse engineer the products for practical and financial reasons, a simpler methodology would be to get industry participants to rate the degree of modularity of the designs. The degree of modularity could then be correlated with data related to flexibility (e.g., how frequently upgraded models are introduced) and to performance (e.g., how persistent the advantage is for each of the innovations operationalized as the number of months it takes for competitors to replicate the design).

7.3.7 Modular business model

When viewing the firm as a system (Sanchez & Heene, 1996), the concept of architecture may be applied at different levels, from concrete activities and resources with low levels of causal ambiguity (e.g., operations) to higher-level, intangible elements. One possibility is to explore whether modularity can be applied to higher-level system elements, such as a firm’s business model. A business model has been defined as a company’s strategic logic for creating value¹³⁹. It may include a value proposition for its stakeholders, a concept for assuring revenue generation for the business, and a high-level design for the supply chain for the business (Mahadevan, 2000).

One view within strategic management holds that successful business models are those that specify complex activity sets with many cross-sectional linkages (see Ghemawat et al., 1998). An example is a 1996 article in which Michael Porter analysed Southwest Airlines’ activity system. Porter (1986) pointed to the existence of some higher-order “strategic themes”, such as limited passenger amenities, frequent, reliable departures, and low ticket prices. These strategic themes are interconnected and the fit between them provide an

Hoogweegen et al. structure the design process.

¹³⁸ Professor James Utterback proposed carrying out such a study during a conversation we had in 1998.

¹³⁹ Admittedly, some uncertainty remains regarding the precise definition of the concept of a business model. Some authors would claim that it is synonymous with the term strategy whereas others (e.g., Linder & Cantrall, 2001) make a distinction between the two.

advantage that is hard to replicate because a late-mover will have to match an early-mover on many different and interlocked dimensions. For example, when Continental Airlines tried to imitate Southwest by introducing Southwest Lite with lower fares, it failed because of the inconsistency between the pre-existing strategic themes (inherent in its full-fare offering) and its new low-cost service.

Based on the approach taken in this thesis, one easily sees that an alternative proposition may be developed: That dynamic markets may require business models that consist of independent and reconfigurable elements. A topic for future research may be to map the business models of a set of companies and try to determine to what extent the different components of the models are inter-connected or not. Some ideas in this regard may be derived from the case studies summarised in Linder & Cantrell (2001): For example, does the business model contain several value propositions (e.g., high value products directed at one segment and low cost products at another)? How easily can individual components be changed? Can different components of the model be "mixed and matched"?

A related issue is to consider more systematically the relative value of inimitability due to complementarities between activities versus the value of flexibility derived from modularity. Rivkin (2000) developed a formal model where the two key parameters (N and K) represent the number of decisions that a firm faces (with regard to strategy, organization, etc.) and the degree to which the decisions interact. The idea is to represent strategies as a combination of choices that may (or may not be) associated with another. Building on complexity theory he models strategic decision making as a search for an optimal combination of choices in a high-dimensional "decision space". The results confirm the theorising of Porter (1986) in suggesting that the sheer complexity of a strategy raises barriers to imitation, even if none of the individual strategic elements or actions are inimitable. This is particularly the case where decisions interact: It is very difficult for competitors to discover the set of decisions that underlie a successful strategy. And if different elements are dependent on each other, imitating some but not all of the elements will usually lead to

failure. It appears that Rivkins' paper does not directly deal with the fact that managers can alter the relationships between decisions – which of course is a key assumption behind the modularity approach. But it does suggest that strategies consisting of independent elements are more easily imitated than those consisting of interdependent elements.

7.3.8 Strategic decision making frameworks

How does one know whether an industry is likely to become (more) modularised? This is a question with important implications for industry participants. Among other things, assumptions about future industry structure may influence how a company defines its very core business (e.g., whether a company positions itself as a component maker or an integrator).

To my knowledge the only attempt at creating a framework to answer this question is that of Schilling (2000). She has developed a high-level framework that can be used to evaluate whether an industry is likely to migrate toward (or away from) from greater levels of modularity. The key factors in her model are:

Heterogeneity of inputs – differential capabilities of firms and diversity of technological options

Synergistic specificity – e.g., whether greater functionality is achieved through component specificity and whether it is difficult for customers to assess component quality and interaction

Urgency – the speed of technological change and competitive intensity

Heterogeneity of demands – customer heterogeneity in desired functions or scale.

I believe this is a promising way of framing the critical issues when discussing potential modularisation of an industry. For example, I have used it when discussing the future of the home building industry in Scandinavia with industry experts. My discussions so far suggest

that there exists a real pressure toward increasing modularisation in the home building industry. Architects in Norway claim that modular homes (customer-configured via the internet) may be produced at significantly lower cost than the average home built today. Yet none of the established companies have so far embraced this logic. However, following the Schilling framework we would predict a movement toward much greater inter-firm modularity during the next 5-10 years. It may occur through the entry of new firms, such as the alliance between IKEA and Skanska in the Nordic region, firms that are already experimenting with related concepts (see their web-site www.boklok.com).

However, there are a couple of ways in which the Schilling (2000) framework may be extended. The first is to consider if it is possible to distinguish between bundling and modularisation. From what I can tell these two concepts (albeit related) are confounded in the model presented in Schilling (2000). This diminishes somewhat the prescriptive relevance of the model – we seem to be unable to determine whether the competitive pressures will lead to changes in the structure of the commercial offering or in the underlying product architecture (or both). The second is to operationalize the constructs and suggest how practitioners are to collect and analyse data on the relevant factors (see section 7.3.9 below concerning the assessment of demand for variety). Finally, it would of course be desirable to empirically test whether the model can be used to predict the adoption of modular product and processes.

7.3.9 Marketing and consumer behaviour

As explained in chapter 2 of this thesis, the origins of current modularity frameworks lie within technology management. It is therefore natural that design and manufacturing considerations have been emphasized in conceptual and empirical research. However, in the future it may be useful to put stronger emphasis on the demand side. In the following I review several possibilities for integrating the modularity literature with theory and research within marketing.

A frequently made assumption in the modularity literature is that there is a latent demand for higher variety, and that the market will absorb whatever levels of variety a manufacturer is able to offer. However, some authors (e.g., Zipkin, 2001) have argued that it is a mistake to assume that every product will sell better with more customized features. And even the same product may be customisable in different ways. In short, the demand for variety is not constant across time, product categories or even across different options within the same product. Some research seems to indicate that companies are struggling to define the optimal way of configuring products from a customer point of view. For example, Ulrich et al. (1998) studied four bicycle makers and found that they offered considerable variety, but for different attributes. Holweg & Pil (2001) found that although some car manufacturers offer a huge variety of optional features, customers typically cite only 4 or 5 factors as being critical to the purchase decision. In other words, there is a need for systematic approaches that can assist in determining the demand for variety and help identify the critical dimensions within which one should offer high variety.

The first task is to document whether it is likely that more variety will be valued by customers. Of course, different approaches are possible. Many companies already produce a mix of standard products and products made to order. Standard products are usually available from stock whereas non-standard products have a lead time as they need to be ordered, scheduled for production, manufactured, and shipped for each customer. Where this is the case it is possible to base the analysis on previously sold products. I have seen this done in one truck manufacturer for which I worked as a consultant. To determine whether the market valued variety, a consultant team compared customer satisfaction and profitability for standard versus non-standard (customized) product models. In this case they found that customers who ordered customized trucks displayed a significantly higher level of satisfaction with their vehicles compared to customers who had ordered standard trucks. It also found that the gross margin for non-standard trucks was significantly higher than for standard models. This led to the development of a new business process intended to support the ordering and

delivery of customized trucks. If historical data are not available it is possible base an analysis on customer surveys. The degree of (dis)satisfaction with current standard offerings may be one indicator as to whether greater degree of customisation is warranted.

A second task is to obtain data that can assist in designing the product offering. For example, it is critical to know for which features variety is important (for which market segments etc.) and for which features variety is less important or even dysfunctional. It is also important to have customer data that can help the company decide whether bundled product offerings would provide more value than customizable or self-configured solutions, and if so, what the logical (and most profitable) bundles are. A number of statistical techniques are available that may aid in the configuration of a product based on customer preferences for different features, such as conjoint analysis and correspondence analysis. These techniques have traditionally been used by marketers to create segmentation and pricing strategies. There is a very extensive literature on market analysis techniques, but I have yet to see research that considers how different statistical tool could support the definition of product offerings in the context of mass customization or modularisation of complex products.

There is also a potential in developing links between the modularity literature and research on consumer behaviour. I am here thinking about the literature that examines consumer demand for variety and the consumer decision making process during shopping. There is actually a field of investigation (rarely cited by modularity scholars) that looks at why consumers seek variety and why they chose to purchase products that differ from the ones they may have purchased in the past. For example, Kahn (1998) reviewed the psychological research on variety-seeking behaviour that suggests that consumers will be looking for something new once an optimal level of satiation has set in. But she also notes differences between different product categories. Variety is usually a benefit in low-involvement, low risk product categories where consumers make frequent purchases and need diversity and stimulation. When there is high involvement and some risk, customers are more

motivated seek a single, optimal choice. A key consideration here is reducing the complexity inherent in having to choose between the many options that may be available.

One important effect of modularity-enabled mass customization can be observed when looking at the dynamics of the sales process. As pointed out by Godeck (2000), customers become more involved in the process of product creation when they can configure the product to their needs. In addition to the satisfaction that results from purchasing the product, consumers may thus receive additional satisfaction from the process itself. Godeck (2000) also points out that how consumers choose a customized product differs dramatically from how consumers choose a non-customized product. It is difficult to make side by side product comparisons if the product is customized. One example is car sales. In Japan, where cars are more frequently sold to individual specifications, haggling over prices almost never occurs (Womack, Jones & Roos, 1990).

An interesting possibility for future research - perhaps for a team consisting of both marketing scholars and modularity scholars – would be to identify the different theoretical approaches and statistical techniques that exists and evaluate their usefulness for product offering definition. One should also discuss if it is possible to develop a framework that takes into account both customer preferences and manufacturing capabilities. By integrating the modularity approach with customer /marketing analysis one may thus able to create a strategic approach to help managers determine the appropriate level of product variety and optimal product configurations given consumer preferences and operating capabilities¹⁴⁰.

7.3.10 Changes in modular systems

In this research I focused largely on the process of implementing modularity, and the resulting effects on flexibility and performance. However, an issue that deserves more attention is how to describe changes in a system that has already been modularised. The notion of process

¹⁴⁰ A highly modular design lowers the cost of providing a high level of variety relative to an integral design. Nevertheless, in most companies there remain inefficiencies in ordering, production or

grammars discussed in chapter 2 suggests that it may be possible to identify elementary patterns of process changes that are generic and applicable across all modular systems (Pentland, 1995; Miller & Friesen, 1980). Following Goldenberg, Mazursky & Solomon (1999) and Baldwin & Clark¹⁴¹ (2000) one may define an *operator* as the most basic step in a transition and *templates* as systematic transitions between the previous configuration of a modular architecture and a new configuration. The templates are obtained by applying some or all of the operators in different sequences. Given the results obtained by applying process grammars in other fields, one would expect that a small number of operators (e.g., splitting a module in two, excluding a module, including a module), combined and re-combined into different sequences, may account for practically all reconfigurations of modular systems.

One application of such a framework is to formally model changes in modular systems. For example, Baldwin & Clark (2000) apply six operators at different points and in different combinations to track the development of the computer from the original designs to today's PC architectures.

Another application would be to develop practical framework to help managers generate and select new possibilities for product or process reconfiguration. Goldenberg et al. (1999) point out that templates are learnable and thus may be used as cognitive tools in generating new organisational designs. For example, the template underlying successful process change in one company may be transferred and tested as a solution to similar problem in a company in a different industry.

Goldenberg et al. (1999) provide experimental evidence that templates can be used to channel creative problem solving. In their experiments, they compared one group of participants using generic templates for developing new products with a second group that used a more unstructured "brain-storming" technique to generate ideas. Their evidence shows that the template group generated ideas that were rated higher in both originality and value.

distribution (or pure technical constraints) that mean that there are large differences in terms of the cost of providing some optional features compared to others.

This result departs from the traditional view that creativity is enhanced by techniques such as lateral thinking and brainstorming. However, Goldenberg et al. (1999) note that it is actually consistent with recent findings in cognitive psychology that show that it can be helpful to channel or restrict the problem solving process in certain ways. People tend to be more creative (i.e., produce ideas of higher originality and value) when they are exploring new uses for existing templates than when they are searching for new templates for predefined uses. One can investigate this principle in the context of organisation design by asking one group of people to generate new configurations (e.g., a new sequence of work activities) simply by brainstorming possible solutions and compare the results with the outputs from a second group that are handed a set of process activities, and then asked to reconfigure these predefined activities using a set of standard templates. We would predict that the second group (which is searching for new uses for existing templates) would be more successful in generating original and useful ideas.

7.4 CONCLUDING REMARKS

Within the social sciences, a single study, however persuasive, rarely has a dramatic effect on the way researchers or managers look upon a problem. It is first when a number of studies converge to form a new approach to defining a problem that paradigms may change. Consequently, more important than the specific findings may be the contribution of this thesis – in conjunction with other research on this topic - in bolstering the strategic flexibility approach to defining dynamic capabilities. In this section I briefly comment on some key implications of the research in this field.

Whereas much theorising within strategic management deals with the role of strategic commitment in achieving sustainable competitive advantage, the emphasis in this research has been on creating *strategic flexibility*. The key argument is that carefully designed, modular

¹⁴¹ The operators defined by Goldenberg et al. (1999) and Baldwin & Clark (2000) were intended to

architectures may provide options to pursue a range of initiatives in response to emerging market opportunities. When I began my doctoral studies in 1996, only a few articles had been published in scholarly journals on strategic flexibility and modularity. During the last few years, many research-oriented and practitioner management journals have published articles related to modularity¹⁴². The last edition of Barney's (2002) textbook in strategic management (Barney, 2002) now devotes a chapter to the issue of flexibility. In short, these concepts are becoming part of the common vocabulary of both academics and practitioners.

As explained in chapter 1, part of the motivation for this research was my interest in "programmed innovation". The focus on architecture reaffirms the value of deliberate planning (even when facing uncertainty) and structure (even when pursuing innovation). These assumptions stand in stark contrast to the theorising of some well-known strategy scholars and organisational scientists.

In various postmodern approaches, flexibility has been equated with a lack of routines, little formal planning, minimal bureaucracy, and a high degree of local autonomy (e.g., Morgan, 1986). Similarly, a more recent series of studies have emphasized the role of *improvisation* (the process of "making it up as you go along") as a strategy for adapting to highly uncertain situations (Moorman & Miner, 1998). As discussed in chapter 2 and chapter 6 of this thesis, this approach largely rejects the postmodern perspective to organisation design. The modularity approach is based on a different set of assumptions:

a) Organisations are not "self-designing". Effective organisational architectures do not occur naturally but must be consciously designed.

b) As coherent systems are not likely to emerge from local trial-and-error learning, it is necessary to design organisations from the perspective of the entire system (Hackel, 1999).

describe changes in product structures. These can be adopted to fit the context of organisation design.

¹⁴² These include Harvard Business Review (Baldwin & Clark, 1997), California Management Review (Thomke & Reinertsen, 1998), Strategic Management Journal (Sanchez, 1995), Academy of Management Journal (Schilling, 2001), Academy of Management Review (Schilling, 2000), and Administrative Science Quarterly (Brusoni et al., 2001).

The initial process of establishing modular organisational architectures thus requires centralised authority.

c) Organisations are more than loosely coupled networks. Organisations are instruments to achieve certain predetermined goals. This requires some degree of structure with regard to formal roles and it requires clearly defined accountabilities.

Effective organisations require what I have termed “architecture” in this thesis: An integrated framework that specifies how an organisation is to satisfy customer needs by employing a set of processes that deliver certain products or service offerings (cf. chapter 6).

Unfortunately, the concepts of design and architecture have taken on a pejorative meaning in the field of strategic management since Mintzberg issued his well-known critique against the “design school”. Mintzberg’s concerns rest on the assumption that design is an analytical process decoupled from action, carried out by a lone CEO, and ill-suited for companies adapting to changing environments. He placed more emphasis on on-going learning based on real-world experience than on analytically derived plans for the future.

However, as pointed out by Liedtka (2000) constructive forethought in the form of plans does not preclude on-going learning based on unfolding events. Although planning certainly may constrain the domain in which emergent processes take place, it also establishes the very resources that emergent processes make use of. Sanchez & Mahoney (1997, p. 12) concluded:

Emergent configurations and deployments of specific product and organisation variations derived from the flexibilities of *planned* modular product and organisation designs enable the playing out of a range of emergent strategies in response to environmental change.

Whereas the overall architecture is pre-planned and deliberate, it essentially provides the options to pursue a range of initiatives in response to emerging market opportunities. The existence of predefined modules that can be combined and recombined dramatically increases the ability to make such adaptations quickly and at low cost. This reconceptualisation helps us

move away from the dichotomy between learning and planning that was the basis for Mintzberg's critique of the design school of strategic management.

The concept of "the modular organisation" combines elements that were previously thought to be contradictory, as expressed in the well-known dualistic typologies of bureaucracy versus adhocracy (Mintzberg, 1983), mechanistic versus organic (Burns & Stalker, 1961), or tightly coupled versus loosely coupled (Orton & Weick, 1990).

- The modular organisation achieves efficiency by producing standardised modules that can be leveraged across products and processes yet maintains flexibility and customisation by combining and re-combining modules to changing or diverse customer needs.
- A strong emphasis is placed on formalisation and standardisation. However, unlike procedures in the bureaucratic organisation, modular architectures primarily define the required *outputs* of processes rather than the detailed task-related routines that need to be performed to produce the outputs. Managers in modular organisations coordinate activities by managing *interactions* among processes.
- The initial decisions regarding overall organisational architecture are *centralised*. Yet this allows subsequent decisions to be decentralised as interactions between modules are co-ordinated by means of the design rules specified in the product and process architectures.

It is this capacity to reconcile previously contradictory notions that suggests that the concept of the "modular organisation" represents a new organisational form and a new principle for competing in dynamic markets.

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